

2320629 - Investigation into DC Transients

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HNC Principles Assignment – James Summers

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Contents

Executive Summary	4
Aims & Objectives	4
HNC Principles Assignment – Investigation into DC Transients	5
Introduction	5
Task 1 – Transient behaviour for the charging of a capacitor	5
Methodology.....	5
Practical.....	5
Charge Voltage Graph	6
Charge Current Graph	6
Calculations	6
Calculations - Charge Voltage (Task 1).....	7
Calculations – Charge Current (Task 1).....	7
Simulated	8
Charge Voltage Transient Graph.....	8
Charge Current Transient Graph	8
Analysis	9
Voltage Comparison Table.....	9
Current Comparison Table	9
Task 2 – Transient behaviour for the discharging of a capacitor	10
Methodology.....	10
Practical.....	10
Discharge Voltage Graph.....	11
Discharge Current Graph.....	11
Calculations	12
Calculations - Discharge Voltage (Task 2)	12
Calculations – Discharge Current (Task 2).....	12
Simulated	13
Discharge Voltage Transient Graph	13
Discharge Current Transient Graph	13
Analysis	14
Voltage Comparison Table.....	14
Current Comparison Table	14
Task 3 – Transient behaviour for a more complex circuit	15
Methodology.....	15
Calculations	16

HNC Principles Assignment – James Summers

Simulated	17
Analysis	18
Task 4 – Transient behaviour for an inductive circuit.....	19
Methodology.....	19
Simulated	19
Charge current transient	19
Discharge current transient.....	20
Calculations	20
Analysis	22
Conclusion & Recommendations	23
Appendix	24
Task 1:	24
.....	24
Task 2:.....	25

Executive Summary

The aim of this assignment is to investigate the changes of behaviour/characteristics in RC and RL circuits when a DC power supply is connected. The investigation will consist of 4 different tasks and the circuits will be investigated using simulated, practical and theoretical methods. The results will then be compared and discussed throughout each section. The overall findings will then be discussed in a conclusion and recommendations section.

Aims & Objectives

The aim of the assignment is to investigate the changes in behaviour of RC and RL circuits and to conduct analysis using mathematical equations and simulation software.

The objectives of the assignment are:

1. Use a range of mathematical formulas and equations to execute calculations on a range of problems.
2. To compare the obtained results (calculated/simulated/practical) and to account for any inconsistencies.
3. To interpret information gathered from the simulations and to use the data correctly and in line with scientific principles.
4. To correctly gather instrument readings from practical circuits, and to use the data within a scientific principle related to the task.

HNC Principles Assignment – Investigation into DC Transients

Introduction

The aim of this assignment is to investigate and analyse the changes in behaviour of RC and RL circuits responses. The circuits will be put into charged and discharged states and the results will be analysed. The results will be compared with theoretical calculations, simulations on Multi-Sim and through practical application where the circuit will be constructed and results will be taken. The results are displayed in tables and graphs and are analysed and discussed within each section. The full findings will then be discussed in a conclusion.

Task 1 – Transient behaviour for the charging of a capacitor

Methodology

The RC circuit shown in Figure 1.0 was constructed on NI Multi-sim. The components consisted of a 6v DC power supply, a single pole double throw switch, a 5.6K Ω and a 10000 μF capacitor. The time constant for this circuit was calculated then 3 random time intervals were selected to take a measurement. The time intervals selected were 56s (1τ) 28s and 112s. The circuit was put into the charge state and a transient graph was set up in order to measure the voltages and current at the randomly selected time intervals, the simulated values were then compared to the theoretically calculated values and the practically measured ones.

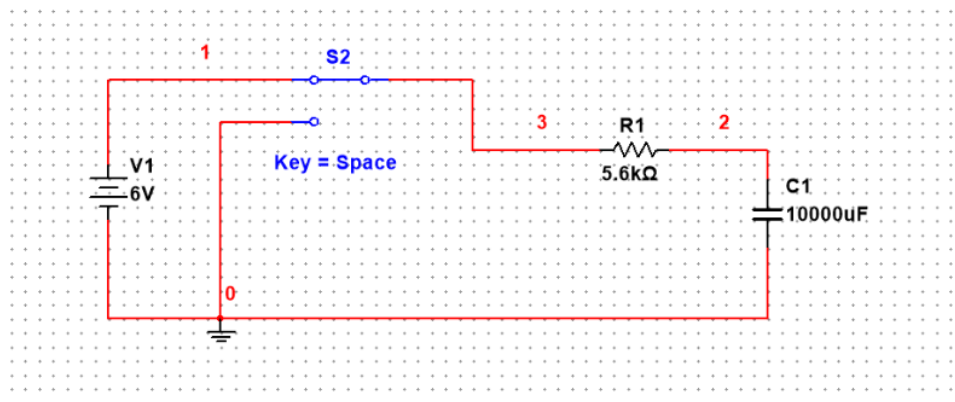


Figure 1.0: Multi-Sim circuit screenshot (Task 1)

Practical

A Practical version of the circuit above was setup on a breadboard, which consisted of the same component values. Then using two multimeters which were connected to the circuit and set up to measure voltage and current readings were taken. In groups of 3, one member used a stop watch to take measurements at 5 second intervals for the first minute, then at 10 second intervals until 5 τ (280s) had been reached. The results were then put into a table as shown in Table 1.0, see Appendix. The time intervals selected (28s, 56s, 112s) are not shown as results in the table, as they are not multiples of 5 or 10. Therefore the selected time intervals were rounded to the nearest measured

time (30s, 60s, 110s) to best represent the values. The table of results was then used to create graphs to show voltage and current growth with respect to time.

