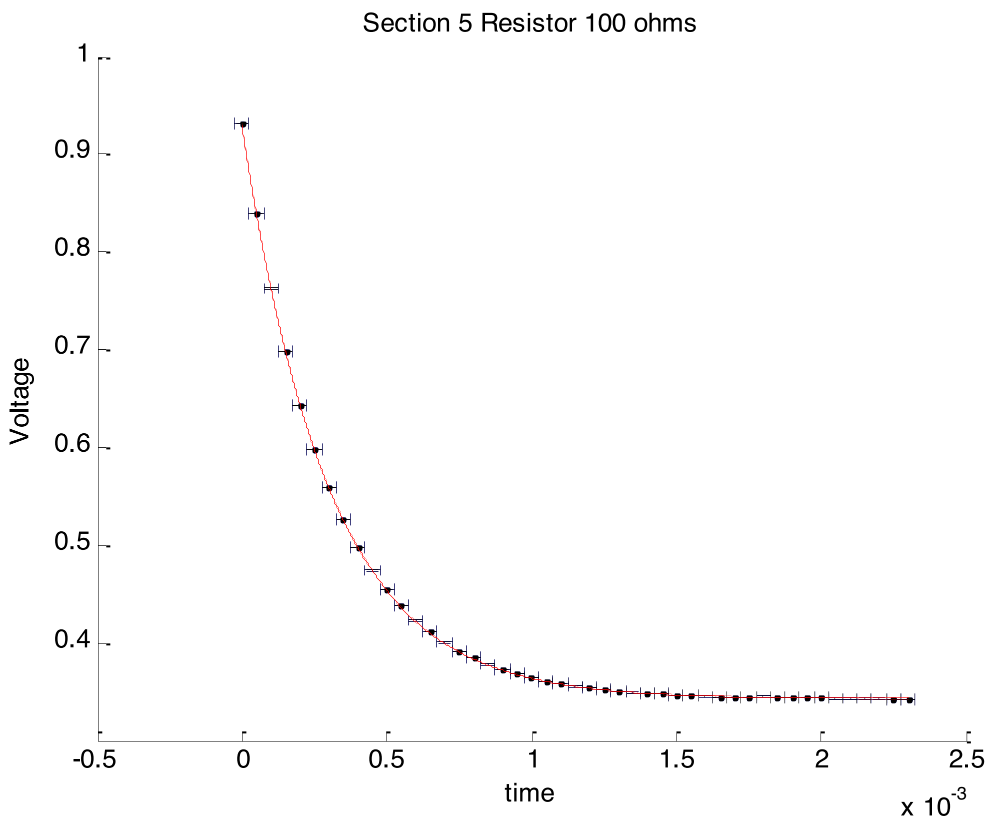
4. **General Lab Score**

Section 5.1

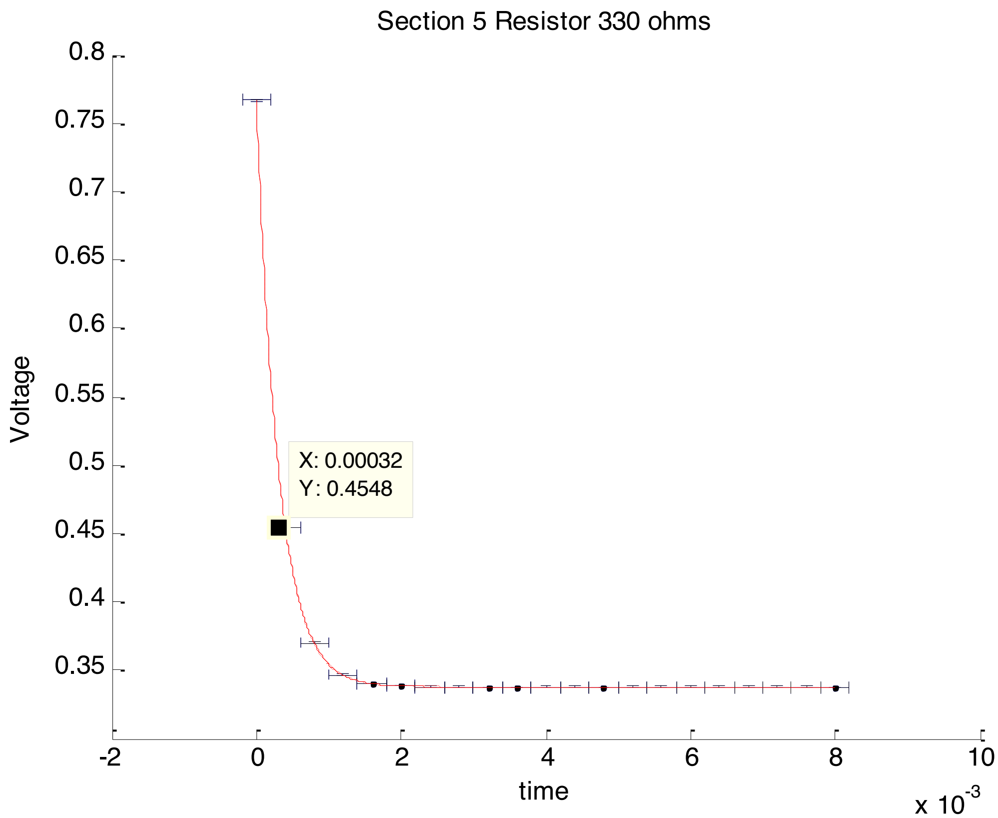
- Resistance/ inductance measurements.

