T.C.

GEBZE TECHNICAL UNIVERSITY

PHYSICS DEPARTMENT

PHYSICS LABORATORY II

EXPERIMENT REPORT

THE NAME OF THE EXPERIMENT

Magnetic Fields of Solenoids / Biot-Savart Law

PREPARED BY

NAME AND SURNAME :
STUDENT NUMBER :
DEPARTMENT :
GROUP NO :
TEACHING ASSISTANT :
DATE OF THE EXPERIMENT : ….. / ….. / ……….
DATE : ….. / ….. / ……….

Signature:

Experimental Procedure:

The Biot-Savart law experiment for finite size solenoid is performed using solenoids of different radii, power supply, tesla meter. In the experiment, we will examine how the magnetic field changes depending on the magnitude of the current passing through the solenoid, the number of turns per unit length of solenoids, and the distance from the center of solenoid.

Before start;
Please check the solenoids, power supply, and magnetic field sensor and connection cables. Experimental set-up is given in Figure 5.1.

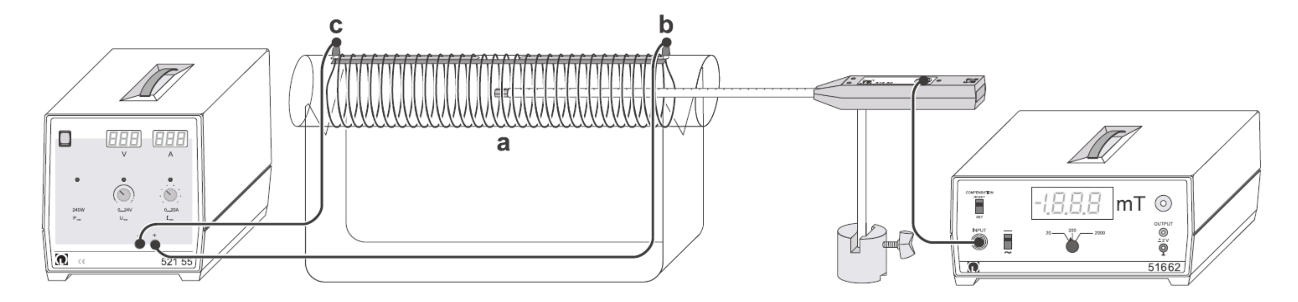


Figure 5.4: Biot-Savart experiment set-up for solenoids.

Warning: ***During the experiment, conducting loops could be hot because of high current. Do not touch or interfere with the rings when power supply is on. Please turn off the power supply when making changes to the experimental set-up.***

I. The dependence of the magnetic field on the current passing through the solenoids:

1. Switch on the tesla meter and calibrate the zero with the key compensation.
2. Connect the ends of the solenoid, 4.5 cm in radius, to the power supply.
3. Place the tip of magnetic field sensor probe at center of the solenoid.
4. Switch on the power supply, and increase the current *I* from 0 to 12 A in steps of 2 A. Each time measure the magnetic field *B*, and fill in tables below.
5. Repeat the same procedure for solenoid with a radius of 6.0 cm

Table 5.1: Magnetic field as a function of current *I* for the solenoid with radius of 4.5 cm.

$[N = 120, L = 40 \text{ cm}, n = 300 \text{ m}^{-1}]$

I (A)	0	2	4	6	8	10	12
B (mT)							

Table 5.2: Magnetic field as a function of current *I* for the solenoid with radius of 6.0 cm.

$[N = 120, L = 40 \text{ cm}, n = 300 \text{ m}^{-1}]$

I (A)	0	2	4	6	8	10	12
B (mT)							

According to the Biot Savart law, the magnetic field at the center of solenoid is given by Equation 5.2,