Charge Voltage Graph

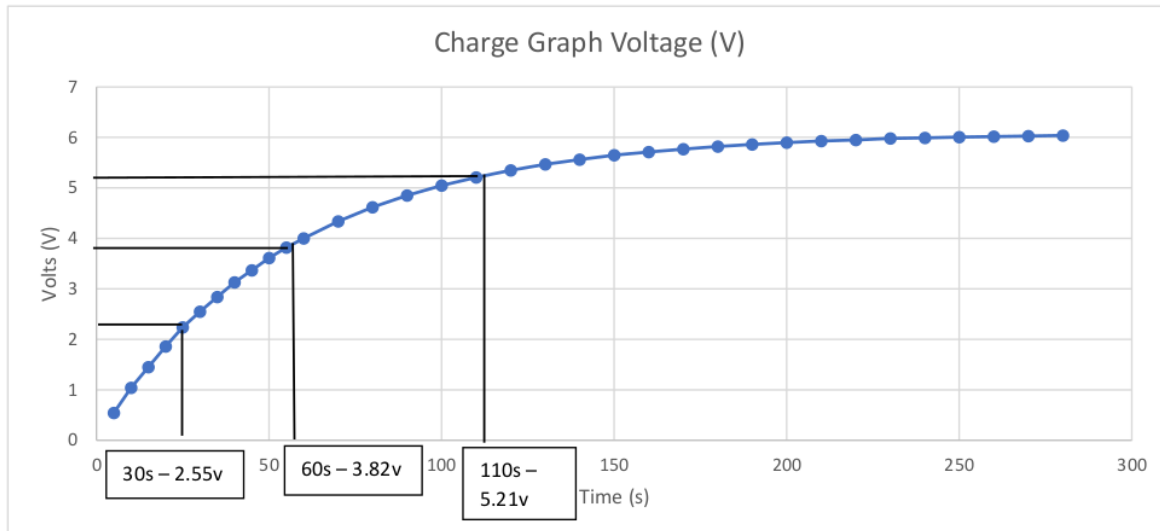


Figure 1.1: Charge voltage graph (Task 1)

The 3 alternate values (30s, 60s, 110s) are shown in Figure 1.1 and 1.2.

Charge Current Graph

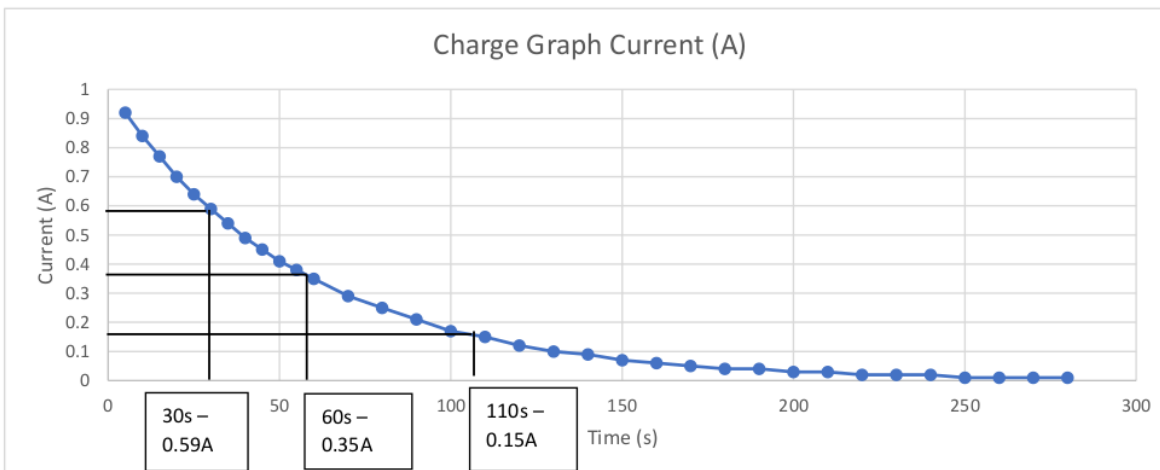


Figure 1.2: Charge current graph (Task 1)

Calculations

The selected time intervals (28s, 56s, 112s) were then calculated theoretically and would later be placed in a table to compare the values across the 3 methods of measurement.

Calculations- Charge Voltage (Task 1)

Calculating the time constant

$$\tau = \text{Resistance } (\Omega) / \text{Capacitance (F)}$$

$$\tau = 5600 \times 10000 \times 10^{-6} = 56\text{s}$$

$$5\tau = 5 \times 56 = 280\text{s}$$

Calculating the voltage at selected time intervals

$$VC = V(1 - e^{-t/\tau})$$

$$\text{Voltage at } 1\tau (56\text{s}) - VC = 6\text{v} (1 - e^{-56/56}) = 3.792\text{V}$$

$$\text{Voltage at } 28\text{s} - VC = 6\text{V} (1 - e^{-28/56}) = 2.361\text{V}$$

$$\text{Voltage at } 112\text{s} - VC = 6\text{V} (1 - e^{-112/56}) = 5.188\text{V}$$

Calculations – Charge Current (Task 1)

Calculating max current

$$\text{Current (I)} = \text{Voltage (V)} / \text{Resistance } (\Omega)$$

$$6\text{V}/5600\Omega = 1.071\text{mA}$$

Calculating current at selected time intervals

$$I = I_{\text{Max}} (e^{-t/\tau})$$

$$\text{Current at } 1\tau - 1.071\text{mA} (e^{-56/56}) = 0.393\mu\text{A}$$

$$\text{Current at } 28\text{s} - 1.071\text{mA} (e^{-28/56}) = 0.649\mu\text{A}$$

$$\text{Current at } 112\text{s} - 1.071\text{mA} (e^{-112/56}) = 0.144\mu\text{A}$$

Proving results

To prove the results are accurate, it is possible to use the law of transients to accurately estimate the calculated voltage as approximately 63.2% of V_{Max} is 1τ . This is shown below:

$$0.632 \times 6\text{v} = 3.792\text{V}$$

It is also possible to accurately estimate the calculated value for current, by following the law of transients for current, 36.8% of I_{Max} is 1τ . This is shown below:

$$0.368 \times 1.071 = 394\mu\text{A}$$

These calculations are a good estimate that the results calculated are accurate as they follow the law of transients.

Simulated

The 3 selected time intervals (28s, 56s, 112s) were then measured on simulation software (Multi-Sim) and a transient graph was set up to measure the voltage and current, the results were placed into a table. The voltage and current transients are shown below:

