T.C.

GEBZE TECHNICAL UNIVERSITY

PHYSICS DEPARTMENT

PHYSICS LABORATORY II

EXPERIMENT REPORT

THE NAME OF THE EXPERIMENT

Inductance of Solenoids

PREPARED BY

NAME AND SURNAME :

STUDENT NUMBER :

DEPARTMENT :

GROUP NO :

TEACHING ASSISTANT :

DATE OF THE EXPERIMENT : ….. / ….. / ……….

DATE : ….. / ….. / ……….

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Experimental Procedure:

There are a number of methods to measure the inductance of a substance. Here we will use the simplest and most basic one: an LC circuit. An LC circuit consists of a capacitor (C) and an inductor (L). Most basic property of this circuit is its oscillatory nature. Charges inside it oscillate with a characteristic frequency:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{9.6}$$

If the value of C is known, by measuring the frequency, the inductance, L, can be found from the expression below:

$$L = \frac{1}{4\pi^2 C f^2} \tag{9.7}$$

This is the experimental expression for inductance that you will need in experimental calculations.

As in mechanical oscillations, one should disturb the system in order to make it oscillate. In an LC circuit, we could do it in two ways:

i) by initially charging the capacitor,

ii) by initially allowing a magnetic flux to pass through the inductor.

We will prefer the second choice. After an oscillation starts, in principle (in the absence of resistance), it would continue permanently. But in practice, all electronic devices and circuit elements have a finite resistance. Therefore, the oscillations are damped, i.e., have diminishing amplitude with time. But no fear! We can anyway observe the oscillation by an analog oscilloscope if we choose right circuit elements.

Instructions

1. Set the circuit as in Figure 9.1.

2. Plug the capacitors of $C_1 = 1$ nF and $C_2 = 470$ pF in a parallel arrangement on appropriate place on the connection box. Note that black lines on the connection box show the connected lines inside it. The internal capacitance of the oscilloscope is approximately 30 pF. Thus effective capacitance of the circuit is $C = 1\text{ nF} + 470\text{ pF} + 30\text{ pF} = 1.5\text{ nF}$.

3. Take two cables and wire the solenoid with unknown L, and plug it in an appropriate place on the connection box to set the LC circuit given below.

4. Wire two cables from the two poles of the capacitor and plug them into the first channel of the oscilloscope.

5. Turn the oscilloscope and function generator on, set the frequency of the latter to $f \cong 2000$ Hz, and seek a good image on the former's display.

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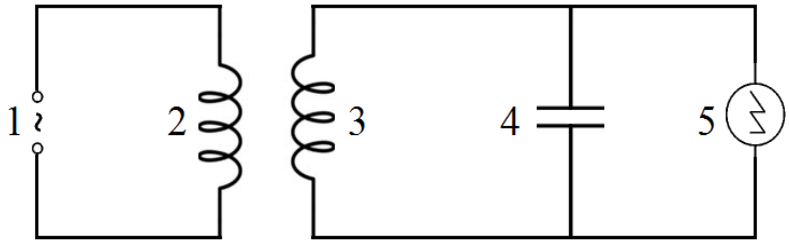
6. You should get an image like in Figure 9.2. This is the amplitude signal of the free damped oscillation in an LC circuit. The oscillation is due to the resistance of all elements in the circuit, especially that of the oscilloscope. But this internal resistance is negligibly weak (there is only a %1 slip effect on the oscillation frequency), and we can assume that the oscillation frequency is equal to that of the ideal LC circuit:

$$\omega = \sqrt{\omega_0^2 - \beta^2} \approx \omega_0 \qquad 9.8$$

here ω_0 is the oscillation frequency of the ideal LC circuit, $\beta = R/2L \ll \omega_0$ is the damping coefficient and ω is the oscillation frequency of the RLC circuit.



