

## The Magnetic Field in a Slinky®

### Purpose

- To investigate the relationship between magnetic field inside a solenoid and the number of turns per metre of the solenoid;
- To determine the value of  $\mu_0$ , the permeability of free space constant.

### Introduction and Theory

A solenoid is made by taking a tube and wrapping it tightly with many turns of wire. When a current passes through the wire, a magnetic field is present inside the solenoid. Solenoids are used to produce magnetic fields. They are seen in many electronic circuits, in magnetic resonance imaging machines in hospitals, etc.

In this lab we will explore how the number of turns per metre affects the magnetic field inside the solenoid. A metal Slinky® will serve as our solenoid. The Slinky® represents the solenoid very well and is readily available. What is more important, it is flexible so we can easily change the number of turns per metre. We measure the magnetic field inside the Slinky® by inserting a *magnetic field sensor* between the coils of the Slinky®. The same measurements also allow us to calculate the permeability constant  $\mu_0$ .

**Apparatus** Draw a labelled diagram of the apparatus and list all other apparatus, along with any identifying numbers.

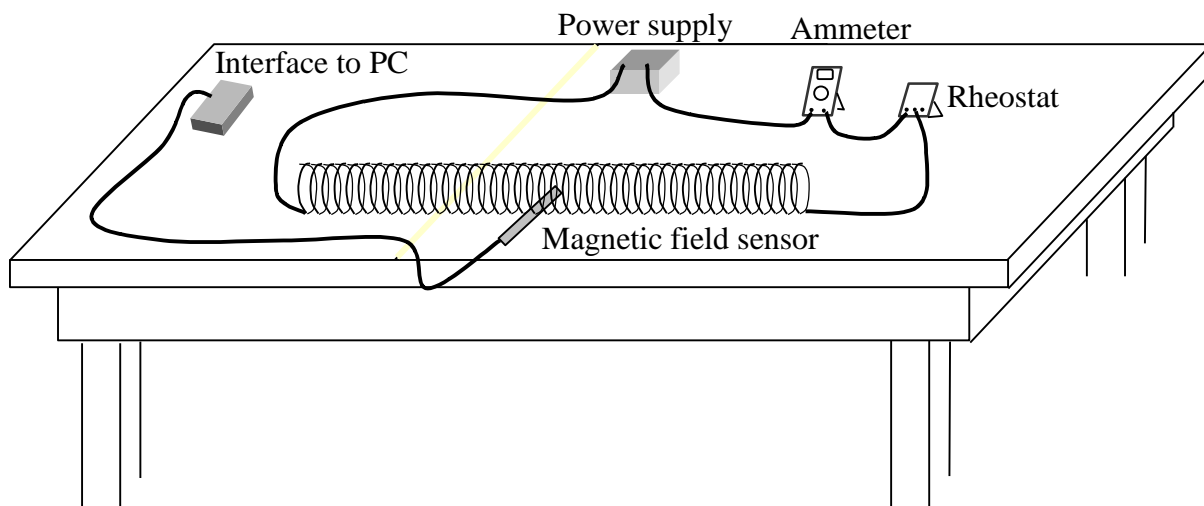


Fig 1

## Initial setup

1. Connect the Vernier magnetic field sensor to Channel 1 of the LabPro interface box. Set the switch on the sensor to “High”.
2. Stretch the Slinky® until it is about 1 m in length. The distance between the coils should be about 1 cm. Use a non-conducting material (tape) to hold the Slinky® at this length.
3. Connect the circuit as shown in Fig 1. Use the +6V DC of the power supply. Set the ammeter to 10 A scale. Make sure you have a way to turn on/off the current in the circuit.

*Warning: Only turn on the current when you are measuring the magnetic field. The Slinky® will get too hot if current is left on continuously, which causes errors in your measurement.*

4. Double click “Logger Pro” icon on the screen and open the file: *\_Physics with Vernier\Physics with Vernier\Physics with Vernier old edition\26 Mag Field Slinky.cmbl*. You should see a graph measuring the magnetic field vs. time. Familiar yourself with the scales of the axes.