$$B = \mu_0 I \frac{N}{L} = \mu_0 I n \qquad 5.2$$

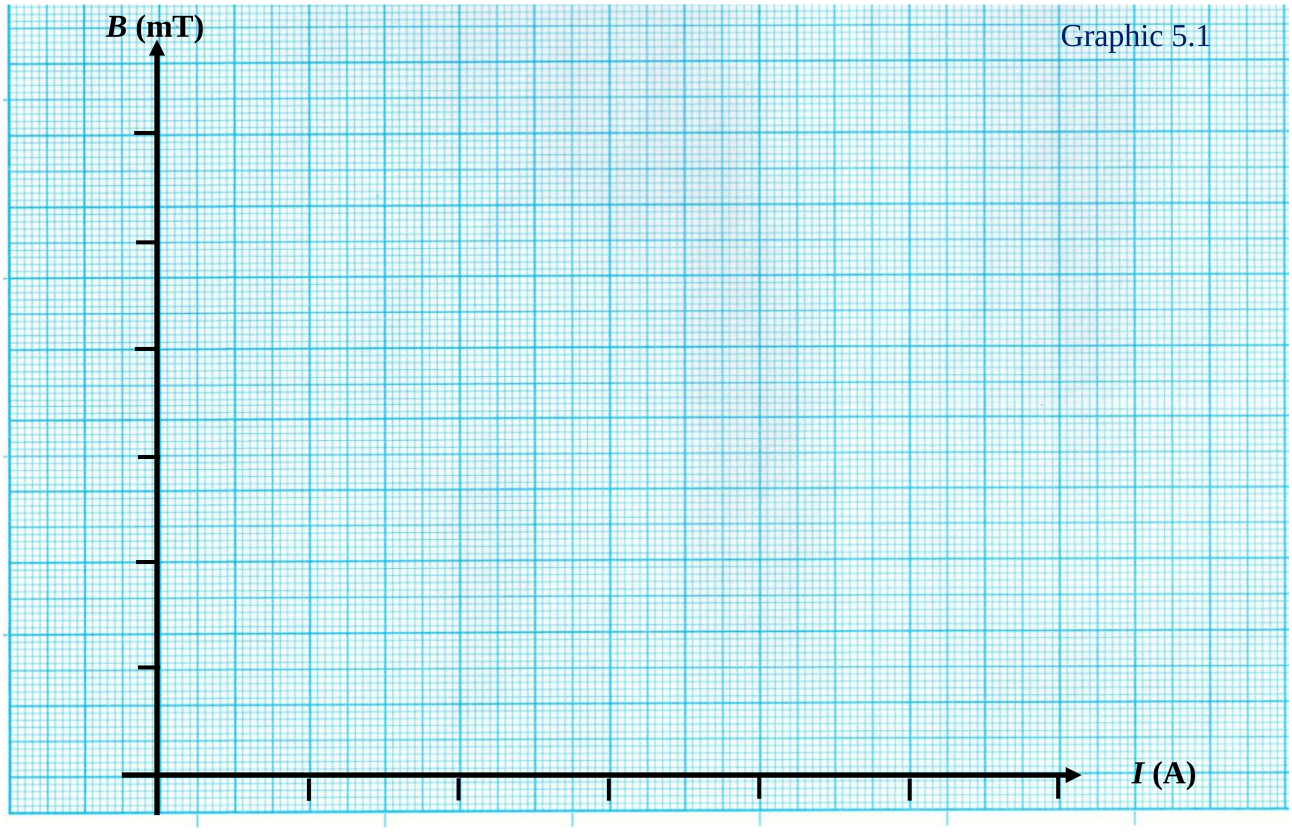
where *N* is total number of turns, L is length of solenoid, and $n = N/L$ is number of turns per unit length.

To observe the relationship between current and magnetic field for solenoids, plot *I* – *B* graphs using rows of Tables 5.1–2.

In Equation 5.2, if magnetic permeability μ_0 and *n* are constant, it is clear that magnetic field *B* is directly proportional to the current *I*. Therefore, we expect a line in the form of $y = mx$, where ***m*** is the slope of the line, passing through the data points and the origin. The slope of the line should be calculated by means of the statistical linear fitting method called the "*least squares method*" its formulae are given below.

Explain the effect of the Solenoid's radius on the magnetic field. what can you say about the slopes of the graphs you will draw? Do you expect the slopes to be equal or different? Explain.

For each solenoid, plot I vs. B graphs. Represent the current I and magnetic field B values on x– and y–axis, respectively. Mark the data points on your graph, and draw the straight lines $y = mx,$ where the slopes m are calculated in the previous steps, passing from the origin.