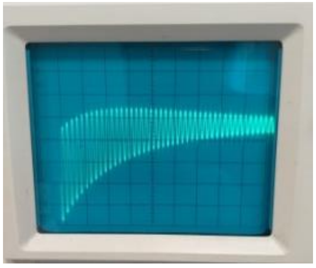


Figure 9.1: (*left*) Schematic of the circuit. (*right*) The picture showing the amplitude of free damped oscillations in the circuit.

1) AC current source,
2) Primary coil to trigger the oscillations in LC circuit,
3) Solenoid under investigation with unknown L ,
4) Capacitor with $C = 1$ nF + 470 pF + 30 pF = 1.5 nF,
5) Oscilloscope to display and measure the voltage signal on the capacitor.

7. Measure the horizontal distance between two peaks seen on display screen. To do this, you have to find the number of units between two successive peaks (N) and know the time factor (τ). The period of oscillations is found as $T = N\tau$. During the experiment, you will probably need to change the time factor; therefore, you should be careful about its value in each measurement. You can read the value of τ from the rightmost button on the front panel.

8. In the lab, only fill the first empty column in the table below. Other columns will be filled at home after calculations, the first one by $f = 1/T$ and the second one after Equation 9.7

Table 9.1:

Solenoid	N	r (mm)	l (mm)	T (s)	f (s^{-1})	L (H)
1	300	20	160			
2	300	16	160			
3	300	13	160			
4	200	20	105			
5	100	20	53			
6	150	13	160			
7	75	13	160			

[$C = 1$ nF + 470 pF + 30 pF = 1.5 nF]

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Calculations and Analysis:

After the original table, you will need $log - log$ graphs to find the winding, length, and radius dependence of inductors. By using the previous table, create the following ones:

Table 9.2: Inductance (L) dependence on the number of turn in solenoids (N)

No	N	L	$\log N$	$\log L$
3				
6				
7				

Table 9.3: Inductance (L) dependence on the length of solenoids (l)

No	l	L/N^s	$\log l$	$\log\ (L/N^s)$
1				
4				
5				

Table 9.4: Inductance (L) dependence on the radius of solenoids (r)

No	r	L	$\log r$	$\log L$
1				
2				
3				

Plot three data using 4th and 5th columns for $x-$ and $y-$axis respectively, and fit them with lines by least squares method and then find their slopes. As you will remember from the first semester lab courses, this analysis will give you powers of associated quantities $(m: s, q, p)$ and thus, the dependence of the inductance on the chosen quantity[1]. Slope (m) is found from the following expression:

$$m = \frac{3\sum_{i=1}^{3} x_i y_i - \sum_{i=1}^{3} x_i \sum_{i=1}^{3} y_i}{3\sum_{i=1}^{3} x_i^2 - (\sum_{i=1}^{3} x_i)^2} \quad 9.9$$

Here x_i and y_i are the logarithmic inputs in 4th and 5th columns taken from above three tables. For example, consider you found the slopes of lines generated from the tables as s, q, p, respectively. That means the following expressions are valid:

$$L \propto N^s; \ \frac{L}{N^s} \propto l^q\ ; \ L \propto r^p \quad 9.10$$

and as a result you will find

$$L = AN^s l^q r^p \quad 9.11$$

for inductance.

[1] *Please refer to "Deneysel Metotlara Giriş" booklet written by Dr. Erbahar for the details of this analysis.*

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Note that we have an idea about the values of the exponents as we have already derived the theoretical expression for it. In this way, you will be able to create your own empirical formula for inductance.

