**Lab 218: LR Circuits**

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**Date of Experiment: 04/18/2024** **Report Submitted: 04/25/2024**

**Course: PHYS 121A 016** **Instructor: Subodh Dahal**

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# 1. INTRODUCTION

## 1.1 OBJECTIVES

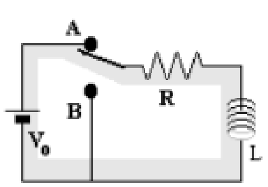
The purpose of this lab was to understand how inductors work when placed in a circuit. In our last lab experiments, we learned how inductors work, how to find the value of L, and how inductors create an induced voltage/current to counter the change in current. Now, we were able to see how inductors work within a circuit, and how their reactance operates. We want to be able to analyze the behavior of inductors as a sort of resistor when given an AC current (which has rapid changes in current).

## 1.2 THEORETICAL BACKGROUND

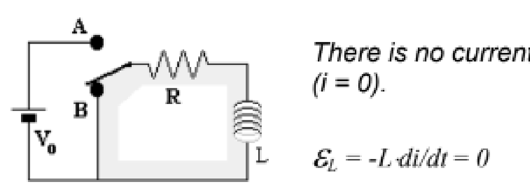
The induced Electromotive force, ε across an inductor is given by:

(1) $\varepsilon_L = -L\frac{di}{dt}$

As seen in Figure 1 there is an RL circuit. The switch can be in position A or B, and if it's in either position for long enough the current will be constant. $\frac{d_i}{d_t} = 0$ when there is no change in current, thus there will be no emf in the inductor.An EMF is present when the current is changing ($\frac{d_i}{d_t} \neq 0$). In this lab we will be moving the switch from A to B to change the current.




At t = 0 (switch is moved to position A)
**Figure 1a.**




At t<0 (switch in position B)
**Figure 1b.**

**I.Current Starts to Flow**

When the switch is moved from B to A, we can use Kirchoff's Law (Figure 1a):

(2) $$V_o - iR - L\frac{di}{dt} = 0$$

, where the voltage across battery is $V_o$ , the resistance, R, and the inductance of the coil, L.

(3) $$i(t) = (\frac{V_o}{R})(1 - e^{-t/\tau})$$

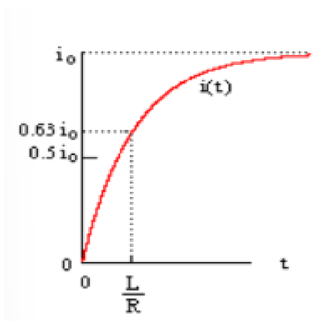
The plot of Equation 3 is below where $\tau = \frac{L}{R}$ is the circuit time constant. Since the inductor's voltage is given by $\varepsilon_L = -L\frac{di}{dt}$,

(4) $$V_L(t) = V_o e^{-t(R/L)}$$

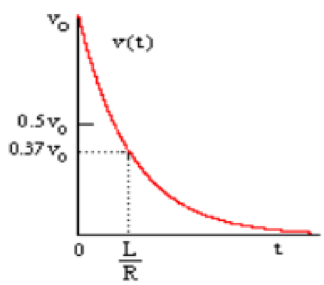
The plot of equation 4 is below. You can now take the natural log of both sides and rewrite equation 3 as:

(5) $$ln[1 - \frac{i(t)}{i_0}] = -\frac{R}{L}t$$

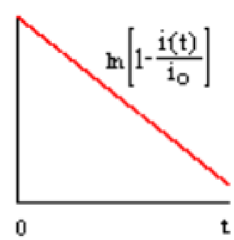
When graphed, we can see that it is a straight line with slope -R/L (see below)



Equation 3 Plot



Equation 4 Plot



Equation 5 Plot

When the switch is moved from B to A or vice versa, a current will start to flow. The inductor will generate an EMF that will resist the current from fully flowing. The current will increase to its maximum value over time. The growth of the current is dependent on the inductance and resistance of the circuit.

## II. Current is Stopped

Before the switch is turned to position B (t<0) the current is constant( $i = \frac{V_o}{R}$ ).

Therefore, $\varepsilon_L = -L\frac{di}{dt} = 0$

The moment the switch is moved into position B, we can apply Kirchoff's Law:

(6) $$iR + L(\frac{di}{dt}) = 0$$

In this equation the resistance in the loop is , R, and the inductance is, L.