R_1: 100 Ω	98.1 ± 0.1 Ω
R_2: 330 Ω	321.1 ± 0.2 Ω
L: 150 mH Inductance	146.9 ± 0.1 mH
R_L: 150 mH Resistance	166.0 ± 0.2 Ω

- Voltage-time plots with fits (refer to Datastudio guide for fitting).



Enter Approximation of Noise Voltage Error: 0.0002393
Enter estimate for parameter A: 0.70
Enter estimate for parameter tau: 0.000225
Enter estimate for parameter B: 0.3364
Parameter A = 5.873071e-01 +/- 3.901827e-04
Parameter tau = 3.003718e-04 +/- 3.751937e-07
Parameter B = 3.427218e-01 +/- 1.160282e-04



Enter Approximation of Noise Voltage Error: 0.000249
Enter estimate for parameter A: 0.4292
Enter estimate for parameter tau: 0.00029
Enter estimate for parameter B: 0.3376
Parameter A = 4.287834e-01 +/- 2.379071e-04
Parameter tau = 3.081195e-04 +/- 4.409319e-07
Parameter B = 3.377801e-01 +/- 5.567916e-05

- Model function with parameters
  Resistor 110 Ω:
    Model function:

$$f(x) = 0.5873 \times e^{\frac{-x}{0.000308}} + 0.3427$$

    Fitted Parameters:
      Parameter A: 0.5873± 0.0004
      Parameter tau: 0.000300±0.000001
      Parameter B: 0.3427±0.0001

  Resistor 330 Ω:
    Model function:

$$f(x) = 0.4288 \times e^{\frac{-x}{0.0003}} + 0.338$$

    Fitted Parameter:
      Parameter A: 0.4288± 0.0004
      Parameter tau: 0.000308±0.000001

