Slinky and Magnetic Field Lab

AP Physics C: Mr. Perkins

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Due: March 15, 2023

1 Introduction

In this lab, we will explore factors that affect the magnetic field inside a solenoid and study how the field varies in different parts of the solenoid. By inserting a Magnetic Field Sensor between the coils of the Slinky, we can measure the magnetic field inside the coil, as well as the value of μ_0.

2 Preliminary Questions

1. **Hold the switch closed. The current should be 2.0 A. Place the Magnetic Field Sensor between the turns of the Slinky near its center. Rotate the sensor and determine which direction gives the largest magnetic field reading. What direction is the white dot on the sensor pointing?**

2. **What happens if you rotate the whtie dot to point the opposite way? What happens if you rotate the white dot so it points perpendicular to the axis of the solenoid?**

3. **Stick the Magnetic Field Sensor through different locations along the Slinky to explore how the field varies along the length. Always orient the sensor to read the maxinum magnetic field at that point along the Slinky. How does the magnetic field inside the solenoid seem to vary along its length?**

3 Data

3.1 Part 1: Magnetic Field and Current Relationship in Solenoid

Current in Solenoid I (A)	Magnetic Field B (mT)
0.5	0.0547
1.0	0.1579
1.5	0.2101
2.0	0.2922

Figure 1: Magnetic Field and Current Relationship in Solenoid

Length of Solenoid (m)	1
Number of Turns	83
Turns/m (m^{-1})	83

Figure 2: Solenoid Measurements

3.2 Part 2: Magnetic Field and Spacing of Turns Relationship in Solenoid

Current in Solenoid I (A): 1.5		
Length of Solenoid (m)	Turns/m (m^{-1})	Magnetic Field (mT)
0.5	166	0.2699
1.0	83	0.2101
1.5	55.3	0.1484
2.0	41.5	0.1190

Figure 3: Magnetic Field and Spacing of Turns Relationship in Solenoid

Number of Turns in Slinky	83

Figure 4: Solenoid Measurements

4 Analysis

1. **Plot a graph of the magnetic field B vs. the current I through the solenoid. How is magnetic field related to the current through the solenoid?**

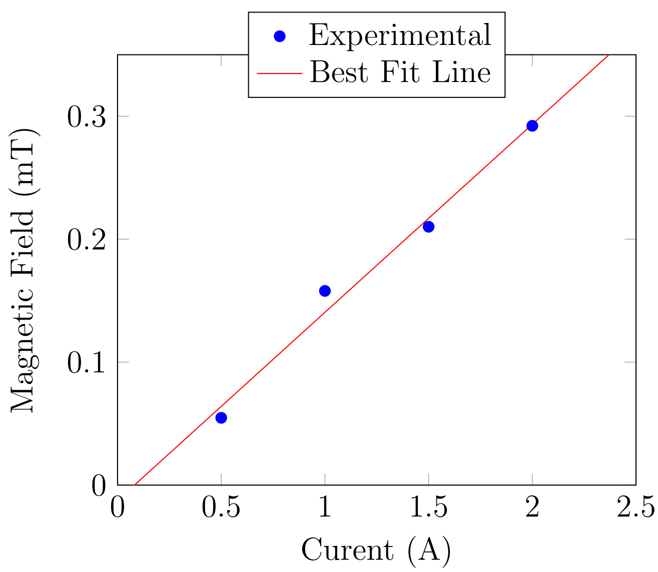

Figure 5: Magnetic Field and Current Relationship in Solenoid

Magnetic field is directly proportional to the current through the solenoid.

2. **Determine the equation of the best-fit line, including the y-intercept. Note the constants and their units.**

The equation of the best-fit line is: $B(I) = 0.15294I - 0.01245$. The slope is $0.152\,94\,\mathrm{mT/A}$. The y-intercept is $-0.012\,45\,\mathrm{mT}$. The graph is shown in Figure 5.

3. **For each of the measurements of Part II, calculate the number of turns per meter. Enter these values in the data table.**

   Refer to Figure 3 for the data table. The number of turns per meter is calculated by dividing the number of turns by the length of the solenoid.