Charge Voltage Transient Graph

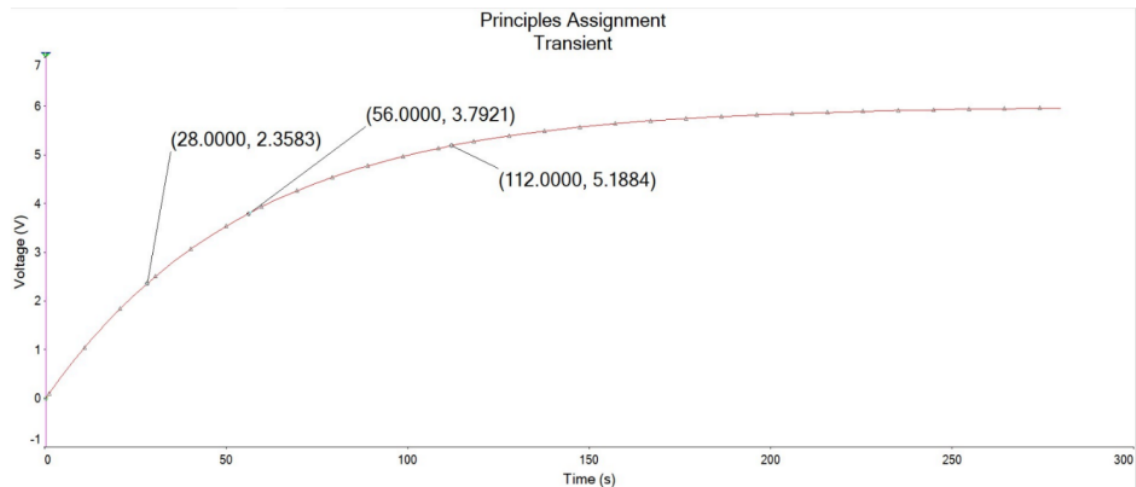


Figure 1.3: Charge voltage transient graph

The 3 selected time intervals are shown on the charge voltage transient graph.

Charge Current Transient Graph

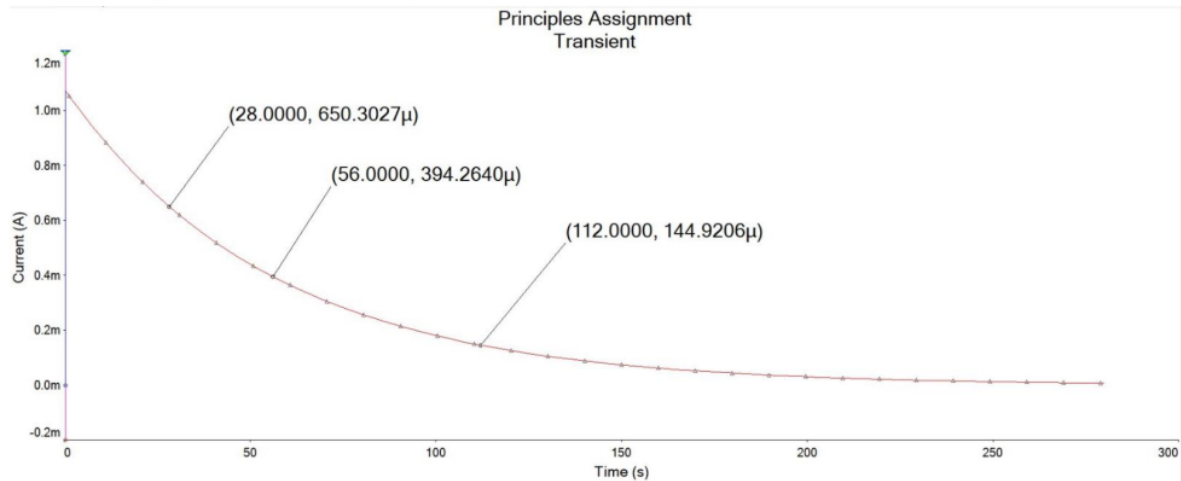


Figure 1.4: Charge current transient graph

The 3 selected time intervals shown on the charge current transient graph.

Analysis

All the obtained results were then placed in a table to compare them, this is shown below:

Voltage Comparison Table

Table 1.1: Voltage comparison table

Time (S)	Calculated (V)	Multi-Sim (V)	Practical (V)
T1 - 56s	3.792	3.792	3.82
T2 - 28s	2.361	2.358	2.55
T3 - 112s	5.188	5.188	5.21

Current Comparison Table

Table 1.2: Current comparison table

Time (S)	Calculated (μA)	Multi-Sim (μA)	Practical (μA)
T1 - 56s	393	394.3	380
T2 - 28s	649	650.3	640
T3 - 112s	144	144.9	150

The results gathered show a few minor inconsistencies between the calculated/simulated and practical values (see Table 1.1 & 1.2). This is due to the practical results being measured at 5s intervals for the first minute and then 10s after the first minute had been reached. This means that the selected time intervals chosen for measurement were not measured as they were not a multiple of 5 or 10. Therefore the measured value was rounded to the closest measured time. Due to the nearest values being used, the results were approximations of the original time intervals selected. As shown in the Proving results section above, the results obtained for the calculated and simulated values follow the law of transients, which provides a good estimate at 1τ .

Task 2 – Transient behaviour for the discharging of a capacitor

Methodology

The RC circuit shown in Figure 2.0 was constructed on NI multi-sim. This is similar to the circuit used in Task 1, but the power supply was changed to a DC pulse unit. This allows the circuit to be measured in a discharged state. The transient graph measuring parameters on multi-sim were changed to measure 560s (10τ), this shows the charge and discharge cycles of the capacitor. The same 3 randomly selected time intervals from the previous task were used: 56s (1τ), 28s and 112s. The practical, calculated and simulated results were put into graphs and tables to allow the data to be analysed.

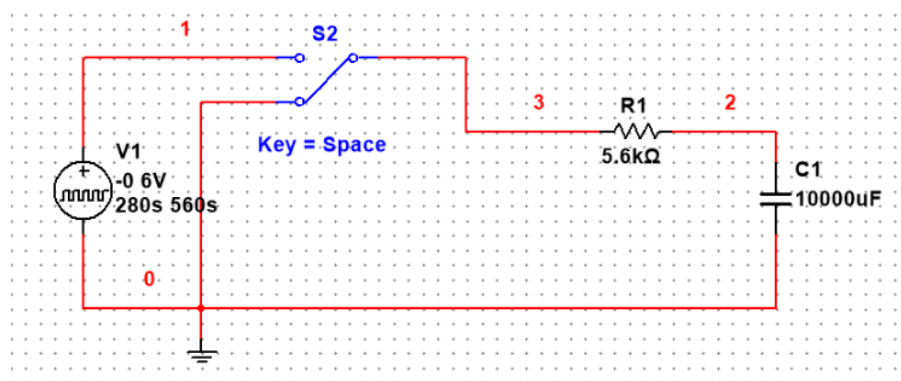


Figure 2.0: Multi-Sim circuit screenshot (Task 2)

Practical

The same practical circuit from Task 1 was reused, this time set up to measure discharge of the capacitor. Working in groups of 3 using two multimeters to measure voltage and current, readings were taken at 5s intervals for the first minute and 10s intervals up to 5τ (280s). The results are shown in Table 2.0 (see Appendix). The time intervals selected are not shown as a result in the table, therefore the closest one was chosen to represent the value. A table of results was then used to create graphs to show voltage and current decay with respect to time.