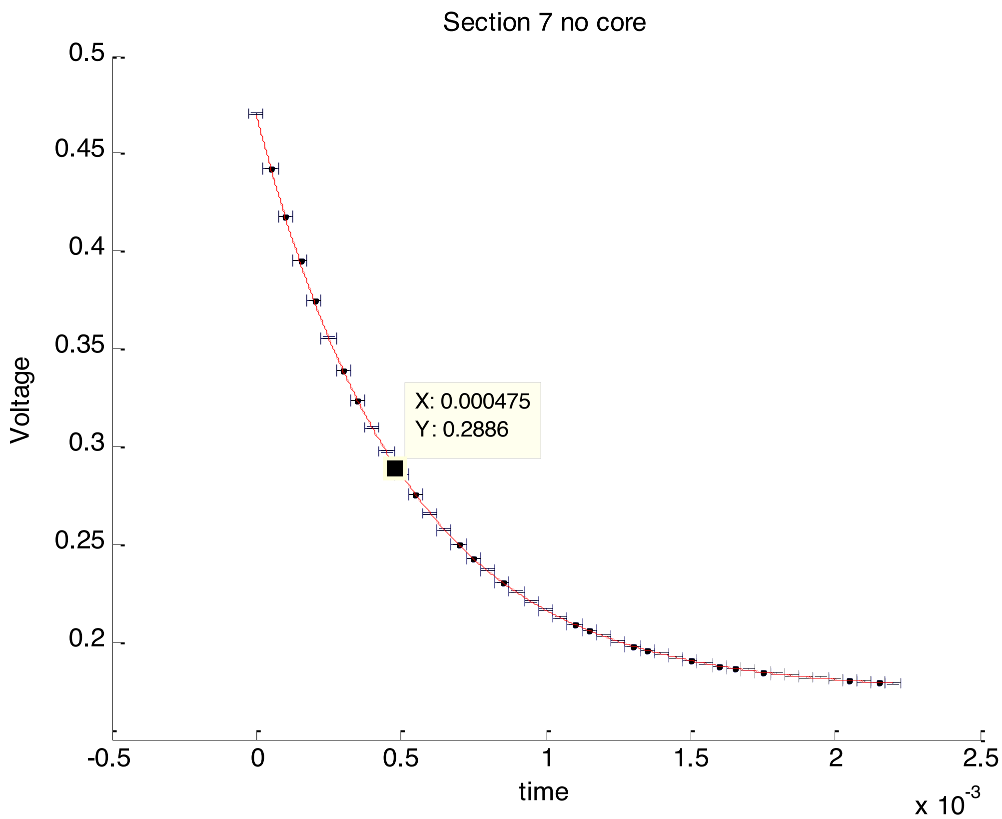
Parameter B: 0.3378±0.0001

Section 7.

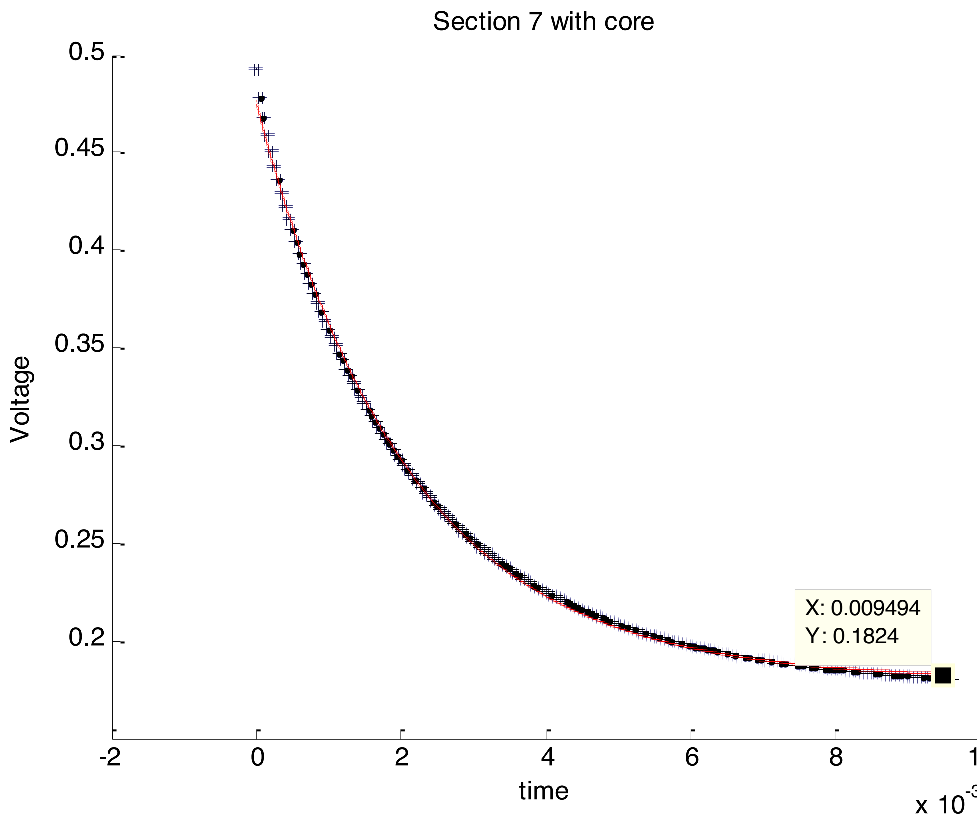
- Resistance/ inductance measurements.

	With Iron Core	Without Iron Core
Time constant	0.000510±0.000006	0.0027±0.0001
Resistor (330Ω)	323.7±5.5	323.7±5.5
Resistance(In)	5.5±0.1	5.5±0.1
Resistance (tot)	329.2±0.2	329.2±0.2
Inductance (In)	21.1±0.1	8.1±0.1

- Voltage-time plots with fits (refer to Datastudio guide for fitting).