Calculate the slopes of the lines that fit the data points on your I *vs.* B graphs, which are plotted in the previous step. In the following formulae, the x_i 's represent the current I, while the y_i's represent the magnetic field B at center of the solenoid. k is the number of data used in calculations.

i) *R* = 4.5 cm;

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

$$m_1 = \frac{\sum_{i=1}^{k} x_i\, y_i}{\sum_{i=1}^{k} x_i^2} =$$

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

ii) *R* = 6.0 cm;

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

$$m_2 = \frac{\sum_{i=1}^{k} x_i\, y_i}{\sum_{i=1}^{k} x_i^2} =$$

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

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Using calculated m values and known n $\left[\frac{N}{L} = \frac{120}{40\ \text{cm}} = 3\ \text{cm}^{-1} = 300\ \text{m}^{-1}\right]$ parameters, we can calculate the magnetic permeability μ_0 using the Equation $\left[B = \mu_0 \frac{N}{L} I = \mu_0 n I \Rightarrow \mu_0 = \frac{B}{I} \times \frac{1}{n} \Rightarrow \mu_0 = m \times \frac{1}{n}\right]$ .Then, compare your results with theoretical value of μ_0 (1.2566×10^{-6} T·m/A).(*Show the calculations in the space given below*.)

$i)\ m_1 \Rightarrow \mu_0 = m \times \frac{1}{n} =$ $\mu_0 =$ ____________T·m/A

$ii)\ m_2 \Rightarrow \mu_0 = m \times \frac{1}{n} =$ $\mu_0 =$ ____________T·m/A

Are the calculated magnetic permeability μ_0 values equal? If not, explain why?

II. The dependence of the magnetic field on the number of turns per unit length of solenoid:

1. Switch on the tesla meter and calibrate the zero with the key compensation.
2. Connect the ends of the adjustable solenoid, 4.0 cm in radius, to the power supply.
3. Place the tip of magnetic field sensor probe at center of the solenoid.
4. Switch on the power supply, and set the current *I* to 10 A.
5. In order to change the number of turn per unit length ($n = N/L$), move the connector sockets symmetrical to each other and measure the magnetic field *B* in each case.
6. Measure the magnetic field *B* in each case and fill in tables below.

Table 5.3: Magnetic field as a function of number of turns per unit length (*n*) of solenoid. [$N = 30$]

L (m)	0.30	0.24	0.18	0.12	0.06
$n = N/L$					
B (mT)					

To observe the relationship between number of turns per unit length and magnetic field for solenoids, plot *n* – *B* graphs using last two rows of Table 5.3.

In Equation 5.2 $\left[B = \mu_0 \frac{N}{L} I = \mu_0 n I\right]$, if magnetic permeability μ_0 and current *I* are constant, it is clear that magnetic field *B* is directly proportional to number of turns per unit length *n*. Therefore, we expect a line in the form of $y = mx$, where *m* is the slope of the line, passing through the data points and the origin. The slope of the line should be calculated by means of the statistical linear fitting method called the "*least squares method*" its formulae are given below.