Discharge Voltage Graph

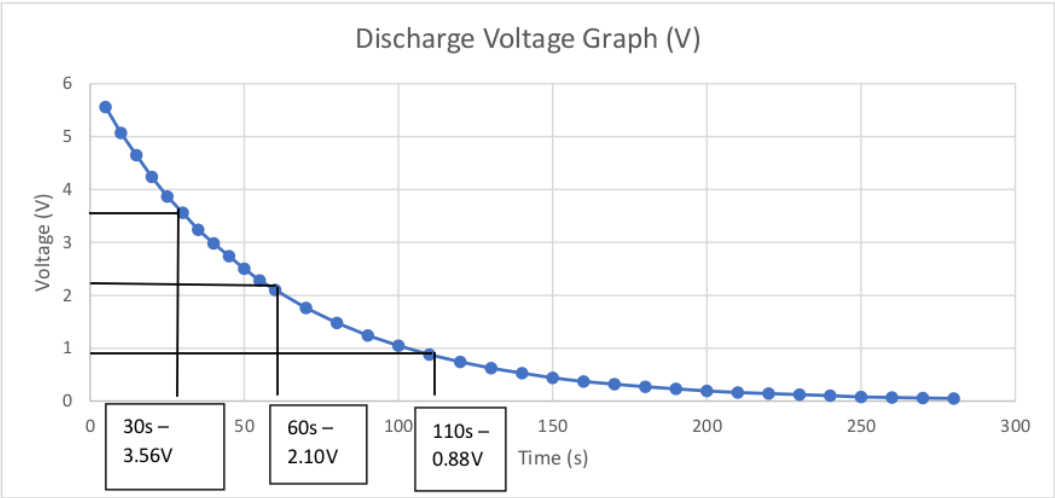


Figure 2.1: Discharge voltage graph

The 3 alternate values (30s, 60s, 110s) are shown in Figure 2.1 and 2.2.

Discharge Current Graph

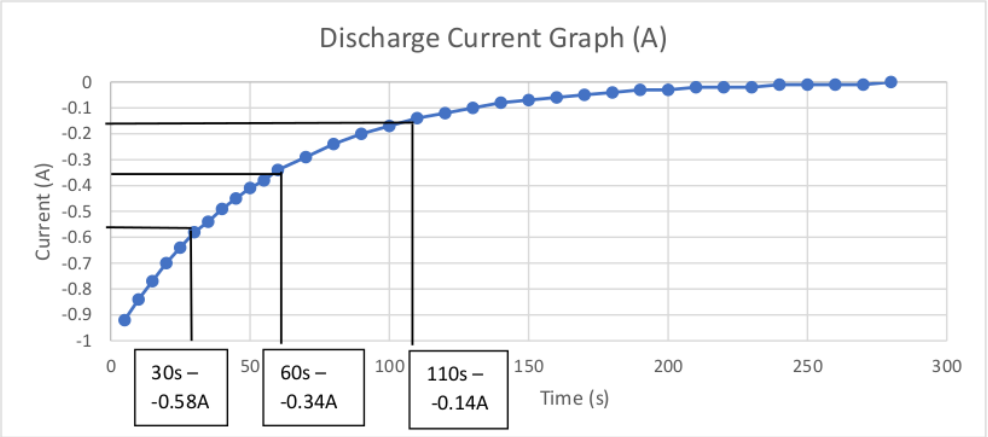


Figure 2.2: Discharge current graph

Calculations

The selected time intervals were then calculated theoretically and recorded in a table to compare against the 3 methods.

Calculations- Discharge Voltage (Task 2)

Calculating voltage at selected time intervals

$$V_c = V_s \times e^{-t/RC}$$

$$V_c = 6 \times e^{-28/5600 \times 10000 \times 10^{-6}} = 3.639v$$

$$V_c = 6 \times e^{-56/5600 \times 10000 \times 10^{-6}} = 2.207v$$

$$V_c = 6 \times e^{-112/5600 \times 10000 \times 10^{-6}} = 0.812v$$

Calculations – Discharge Current (Task 2)

Calculating max current

$$\text{Current (I)} = \text{Voltage (V)} / \text{Resistance (}\Omega\text{)}$$

$$6V/5600 \Omega = 1.071mA$$

Calculating current at selected time intervals

$$I = -I_{Max}(e^{-t/\tau})$$

$$I = -1.071 (e^{-28/56}) = -649.59\mu A$$

$$I = -1.071 (e^{-56/56}) = -393.99\mu A$$

$$I = -1.071 (e^{-112/56}) = -144.94\mu A$$

Proving results

When in a discharged state the laws of transients, states 36.8% of V_{Max} is 1τ and the same for current. This is shown below:

$$0.368 \times 6 = 2.208V$$

$$0.368 \times 1.071 = 394.1 \mu A$$

These calculations are a good estimate that the results calculated are accurate as they follow the law of transients.

Simulated

The 3 selected time intervals were then measured on simulation software (Multi-Sim) and a transient graph was set up to measure the voltage and current. The results were placed into a Table 2.1 and 2.2. The voltage and current transients are shown below:

Discharge Voltage Transient Graph

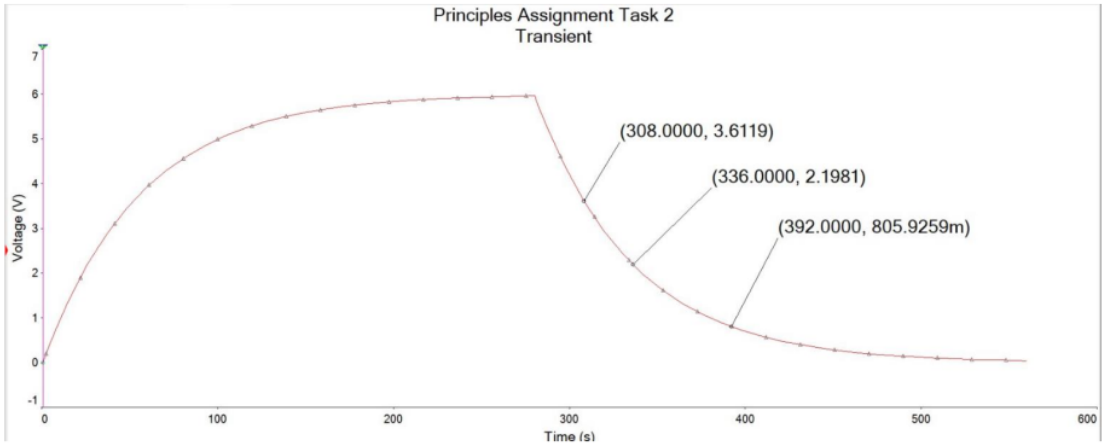


Figure 2.3: Discharge voltage transient graph

The 3 selected time intervals shown on the discharge voltage transient graph (Figure 2.3).