Enter Approximation of Noise Voltage Error: 0.00024
Enter estimate for parameter A: 0.2942
Enter estimate for parameter tau: 0.000475
Enter estimate for parameter B: 0.1789
Parameter A = 2.952971e-01 +/- 1.027026e-04
Parameter tau = 5.103676e-04 +/- 4.327959e-07
Parameter B = 1.747968e-01 +/- 5.885074e-05



Enter Approximation of Noise Voltage Error: 0.00021
Enter estimate for parameter A: 0.3125
Enter estimate for parameter tau: 0.002
Enter estimate for parameter B: 0.1804
Parameter A = 2.954865e-01 +/- 7.010088e-04
Parameter tau = 2.081141e-03 +/- 1.131808e-05
Parameter B = 1.799013e-01 +/- 3.500620e-04

- Model function and fitted parameters

No core:

Model function:

$$f(x) = 0.2953 \times e^{\frac{-x}{0.000510}} + 0.1758$$

Fitted Parameter:

Parameter A: 0.2953 ± 0.0001
Parameter tau: 0.000510±0.000001
Parameter B: 0.1758 ±0.0001

With core:

Model function

$$f(x) = 0.2953 \times e^{\frac{-x}{0.000510}} + 0.1758$$

Fitted Parameter:

Parameter A: 0.2955 ± 0.0007

Parameter tau: 0.00208±0.00001
Parameter B: 0.1799 ±0.0003

5. Analysis
Section 5.1

- Determine the resistance ratio: $\frac{R_{tot,1}}{R_{tot,2}}$ and uncertainty.

$$\frac{R_{tot,1}}{R_{tot,2}} = \frac{R_L + R_1}{R_L + R_2} = 0.542$$

Error of propagation:

$$R_{tot,1} = \sqrt{\partial R_L{}^2 + \partial R_1{}^2} = 0.2$$

$$R_{tot,2} = \sqrt{\partial R_L{}^2 + \partial R_2{}^2} = 0.3$$

$$\partial \frac{R_{tot,1}}{R_{tot,2}} = \partial R_{rat} = \sqrt{(\frac{\partial R_{rat}}{\partial R_1}\partial R_1)^2 + (\frac{\partial R_{rat}}{\partial R_2}\partial R_2)^2} = 0.006$$

Ans=0.542 ± 0.006

- Determine measured τ's and uncertainties from fitted parameters.
  Expected τ (from Eq 5):

$$\tau_1 = \frac{L}{R_{tot,1}} = \frac{0.1469}{264.1} = 0.000556$$

Error of Propagation:

$$\partial\, \tau_1 = \sqrt{(\frac{\partial \tau_1}{\partial L}\partial L)^2 + (\frac{\partial \tau_1}{\partial R}\partial R)^2} = 0.000008$$

τ_1=0.000556±0.000008

$$\tau_2 = \frac{L}{R_{tot,2}} = \frac{0.1469}{487.1} = 0.000301$$

Error of Propagation:

$$\partial\, \tau_2 = \sqrt{(\frac{\partial \tau_2}{\partial L}\partial L)^2 + (\frac{\partial \tau_2}{\partial R}\partial R)^2} = 0.000011$$

τ_2=0.000301±0.000011

Measured τ's from fitted parameters

$\tau_1 = 0.000300 \pm 0.000001$

$\tau_2 = 0.000308 \pm 0.000001$

- Determine τ ratio: $\frac{\tau_1}{\tau_2}$ and uncertainty.

Expected $\frac{\tau_1}{\tau_2}$= 1.847

Error of Propagation:

$$\partial \frac{\tau_1}{\tau_2} = \partial\tau_{ratio} = \sqrt{(\frac{\partial\tau_{rat}}{\tau_1}\partial\tau_1)^2 + (\frac{\partial\tau_{rat}}{\tau_2}\partial\tau_2)^2} = 0.073$$

Expected $\frac{\tau_1}{\tau_2}$= 1.847±0.073

Measured $\frac{\tau_1}{\tau_2}$= 0.974

Error of propagation:

$$\partial \frac{\tau_1}{\tau_2} = \partial\tau_{ratio} = \sqrt{(\frac{\partial\tau_{rat}}{\tau_1}\partial\tau_1)^2 + (\frac{\partial\tau_{rat}}{\tau_2}\partial\tau_2)^2} = 0.004$$

Measured $\frac{\tau_1}{\tau_2}$= 0.974±0.004

- Given L is fixed, show the relationship between these ratios. Verify this with a quantitative comparison. *Does τ's dependence on R agree with Eq. 5?*

$$L = \tau R \text{ so } \frac{\tau_1}{R_{tot,2}} = \frac{\tau_2}{R_{tot,1}} \text{ hence } \frac{\tau_1}{\tau_2} = \frac{R_{tot,2}}{R_{tot,1}}$$

Expected $\frac{\tau_1}{\tau_2}$= 1.847±0.073

$\frac{R_{tot,2}}{R_{tot,1}}$ = 1.845 ± 0.002

Percentage Error:

$$\frac{|Theoretical - Experimental|}{Experimental} \times 100\%$$

$$\frac{\left|\text{Expected } \frac{\tau_1}{\tau_2} - \frac{R_{tot,2}}{R_{tot,1}}\right|}{\frac{R_{tot,2}}{R_{tot,1}}} \times 100\% = 0.1\%$$