4. **Plot a graph of magnetic field B vs. the turns per meter of the solenoid (n).**

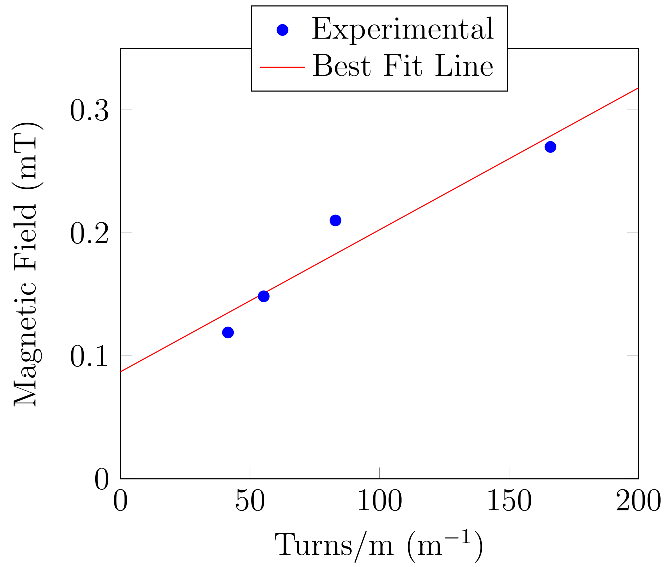

Figure 6: Magnetic Field and Spacing of Turns Relationship in Solenoid

5. **How is magnetic field related to the turns/meter of the solenoid?**

   Magnetic field is directly proportional to the turns/meter of the solenoid.

6. **Determine the equation of the best-fit line to your graph. Note the constants and their units.**

   The equation of the best-fit line is: $B(n) = 0.00115465n + 0.0870302$. The slope is $0.001\,154\,65\,\mathrm{mT/m}$. The y-intercept is $0.087\,030\,2\,\mathrm{mT}$. The graph is shown in Figure 6.

7. **From Ampere's law, it can be shown that the magnetic field B inside a long solenoid is $B = \mu_0 nI$ where μ_0 is the permeability constant. Do your results agree with this equation? Explain.**

   Ampere's law suggests that B is proportional to I, which agrees with Figure 5. It also suggests that B is proportional to n, which agrees with Figure 6.

8. **Assuming the equation in the previous question applies for your solenoid,**

calculate the value of μ_0 using your graph of B vs. n.

$$\begin{aligned} I &= 1.5 \text{ A} \\ \mu_0 &= \frac{B}{nI} \\ &= \frac{B}{1.5n} \end{aligned}$$

B/n is the slope of Figure 6. The slope is $1.154\,65 \times 10^{-3}$ mT/m, or $1.154\,65 \times 10^{-6}$ T/m.

$$\begin{aligned} \mu_0 &= \frac{1.15465 \times 10^{-6}}{1.5} \\ &\approx 7.697\,67 \times 10^{-7}\,\mathrm{N/A^2} \end{aligned} \tag{1}$$

9. **Look up the value of μ_0, the permeability constant. Compare it to your experimental value.**

   The value of μ_0 is $4\pi \times 10^{-7}\,\mathrm{N/A^2}$. The experimental value is $7.697\,67 \times 10^{-7}\,\mathrm{N/A^2}$. We compute the percent error as:

$$\begin{aligned} \delta &= \frac{|\text{Experimental Value} - \text{Theoretical Value}|}{\text{Theoretical Value}} \\ &= \frac{7.69767 \times 10^{-7} - 4\pi \times 10^{-7}}{4\pi \times 10^{-7}} \\ &\approx 38.74\% \end{aligned} \tag{2}$$

10. **Was your Slinky positioned along an east-west, north-south, or on some other axis? Will this have any effect on your readings?**

5 Extensions

1. **Carefully measure the magnetic field at the end of the solenoid. How does it compare to the value at the center of the solenoid? Try to prove what the value at the end should be.**

2. **Study the magnetic field strength inside and around a toroid, a circular-shaped solenoid.**

3. **If you have studied calculus, refer to a calculus-based physics text to see how the equation for the field of a solenoid can be derived from Ampere's law.**

4. **If you look up the permeability constant in a reference, you may find it listed in units of henry/meter. Show that these units are the same as tesla-meter/ampere.**

5. **Take data on the magnetic field intensity vs. position along the length of the solenoid. Check the field intensity at several distances along the axis of the Slinky past the end. Note any patterns you see. Plot a graph of magnetic field (B) vs. distance from center. How does the value at the end of the solenoid compare to that at the center? How does the value change as you move away from the end of the solenoid**

6. **Insert a steel or iron rod inside the solenoid and see what effect that has on the field intensity. Be careful that the rod does not short out with the coils of the Slinky. You may need to change the range of the Magnetic Field Sensor.**

7. **Use the graph obtained in Part I to determine the value of μ_0.**