Discharge Current Transient Graph

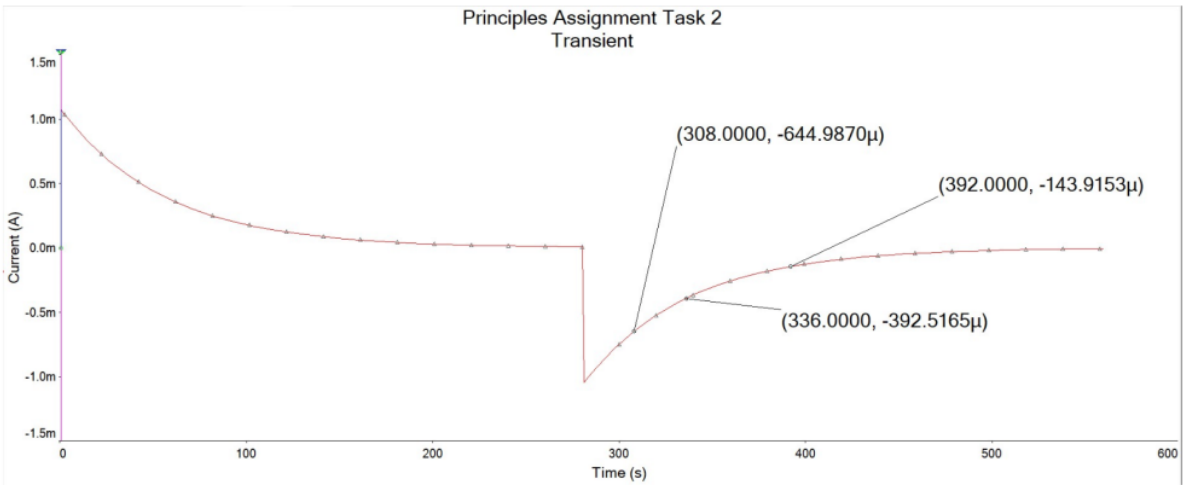


Figure 2.4: Discharge current transient graph

The 3 selected time intervals shown on the discharge current transient graph (Figure 2.4).

Analysis

All the obtained results were then placed in a Table 2.0 and 2.1 to compare.

Voltage Comparison Table

Table 2.1: Voltage comparison table

Time (S)	Calculated (V)	Multi-Sim (V)	Practical (V)
T1-56s	2.207	2.198	2.28
T2-28s	3.639	3.611	3.56
T3-112s	0.812	0.805	0.88

Current Comparison Table

Table 2.2: Current comparison table

Time (S)	Calculated (μA)	Multi-Sim (μA)	Practical (μA)
T1-56s	-393.9	-392.5	-380
T2-28s	-649.59	-644.9	-580
T3-112s	-144.9	-143.9	-140

The results gathered show a few minor inconsistencies between the calculated/simulated and practical values (see Table 2.1 & 2.2). The same practical conditions for Task 1 were repeated for Task 2 therefore the same inconsistencies with results occurred. The same control measures were used to choose suitable results. Using the law of transients, the results were proved. Estimation calculations were conducted to see if the results obtained were accurate to what was calculated for 1τ .

Task 3 – Transient behaviour for a more complex circuit

Methodology

The RC circuit shown in Figure 3.0 was constructed on NI Multi-Sim. It consisted of a 12v DC supply; a SPDT switch; 2 resistors in parallel, which are rated at 6k Ω & 12k Ω and a 2000 uF capacitor. The circuit was firstly reduced using the Product Over Sum method and Potential Division to calculate the equivalent RC circuit.

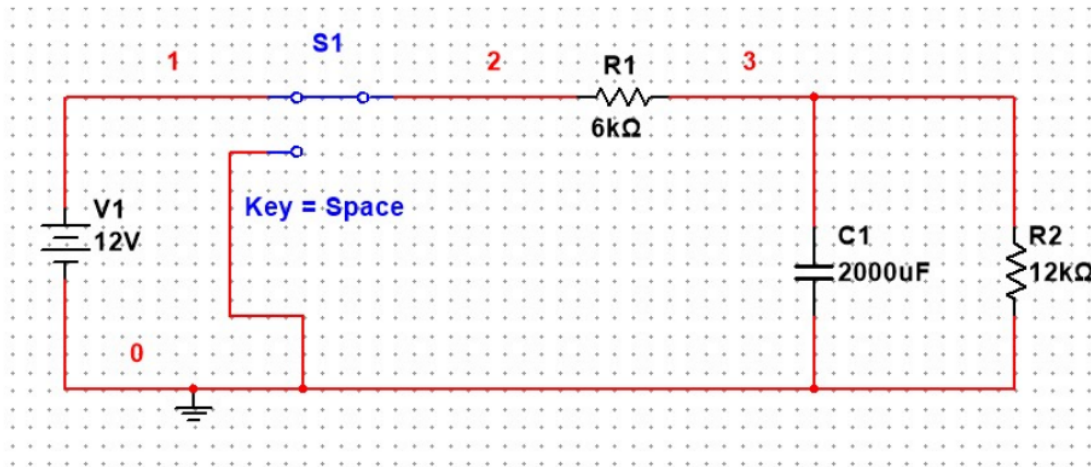


Figure 3.0: Multi-Sim circuit screenshot (Task 3)

Equivalent circuit calculations – new resistor value

$$R1 \times R2 / R1 + R2$$

$$6000 \times 12000 / 6000 + 12000 = 4000 \Omega$$

Equivalent circuit calculations – new power supply value

$$V2 = V_{in} \times R2 / R1 + R2$$

$$12 \times 12000 / 6000 + 12000 = 8V$$

The reduced circuit values consisted of an 8v DC power supply and a 4000 Ω resistor and is shown in Figure 3.1. The equivalent circuit was then used to complete the charge and discharge calculations for current, and to calculate the initial and final currents of the supply.