(7) $i(t) \ = \ (\frac{V_o}{R})e^{-t/\tau}$

Equation 7 plotted on the next page. Since the EMF across the inductor is $\varepsilon_L = - L(\frac{di}{dt})$

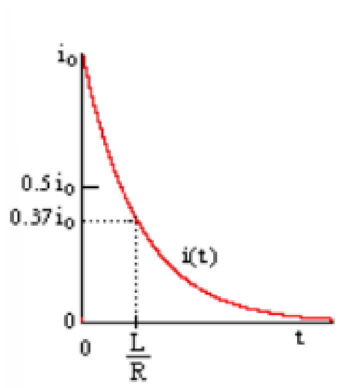
(8) $V_L(t) \ = \ V_0 e^{-t(R/L)}$ Equation 8 plotted below.

Taking the natural log on both sides we can rewrite equation 7:

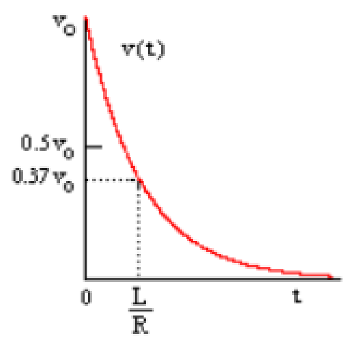
(9) $ln[\frac{i(t)}{i_0}] \ = \ - (\frac{R}{L})t$

Again Equation 9 when plotted is a straight line with slope -R/L.

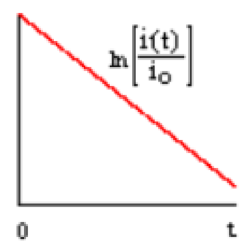
When the switch is moved from A to B, currents will stop flowing. The inductor will generate an EMF that will still continue over time. The decrease of the current is dependent on the inductance and resistance of the circuit.