Use data from Table 9.2 and calculate the slope s of the line using the linear fitting formulae that fits the data points on your $\log N - \log L$ graph. In the following sums, the x_i's represent the $\log N$ values on the x–axis, while the y_i's represent the $\log L$ values on the y–axis of your graphs. k is the number of data used in calculations.

$$\sum_{i=1}^{3} x_i =$$

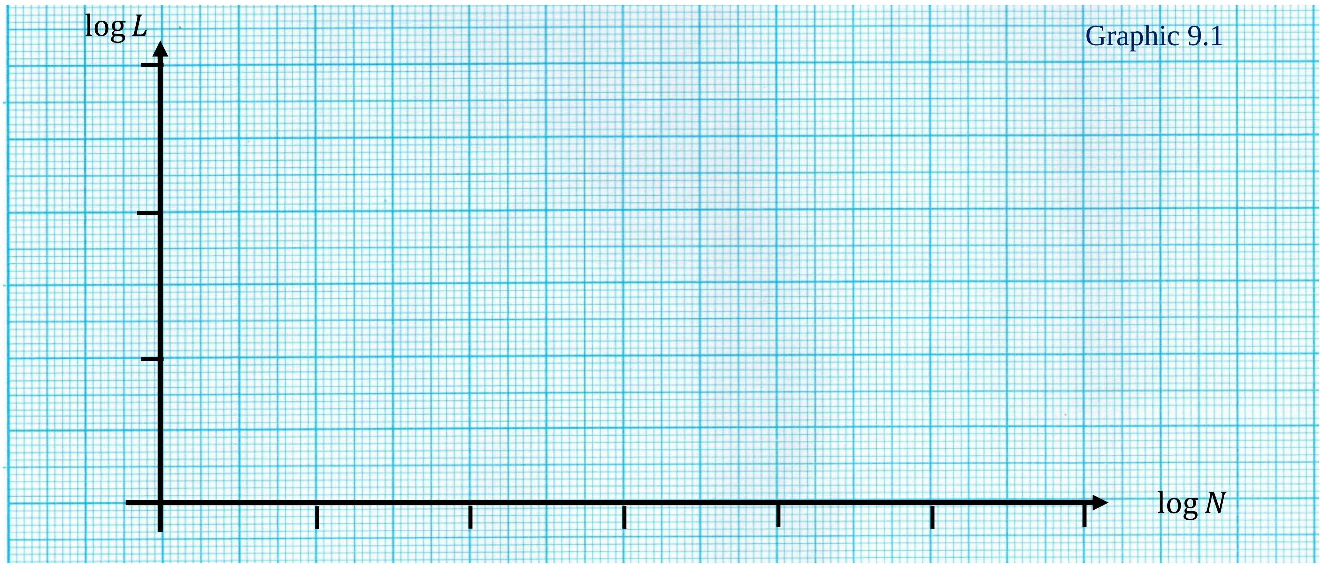
$$\sum_{i=1}^{3} y_i$$

$$\sum_{i=1}^{3} {x_i}^2 =$$

$$\sum_{i=1}^{3} x_i \, y_i =$$

$$s = \frac{3\sum_{i=1}^{3} x_i y_i - \sum_{i=1}^{3} x_i \sum_{i=1}^{3} y_i}{3\sum_{i=1}^{3} {x_i}^2 - \left(\sum_{i=1}^{3} x_i\right)^2} =$$

In the following graph, plot $\log N - \log L$ by using $\log N$ and $\log L$ columns of Table 9.2 as x– and y–axis, respectively. Represent the data as points on your graph and draw the straight line $\log L = s \log N$.



Graphic 9.1

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Use data from Table 9.3 and calculate the slope q of the line using the linear fitting formulae that fits the data points on your $\log l - \log(L/N^S)$ graph. In the following sums, the x_i 's represent the $\log l$ values on the x–axis, while the y_i's represent the $\log(L/N^S)$ values on the y–axis of your graphs. k is the number of data used in calculations.