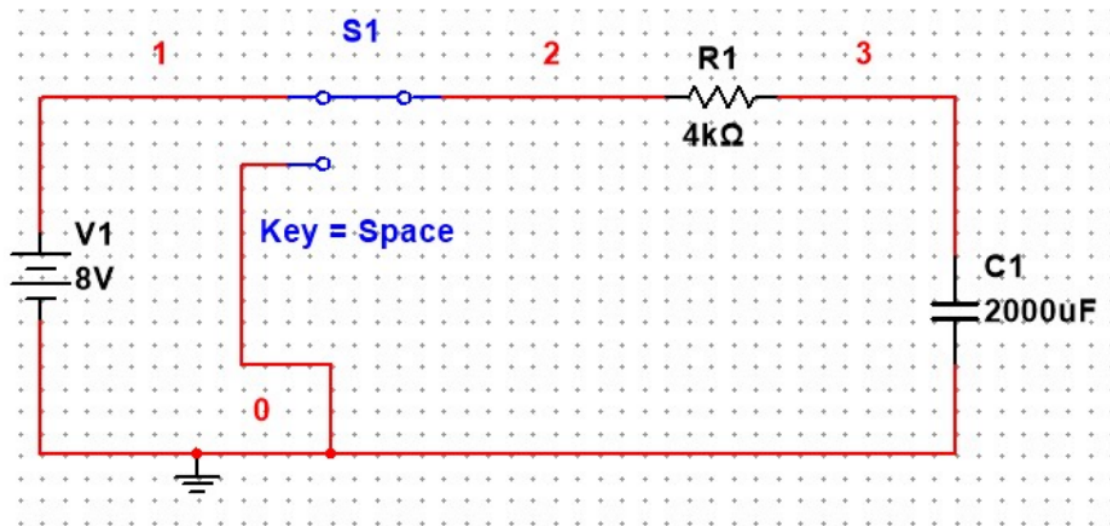


Figure 3.1: Multi-Sim screenshot of reduced circuit (Task 3)

Calculations

Calculating the time constant

$$\tau = \text{Resistance } (\Omega) \times \text{Capacitance (F)}$$

$$4000 \times 2000 \times 10^{-6} = 8\text{s}$$

$$5\tau = 5 \times 8 = 40\text{s}$$

Calculating the max current

$$I_{\text{max}} = V/R$$

$$8/4000 = 2\text{mA}$$

Calculating the charge current at 1 time constant (1 τ)

$$I_{\text{Max}}(e^{-t/T})$$

$$2 \times 10^{-3} (e^{-8/8}) = 735.7\mu\text{A}$$

Calculating the discharge current at 1 time constant (1 τ)

$$-I_{\text{Max}}(e^{-t/\tau})$$

$$-2 \times 10^{-3} (e^{-8/8}) = -735.7\mu\text{A}$$

Proving results

It is possible to accurately estimate the calculated value for current, by following the law of transients, 36.8% of I_{Max} is 1τ . This is shown below:

$$\text{Charge: } 0.368 \times 2\text{mA} = 736 \mu\text{A}$$

$$\text{Discharge: } 0.368 \times -2\text{mA} = -736 \mu\text{A}$$

The calculations shown above provide proof of a good estimate that the calculated results for 1τ are accurate.

Proving initial and final current

$$I_{Max}(e^{-t/T})$$

$$\text{Initial current} = 2 \times 10^{-3} (e^{-0/8}) = 2\text{mA}$$

$$\text{Final current} = 2 \times 10^{-3} (e^{-40/8}) = 0.013\text{mA}$$

Simulated

The circuit was then simulated to measure the charge current at 1τ .

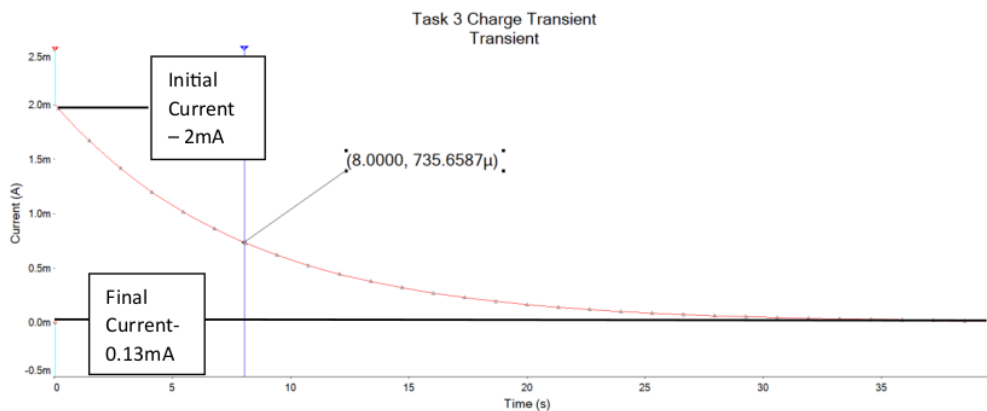


Figure 3.2: Charge current transient graph

The charge current measured at 1τ (735.6 μA).

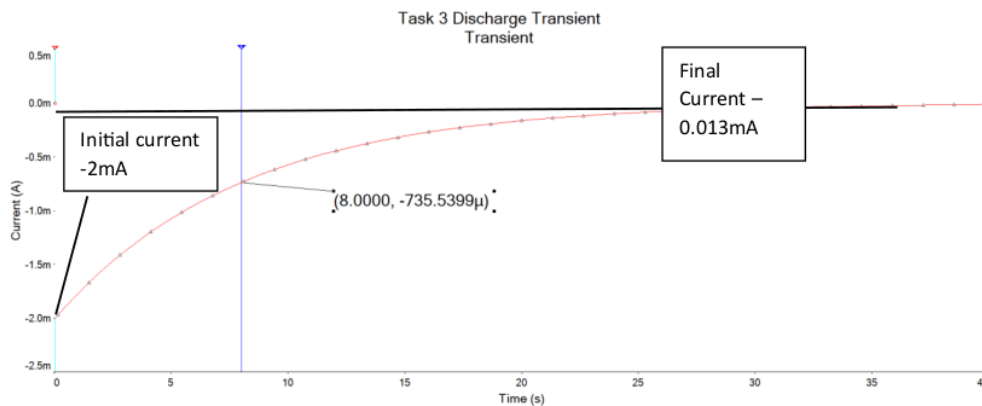


Figure 3.3: Discharge current transient graph

The discharge current measured at 1τ ($-735.5\mu\text{A}$).