Equation 7 Plot



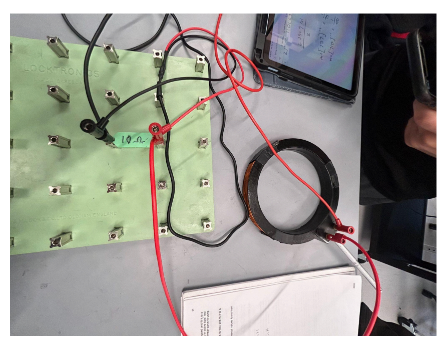
Equation 8 Plot



Equation 9 Plot

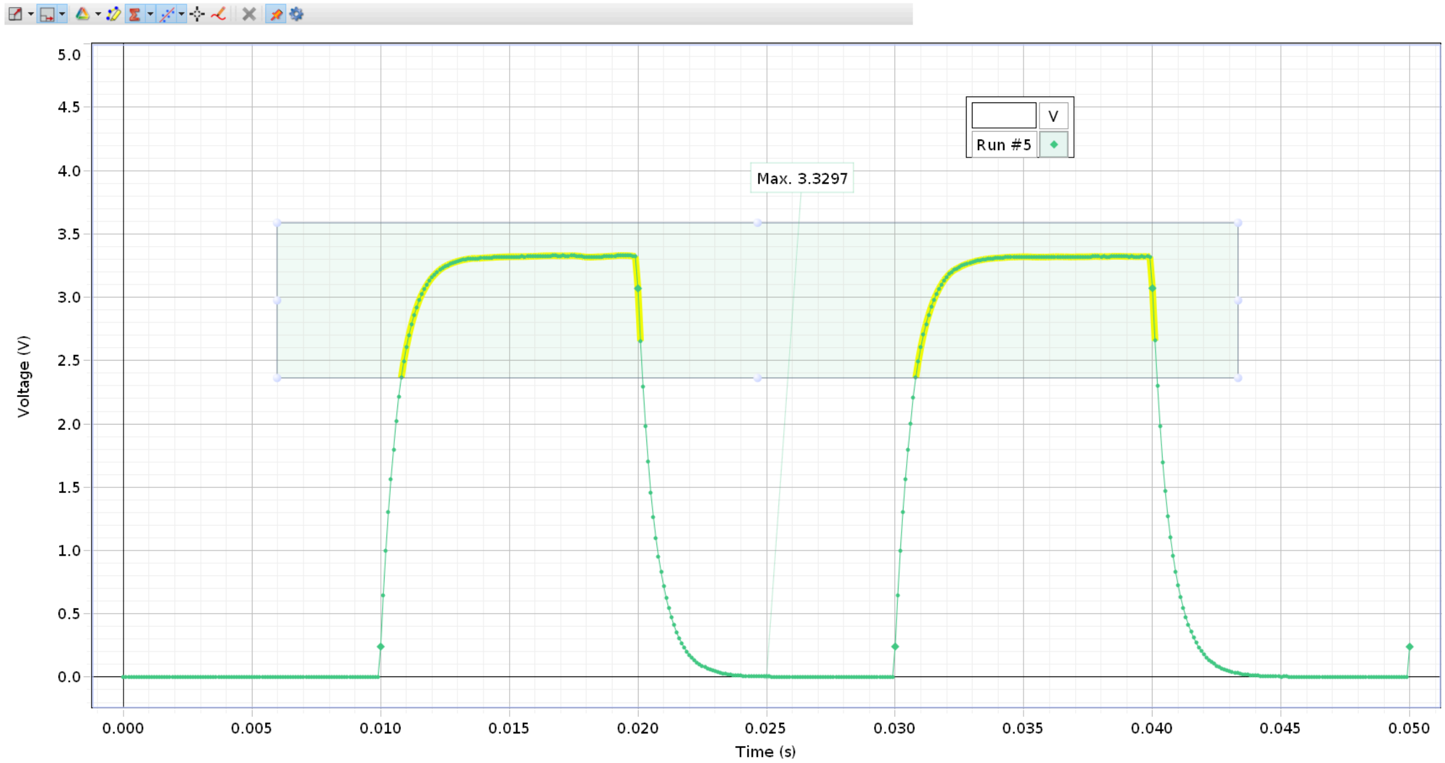
2. **EXPERIMENTAL PROCEDURE**

Various inductors were connected in series with a 10 Ω resistor, with the entire circuit then connected into a computer. Software was used to apply an AC current to the circuit, as well as to record the current through the circuit over time. Current-time graphs were then analyzed to experimentally determine the time constant of each RL circuit, which were then compared to the theoretical time constants for each circuit.