$$\sum_{i=1}^{3} x_i =$$

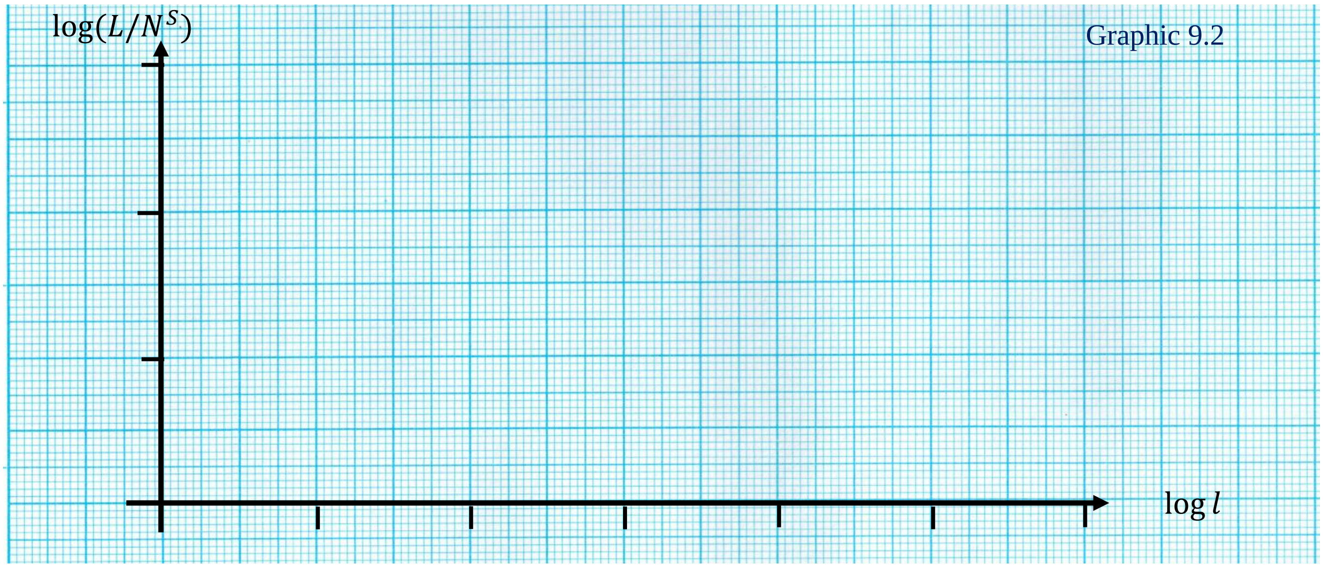
$$\sum_{i=1}^{3} y_i =$$

$$\sum_{i=1}^{3} {x_i}^2 =$$

$$\sum_{i=1}^{3} x_i\, y_i =$$

$$q = \frac{3\sum_{i=1}^{3} x_i y_i - \sum_{i=1}^{3} x_i \sum_{i=1}^{3} y_i}{3\sum_{i=1}^{3} {x_i}^2 - \left(\sum_{i=1}^{3} x_i\right)^2} =$$

In the following graph, plot $\log l - \log(L/N^S)$ by using $\log l$ and $\log(L/N^S)$ columns of Table 9.3 as x– and y–axis, respectively. Represent the data as points on your graph and draw the straight line $\log(L/N^S) = q \log l$.



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Use data from Table 9.4 and calculate the slope p of the line using the linear fitting formulae that fits the data points on your $\log r - \log L$ graph. In the following sums, the x_i's represent the $\log r$ values on the x–axis, while the y_i's represent the $\log L$ values on the y–axis of your graphs. k is the number of data used in calculations.