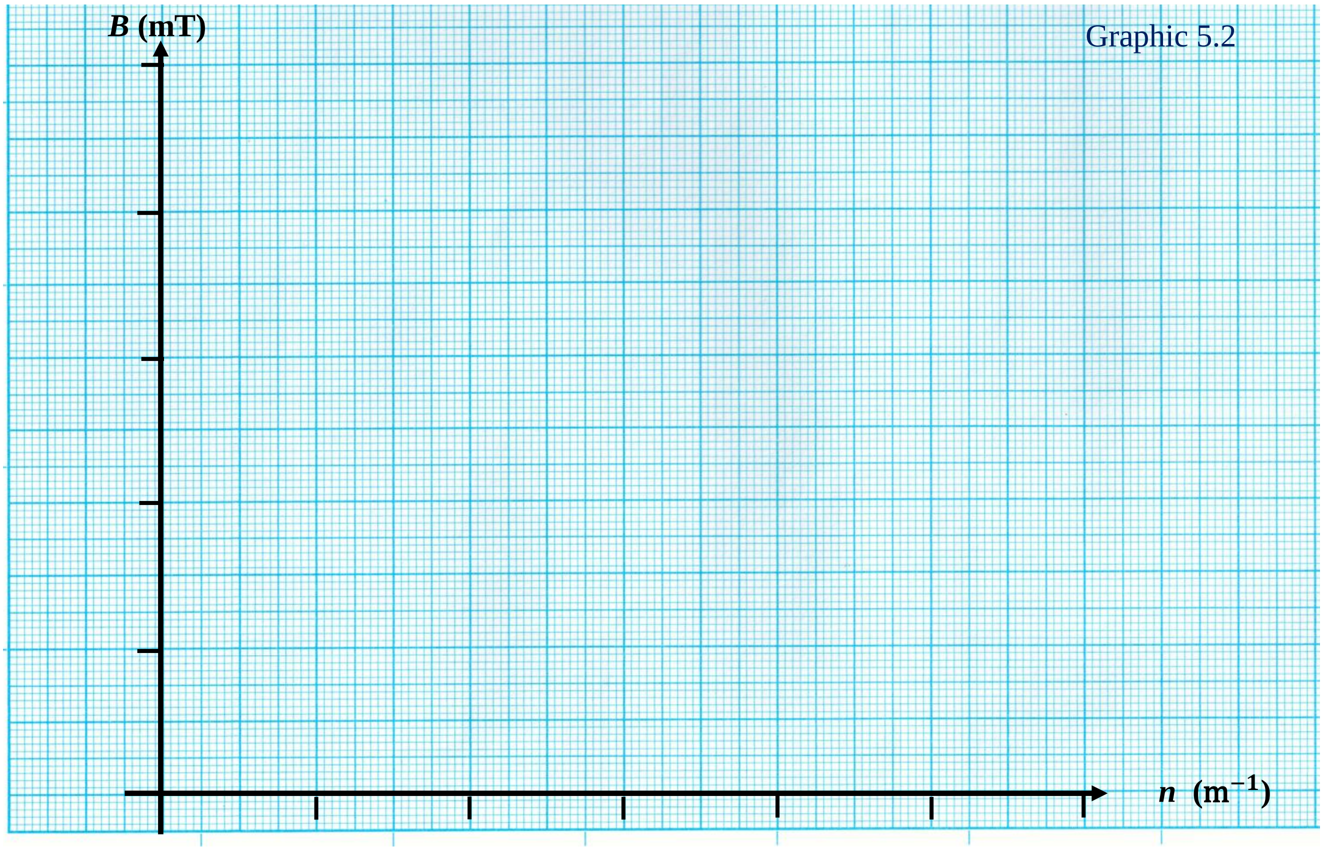
Calculate the slopes of the lines that fit the data points on your *n vs. B* graph, which are plotted in the following step. In the following formulae, the x_i's represent the number of turns per unit length (*n*), while the y_i's represent the magnetic field (*B*) at center of the solenoid. *k* is the number of data used in calculations.

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

$$m_1 = \frac{\sum_{i=1}^{k} x_i\, y_i}{\sum_{i=1}^{k} x_i^2} =$$

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

Use data from Table 5.3, plot n vs. B graph for adjustable solenoid. Represent the number of turns per unit length n and magnetic field B values on x– and y–axis, respectively. Mark the data points on your graph, and draw the straight lines $y = mx$, where the slopes m are calculated in the previous step, passing from the origin.



How does the induced magnetic field at the center of the solenoid change with the number of turns? Elaborate your answer by using the theoretical formulation in addition to your experimental findings.

III. The dependence of the magnetic field on the distance from center of the solenoid:

1. Switch on the tesla meter and calibrate the zero with the key compensation.
2. Connect the ends of the solenoid, 4.5 cm in radius, to the power supply.
3. Place the tip of magnetic field sensor probe at center of the solenoid.
4. Switch on the power supply, and set the current *I* to 12 A.
5. Move the tip of magnetic field sensor probe away from the solenoid. Increase the distance *x* beginning from center of the solenoid up to 20 cm (edge of the solenoid) in 4 cm steps. Each time measure the magnetic field *B*, and fill in tables below.
6. Repeat the same procedure for solenoid with a radius of 6.0 cm

Table 5.4: Magnetic field as a function of distance *x* from the center of the conducting loop with 4.5 cm in radius.

x (cm)	0	4	8	12	16	20
B (mT)						

Table 5.5: Magnetic field as a function of distance *x* from the center of the solenoid with 6.0 cm in radius.