3.1 **RESULTS**

**Solenoid:**

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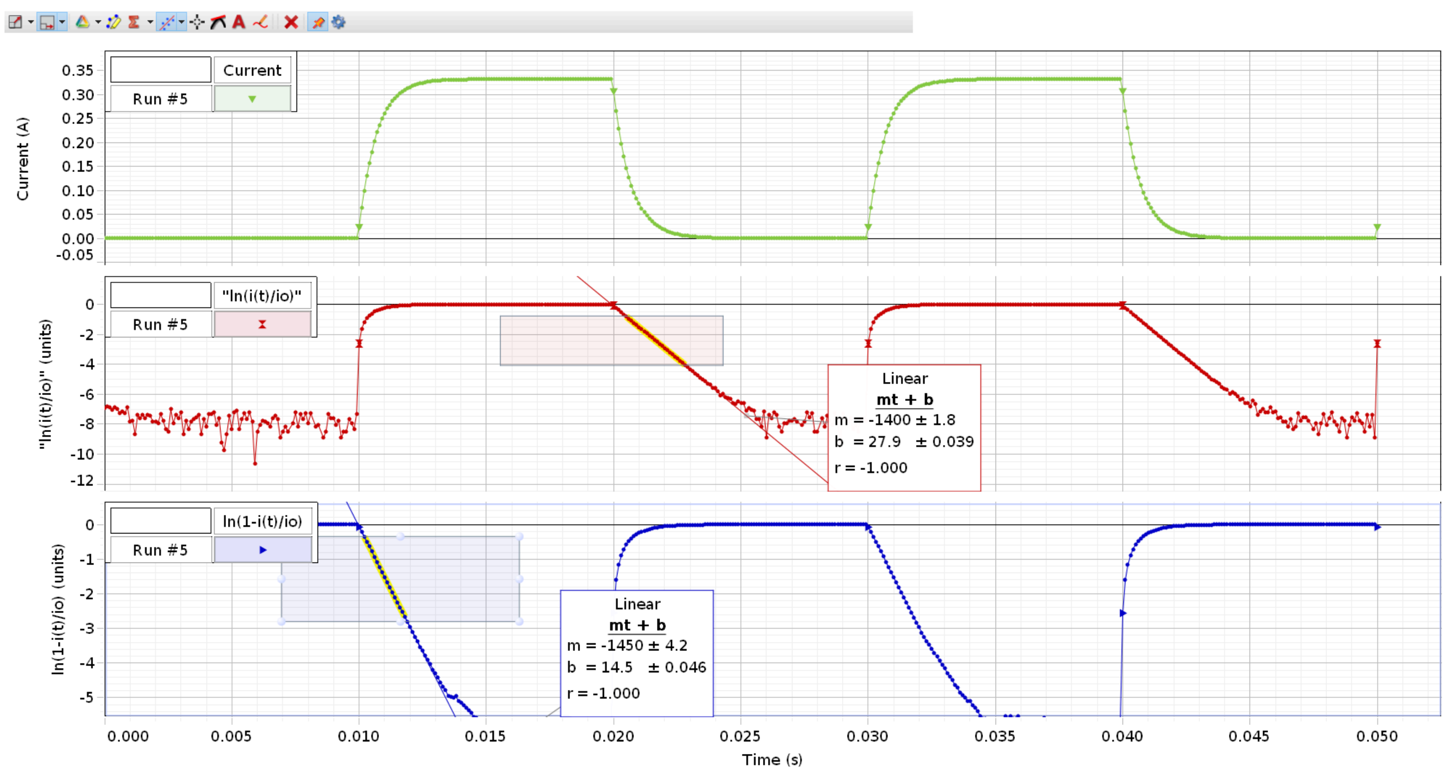
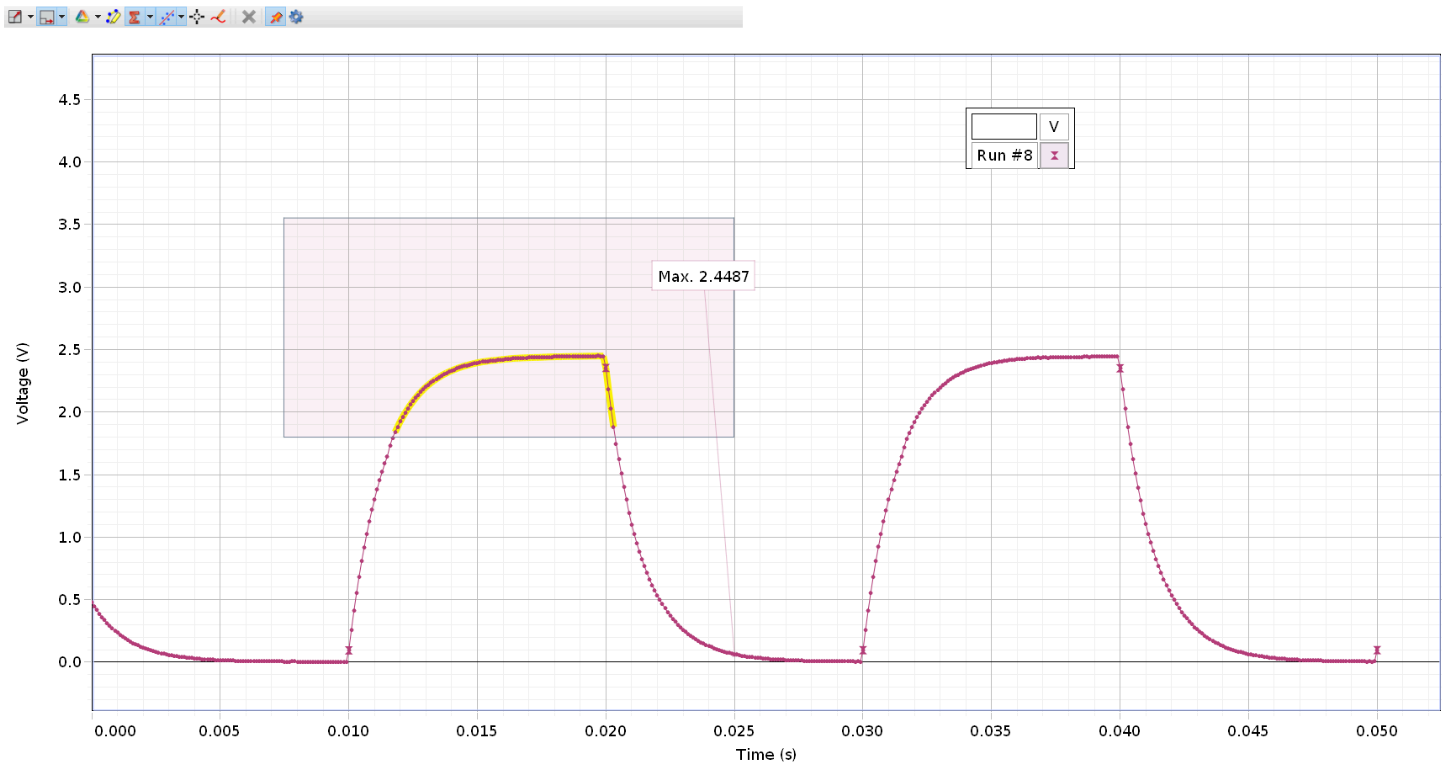