$$\sum_{i=1}^{3} x_i =$$

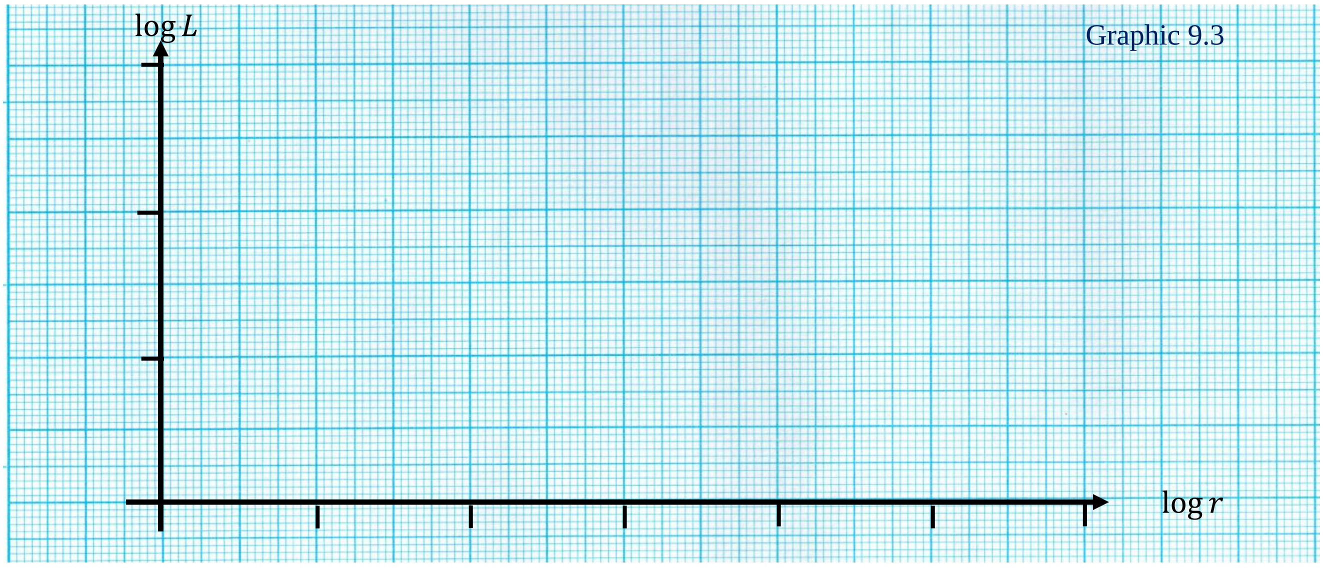
$$\sum_{i=1}^{3} y_i =$$

$$\sum_{i=1}^{3} x_i^2 =$$

$$\sum_{i=1}^{3} x_i\, y_i =$$

$$p = \frac{3\sum_{i=1}^{3} x_i y_i - \sum_{i=1}^{3} x_i \sum_{i=1}^{3} y_i}{3\sum_{i=1}^{3} x_i^2 - \left(\sum_{i=1}^{3} x_i\right)^2} =$$

In the following graph, plot $\log r - \log L$ by using $\log r$ and $\log L$ columns of Table 9.4 as x– and y–axis, respectively. Represent the data as points on your graph and draw the straight line $\log L = p \log r$.



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Fill the following table with powers calculated by fitting in previous sections.

Table 9.5: Comparison of powers. Theoretical values are taken from Equation 9.5.

power	s	q	p
theory	2	-1	2
fitting			

Conclusion, Comment and Discussion:

(Tips: Explain your general observations and experimental findings objectively and scientifically with your original sentences. Compare the derived exponents by theoretical expression. Discuss and explain your results.)

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Questions:

1. Derive the expression for the frequency of a LC circuit.

2. Propose some other methods to find the inductance.

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3. Find the derived units henry and farad in terms of basic quantities of the SI system.

4. List the magnetic permeability and inductance values of some important materials: iron, steel, cobalt, aluminum, plastic, glass, water, air, vacuum, etc., in two columns.

Sources

1. Young and Feedman, Sears and Zemansky's University Physics, 14th Edition, Pearson (2016).

2. For a simulation of RLC circuit and many of other systems:
http://www.vias.org/simulations/simusoft_dampedcircuit.html

3. A simulative explanation of LC oscillatory circuit from energy point of view and analogies with mechanics:
http://dev.physicslab.org/Document.aspx?doctype=3&filename=Induction_LCcircuits.xml

4. Erbahar D, "Deneysel Metotlara Giriş", GTÜ Fizik Bölümü (2015).
http://www.gtu.edu.tr/Files/UserFiles/90/Deneysel_metotlara_giri_1.pdf

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