In a charged state the initial current from the supply would be 2mA and after 5τ would decrease to 0.013mA, this would be the opposite in a discharged state beginning at -2mA and increase to 0.013mA. This is highlighted in the transient graphs in Figure 3.2 and 3.3 and the proving results section.

Analysis

All the obtained results were then placed in Table 3.0 to be analysed and compared.

Table 3.0: Charge and discharge current comparison table

Time (S)	Calculated (μA)	Multi-Sim (μA)
Charge - 8	735.7	735.6
Discharge - 8	735.7	735.5

The results in Table 3.0 show very little difference between the simulated and the calculated, this is to be expected however as they are in a theoretical environment and do not have any real-life inconsistencies. The minor differences are down to rounding errors in the calculations. The final current is calculated to be slightly above 0mA this is due to 5τ being 99.3% of the maximum current. As mentioned, the calculated results were proven as seen in the Proving results section, where an estimation calculation was used to check the value for 1τ .

Task 4 – Transient behaviour for an inductive circuit

Methodology

The RL Circuit shown in Figure 4.0 was constructed on NI Multi-Sim, it consists of a 12v DC power supply, a 15 Ω resistor and a 3H inductor. The circuit will be simulated to show charge and discharge current and the results will be put into tables to compare the results. A manual plot was calculated to compare against the simulated results. The time taken for the current to decay to 100mA and 10mA was also calculated.

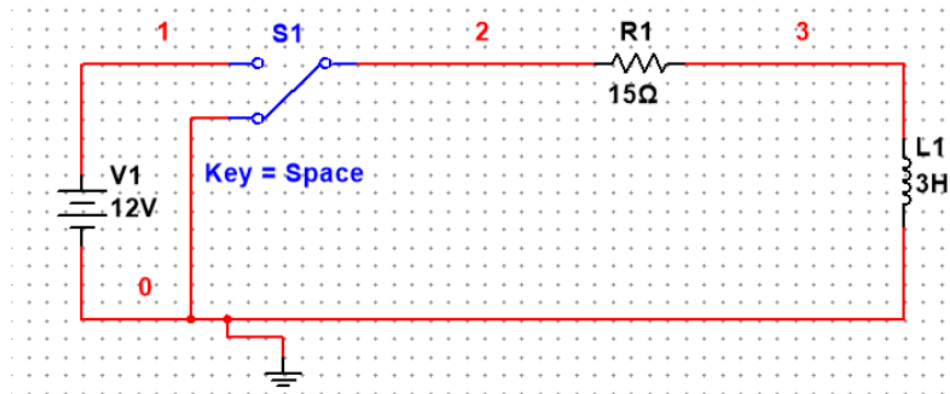


Figure 4.0: Multi-Sim circuit screenshot (Task 4)

Simulated

The circuit was then simulated to measure the charge current at 1 τ (0.2s) and the max current of the circuit at 5 τ (1s).

Charge current transient

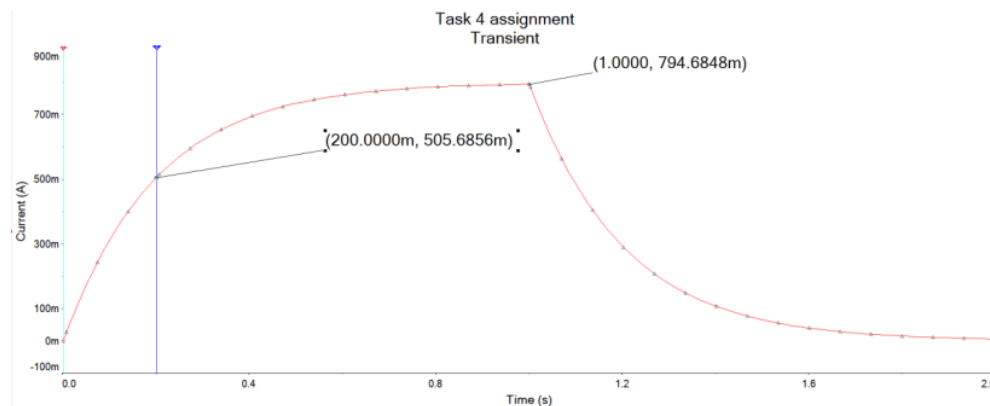


Figure 4.1: Charge current transient graph

The inductor current measured at 1 τ (505.6mA) and the I_{Max} of the circuit (794.6mA).

Discharge current transient

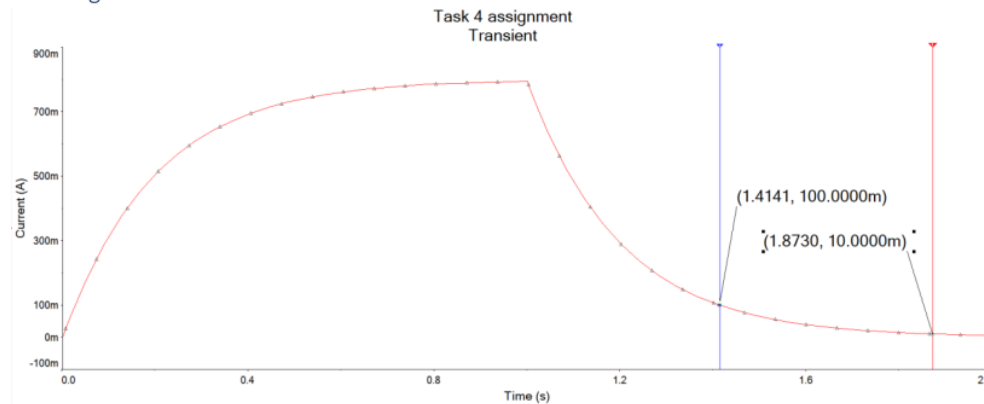


Figure 4.2: Discharge current transient graph

The time measured on the transient graph as the current falls to 100mA (0.414s) and 10mA (0.873s).