Linear Method

## **Loop:**

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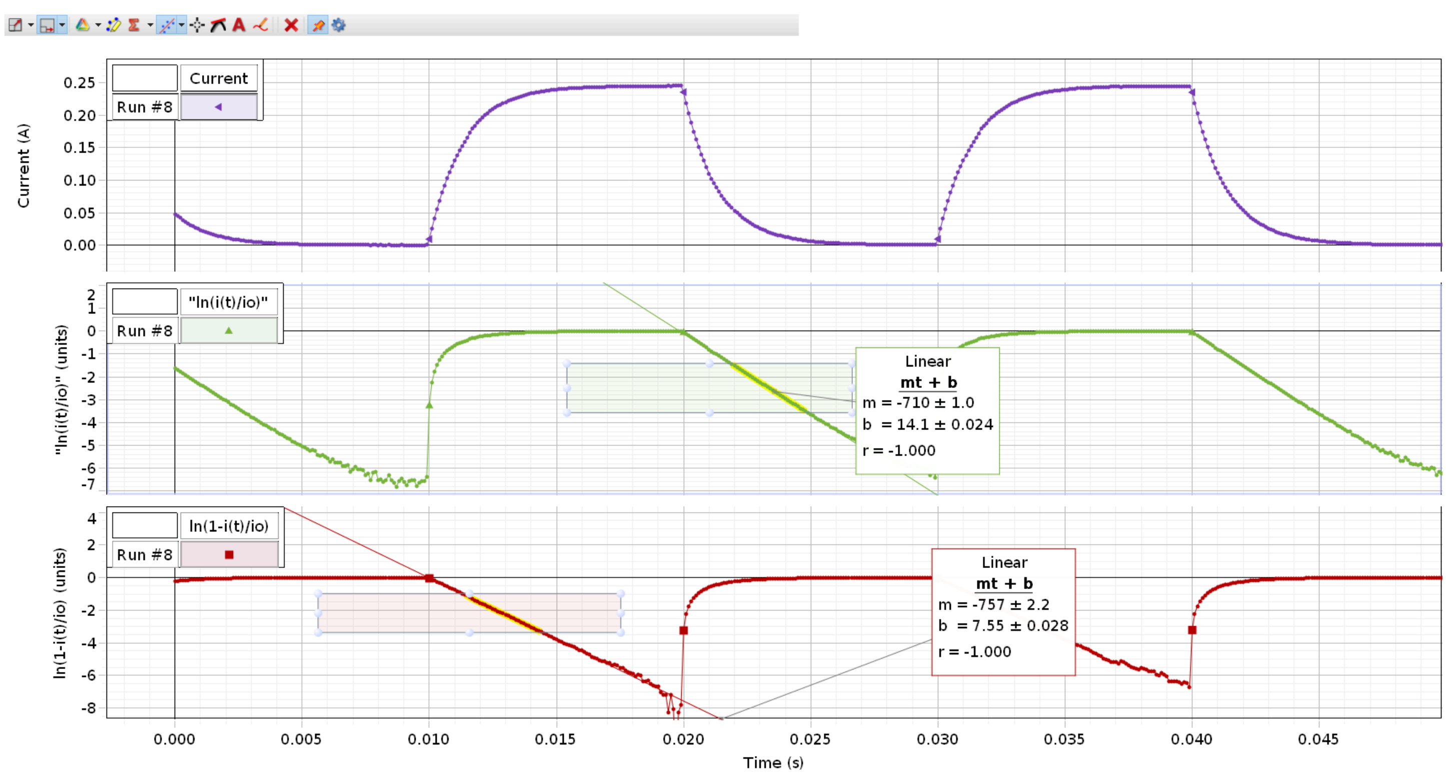