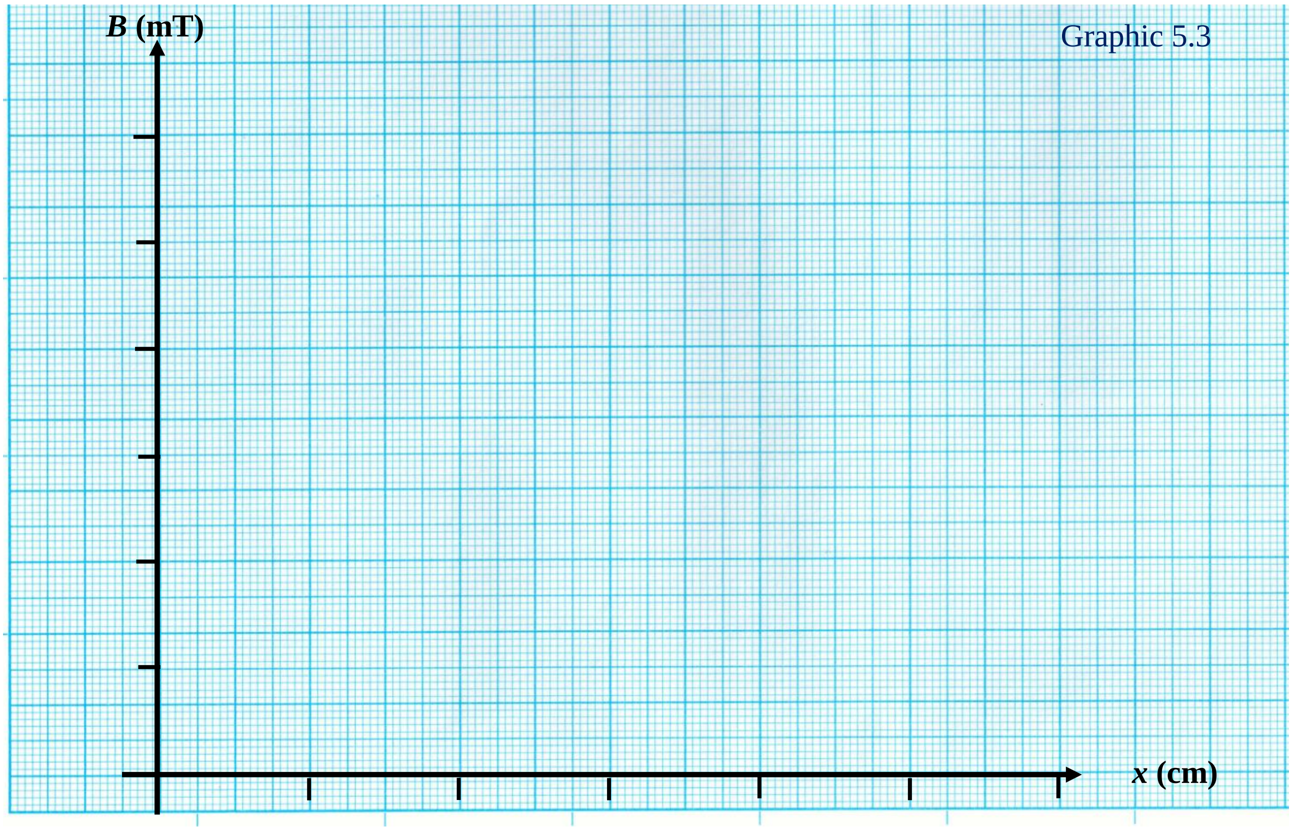
x (cm)	0	4	8	12	16	20
B (mT)						

For infinitely long solenoids ($L \gg R$), the magnetic field inside the solenoid is given by the Equation 5.2, and is constant along the axis of the solenoid. However, the magnetic field depends on the position of the point on axis of the finite size solenoid ($L \sim R$). Equation 5.4 expresses the change of magnetic field depending on the distance from the center.

$$B_x = \frac{\mu_0 n I}{2}\left(\frac{x + L/2}{\sqrt{(x + L/2)^2 + R^2}} - \frac{x - L/2}{\sqrt{(x - L/2)^2 + R^2}}\right) \qquad 5.4$$

To investigate the dependence of magnetic field *B* on the distance *x* from center of finite size solenoid, plot *x* – *B* graphs using rows of Tables 5.4–5.

You are asked to plot *x* vs. *B* graph using Tables 5.4–5. Choose the *x*–axis as *the distance from the center of the solenoids* (*x*) and the *y*–axis as *magnetic field* (*B*). Represent the data as points on your plots. Draw a curve on your graph that fits best to your data points by *crude eye estimation*. According to Equation 5.4, what type of a curve is expected to pass through those points, why?



Conclusion, Comment and Discussion:

(Tips: Explain your general observations and experimental findings objectively and scientifically with your original sentences. Please give detailed explanations about what you have learned from the experiment and also explain the possible errors and their reasons.)

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Questions:

1. Show that for $L \gg R$, Equation 5.4 is equivalent to Equation 5.2.

2. Calculate the expected ratio of the magnetic field between the ends of the solenoid $(x = L/2\ or - L/2)$ and its center $(x = 0)$ for a finite length solenoid for $L \sim R$ and $L \gg R$ cases by using Equation 5.4.

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