Calculations

Calculate the time constant

$$\tau = \text{Resistance } (\Omega) / \text{Inductance } (L)$$

$$15/3 = 0.2s$$

$$5 \tau = 1s$$

Calculate max current

$$I = V/R$$

$$12/15 = 0.8A$$

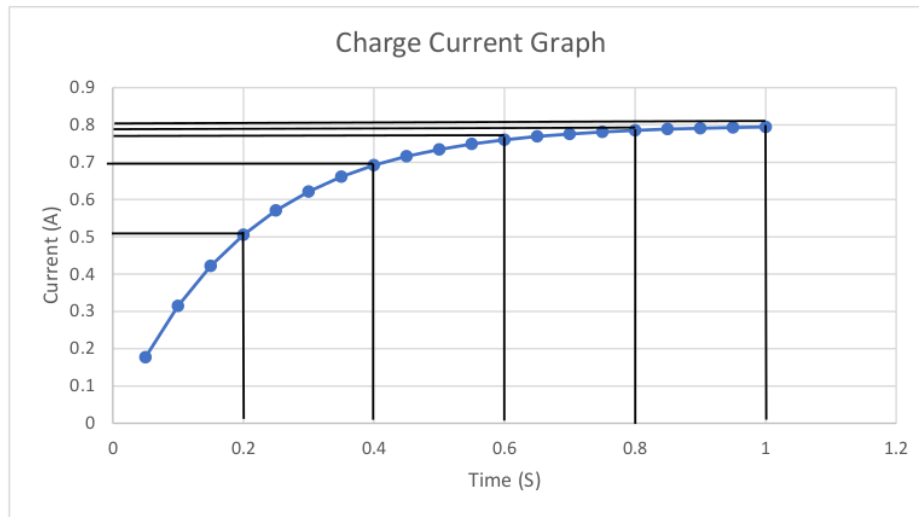


Figure 4.3: Charge current manual plot graph

Using the formula shown below, the manual plots results were placed into excel, Table 4.0. The data was then shown in a graph Figure 4.3.

$$I_{Max}(1 - e^{-t/T})$$

Table 4.0: Table to compare manual plot against simulated

Time (S)	Manual Plot (A)	Simulated (A)
0.2	0.505	0.505
0.4	0.691	0.692
0.6	0.760	0.760
0.8	0.785	0.785
1	0.794	0.794

Time for current to decrease to 100mA

To be able to calculate the time taken, the formula had to be transposed. The final formula is shown below.

$$t = T[\ln \left[\frac{IL}{I_{max}} \right]]$$

$$0.2[\ln(100\text{mA}/800\text{mA})] = -0.415 \text{ s}$$

Time for current to decrease to 10mA

$$0.2[\ln(10\text{mA}/800\text{mA})] = -0.876 \text{ s}$$

Table 4.1: Table to compare calculated time for current to decrease, against simulated.

Current (mA)	Calculated (S)	Simulated (S)
100	0.415	0.414
10	0.876	0.873

Proving results

It is possible to accurately estimate the value of current at 1τ , this can be done using the law of transients for RL circuits, as 63.2% of I_{Max} is equivalent to 1τ . This is shown below:

$$0.368 \times 0.8\text{A} = 505.6 \text{ mA}$$

Analysis

From the results in Tables 4.0 and 4.1 there is very minimal difference between manual plot and simulated and calculated against simulated. This is to be expected as they are in a theoretical environment, the differences in the results would likely be down to rounding errors in the calculations. As shown in the Proving results section the value for 1τ was proven to be exactly the same as the value measured in the simulation software, this confirming that the value measured was correct

Conclusion & Recommendations

In conclusion, all 4 tasks in the investigation into RC and RL circuits shows that the results gathered indicate that the calculated/simulated results were very similar in value, whilst the practical had multiple discrepancies. There are many reasons why this could have occurred, including real life inconsistencies, such as tolerances on components such as resistors or inductors. It could also include small cable resistances. There is also the opportunity for human error when operating the stopwatch or when the results are recorded. This provides a margin of error. However, the calculated and simulated results are more accurate due to them not taking into account the real-life inconsistencies providing no such opportunity for error. As the results were shown to be proven in each section using the laws of transients for voltage and current, by highlighting the significant time intervals within a charge and discharge curve and making an estimation.

Recommendations

To improve the results obtained within the investigation there would need to be a larger amount of data collected, this could be done by continuing to measure the time intervals in Task 1 at 5s, instead of 10s) all the way up to 280s, this would then provide more accurate results for the randomly selected time intervals of measure. To further improve this more sets of results could be taken, for example repeating the measurements 3 times and taking an average result of them all. To eliminate the aspects of human error, an electronic data logger should take the measurements to maintain maximum accuracy. To help make the results more accurate it would also be a good idea to test each electrical component to check they're value to see if its suitable for what's required within the task and to see if it close enough to the tolerance stated by the manufacturer.

Appendix

Task 1:

Table 1.0: Practical results showing charge voltage and current.

Charge		
Time (S)	Voltage (V)	Current (A)
5	0.54	0.92
10	1.04	0.84
15	1.45	0.77
20	1.86	0.7
25	2.24	0.64
30	2.55	0.59
35	2.84	0.54
40	3.13	0.49
45	3.37	0.45
50	3.61	0.41
55	3.82	0.38
60	4.00	0.35
70	4.34	0.29
80	4.62	0.25
90	4.85	0.21
100	5.05	0.17
110	5.21	0.15
120	5.35	0.12
130	5.47	0.1
140	5.56	0.09
150	5.65	0.07
160	5.71	0.06
170	5.77	0.05
180	5.82	0.04
190	5.86	0.04
200	5.9	0.03
210	5.93	0.03
220	5.95	0.02
230	5.98	0.02
240	5.99	0.02
250	6.01	0.01
260	6.02	0.01
270	6.03	0.01
280	6.04	0.01

Task 2:

Table 2.0: Practical results showing discharge voltage and current

Discharge		
Time (S)	Voltage (V)	Current (A)
5	5.56	-0.92
10	5.07	-0.84
15	4.65	-0.77
20	4.24	-0.70
25	3.87	-0.64
30	3.56	-0.58
35	3.24	-0.54
40	2.98	-0.49
45	2.74	-0.45
50	2.50	-0.41
55	2.28	-0.38
60	2.10	-0.34
70	1.76	-0.29
80	1.48	-0.24
90	1.24	-0.20
100	1.05	-0.17
110	0.88	-0.14
120	0.74	-0.12
130	0.62	-0.10
140	0.53	-0.08
150	0.44	-0.07
160	0.37	-0.06
170	0.32	-0.05
180	0.27	-0.04
190	0.23	-0.03
200	0.19	-0.03
210	0.16	-0.02
220	0.14	-0.02
230	0.12	-0.02
240	0.10	-0.01
250	0.08	-0.01
260	0.07	-0.01
270	0.06	-0.01
280	0.05	0.00