Linear Method

## 3.2 CALCULATION

| Theoretical Time Constant | |
|---|---|
| $\tau_{loop} = L_{loop} / (R + R_{loop}) = 23 \cdot 10^{-3}\ \mathrm{H} / (10.0 + 6.4\ \Omega)$<br>$= 1.40 \cdot 10^{-3}\ \mathrm{s}$ | $\tau_{solenoid} = L_{solenoid} / (R + R_{solenoid}) = 8.27 \cdot 10^{-3}\ \mathrm{H} / (10.0 + 1.9\ \Omega)$<br>$= 6.95 \cdot 10^{-4}\ \mathrm{s}$ |

| Experimental Time Constant | |
|---|---|
| $\tau_{solenoid} = m^{-1} = 757^{-1} = 1.32 \cdot 10^{-3}$ s<br>$= 710^{-1} = 1.41 \cdot 10^{-3}$ s<br><br>$\tau_{avg} = 1.36 \cdot 10^{-3}$ s | $\tau_{solenoid} = m^{-1} = 1400^{-1} = 7.14 \cdot 10^{-4}$ s<br>$= 1450^{-1} = 6.70 \cdot 10^{-4}$ s<br><br>$\tau_{avg} = 7.02 \cdot 10^{-4}$ s |
| **Percentage Difference** | |
| $\%_{diff} = \lvert 1.36 \cdot 10^{-3} - 1.40 \cdot 10^{-3}$ s$\rvert$ / $1.36 \cdot 10^{-3}$ s = 0.0276<br>= 2.76 % | $\%_{diff} = \lvert 6.95 \cdot 10^{-4} - 7.02 \cdot 10^{-4}$ s$\rvert$ / $6.95 \cdot 10^{-4}$ s = 0.0101<br>= 1.01 % |

## 4. ANALYSIS and DISCUSSION

We learned more about RL circuits. For this experiment, we used an RL circuit consisting of resistors and inductors connected by a loop and a solenoid.Until the inductor reaches its maximum value, the current increases.The values were determined by the applied voltage, circuit resistance, and inductor inductance. For practical applications, the steady-state current must fulfill the circuit's intended parameters. The experimental findings showed that the time constant (τ) of the RL circuit is 0.5s. This time constant reflects the time it takes for the circuit's current to reach around 63.2% of its ultimate steady-state value. RL circuits have properties like energy storage and release. When current goes through an inductor, it stores energy in its magnetic field, which is then released when the current changes. Understanding the energy dynamics of RL circuits is critical for applications like power electronics and electromagnetic systems. In practical applications, RL circuits are widely used in domains like power supply, motor control, signal processing, and telecommunications. Understanding the behavior of RL circuits allows engineers to create efficient and dependable systems that are suited to specific needs.

## 5. CONCLUSIONS

In this lab, we learnt more about RL circuits. For this experiment, we used an RL circuit consisting of resistors and inductors connected by a loop and a solenoid.Until the inductor reaches its maximum value, the current increases. We achieved the maximum and linear fit of the graphs, which is the inverse time constant. This experiment taught us how to set up RL circuits and how current flows through them. This experiment offered useful information on the behavior of RL circuits. By measuring the time constant and examining the transient and steady-state responses, we obtained a better understanding of how RL circuits react to voltage and current changes. Further investigations might look into how varying resistor and inductor values affect the behavior of RL circuits.

6. **Raw Data**

Experiment One

$$1)\ m = -1400(8.27\times10^{-3}) = R_{ta} = 11.578 - 10 = 1.578\ \Omega$$

$$2)\ m = -1450(8.27\times10^{-3}) = 11.99 - 10 = 1.99\ \Omega$$

$$\frac{1.99 + 1.578}{2} = R_L = 1.784\ \Omega$$

Theoretical: $1.784\ \Omega$ Actual: $1.9\ \Omega$

$$m = -1400 = -\frac{R}{L} \qquad \tau = \frac{L}{R}$$

$$\left[1400 = \frac{R}{L}\right]^{-1} \qquad \tau = \frac{1}{1400} \approx 0.000714$$

$$m = -1450$$

$$\left[1450 = \frac{R}{L}\right]^{-1} \qquad \tau = 0.000690$$

Experiment Two

1) $m = 757(23\times10^{-3}) = 17.411 - 10 = 7.41$

2) $m = 710(23\times10^{-3}) = 16.33 - 10 = 6.33$

$$\frac{6.33 + 7.41}{2} = 6.87\ \Omega$$

$$m = [757]^{-1} = \frac{1}{757} = \tau \approx 0.001321$$

$$m = [710]^{-1} = \frac{1}{710} \approx 0.001408$$