T-test:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

where

$\overline{x_1}$=mean value of Experimental Value
$\overline{x_2}$= mean value of Theoretical Value
S_1 = Standard deviation of Experimental Value
S_2 = Standard deviation of Theoretical Value
N_1= Number of data in Experimental Value
N_2= Number of data in Theoretical Value

In this case,
$\overline{x_1}$=1.845
$\overline{x_2}$= 1.847
$S_1 = 0.006$
$S_2 = 0.073$
N_1= 1
N_2= 1

t-value= -0.027

Percentage error	t-value
0.1%	0.027

Yes, τ's dependence on R agree with Eq(5).

- With knowledge of the circuit's total resistance determine the inductance value of the inductor; *does it agree with the labeled value (quant. Compare)?*

	τ	R	L
Resistor 1	0.000300±0.000001	264.1 ± 0.2 Ω	0.0792±0.0002
Resistor 2	0.000308±0.000001	487.1 ± 0.3 Ω	0.1500±0.0005

Expected	---------------	-----------------	0.1469±0.0001

	R1-L vs Ex L	R2-L vs Ex L
Percent Error	85.5%	2.1%
t-value	-234.5	6.129

The result of the L_1 shows a great difference on t-value and percent error with the labeled value. Therefore, in this case, I cannot prove the dependence of τ on R according to Equation 5. However, I do not think that this is because of the lack of accuracy or calculation error. I speculate this as a random error from the data collected with resistor 100 ohms. Prior to taking the measurement, the device failed to deliver the expected result several times. Both TA's came to help and spent a lot of time trying to get the machine to work.

- Derive relationship between steady state voltage (t>> τ) of the inductor and the resistances in the circuit (as well as the applied voltage). Calculate values for the voltage for both resistors.

According to Ohm's Law: $I_{max} = \frac{V}{R_{total}}$

$$V_{steady,L} = V_0 - V_R = V_0 - IR_r$$

Therefore

$$V_{steady,L} = V_0 - \frac{V}{R_{total}} R_r = \frac{V_0 R_L}{R_r + R_L}$$

For Resistor 1:

$V_0 = 1$ $\quad$ $V_{steady,L} = 0.628$

For Resistor 2:

$V_0 = 1$ $\quad$ $V_{steady,L} = 0.300$

Error of Propagation:

$$\partial V_{steady,L} = \sqrt{\left(\left(\frac{V_0}{(R_r + R_L)} - \frac{V_0 R_L}{(R_r + R_L)^2}\right) \times \partial R_L\right)^2 + \left(-\frac{V_0 R_L}{(R_r + R_L)^2} \times \partial R_r\right)^2}$$

Voltage of Resistor 1: 0.628± 0.001 V
Voltage of Resistor 2: 0.300± 0.001 V

- Determine steady state voltage from both plots fitted parameters and verify the expected values.

  Voltage of measured Resistor 1 (100 ohms): 0.3427±0.0001

  Voltage of Resistor 2(330 ohms): 0.3378±0.0001

	V of R1	V of R2
%Error	83.3%	11.2%
t-value	264.9	37.6

See note of Analysis Section 5.1 Question 5.

Section 7

- Determine τ values from fitted parameters (with/without core).

  From Eq (5) and its error of propagation in Analysis Section 5.1 second question:

  No core 0.000510±0.000001

  With core: 0.00208±0.00001

- Determine the inductance values (with and without core)

	With Iron Core	Without Iron Core
Resistor (330Ω)	323.7±5.5	323.7±5.5
Resistance(In)	5.5±0.1	5.5±0.1
Resistance (tot)	329.2±0.2	329.2±0.2
Inductance (In)	0.0211±0.1	0.0081±0.1
τ	0.000641±0.0003	0.00246±0.0003

6. **Discussion**

Yes, the inductance value is different than in the absence of the iron core. The iron core has a stronger magnetic field that induces the inductor even more, hence the increase of inductance. The change of magnetic field passing through the solenoid induces a voltage, hence the inductance. The inductance is directly proportional to the magnetic flux. Eq(2) shows that the magnetic flux is directly proportional to the cross-sectional area of the inductor. The greater the area, the more inductance. It is also correlates to the number of turns in the wire. The more turns in wire the more inductance. Also the shorter the time is spent on the same magnetic flux the greater inductance. This suggests the origin of the inductance is based on the circuits components such as the wire and the nature of the inductor, these directly affect the magnetic flux and the inductance.