## Data

To investigate the relationship between the magnetic field inside the solenoid  $B$  and the number of turns per meter  $n$ , we will

- (a) Keep the current through the Slinky®  $I$  at a constant value;
- (b) Fix total turns  $N$ , and change  $n$  by changing the Slinky®’s length from 0.5 m to 1.5 m;
- (c) Measure the magnetic field  $B$  for each length.

## Precautions for data taking

1. If you have unstretched part of coils at the ends, do not include it for either the total turns  $N$  or the length  $L$ .
2. When the length is short, the magnetic field may be large enough to cause the field sensor to saturate. Start with  $I = 1.5$  A and  $L = 0.50$  m (shortest length). If your sensor does not saturate at this setting, you will be okay for longer lengths. Wiggle the sensor slightly and you should see the reading of the  $B$  field change. If not, your sensor is saturated and you need to lower the current. After you decide on the current, *keep it the same for all the lengths*.

3. For each length, do a trial run before real data taking: position the magnetic field sensor in the middle of the Slinky® and click  button. Check two things for a trial run:
- Do you read zero magnetic field with no current? If not, you need to zero the reading with the  button and do the trial run again.
  - Do you read maximum value with the current on? If not, your sensor may not be pointing in the direction of the magnetic field. Rotate the sensor until the reading is maximum.
4. A good run should look like Fig 2. Find the mean, maximum and minimum values of the magnetic field over the constant region by clicking the  button. Record your results in a table like below. The uncertainty in  $B$  is given by  $0.5 \times (\text{Max.} - \text{Min.})$ .

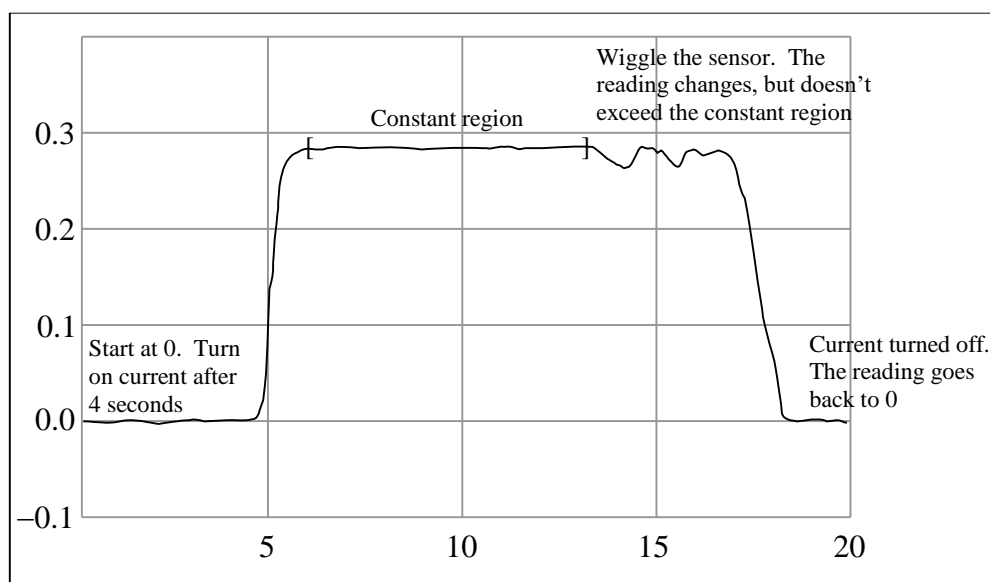


Fig 2

5. After obtaining data for 0.5 m length, repeat same measurement for 6 Slinky® lengths between 0.5 m and 1.5 m.

The total number of turns $N$				$\pm$	
The current through the Slinky® (A)				$\pm$	
Length of Solenoid $L$ (cm)	Turns per meter $n$ (m <sup>-1</sup> )	Magnetic Field $B$ (10 <sup>-3</sup> T)			
		Mean	Min.	Max.	Uncertainty
$\pm$	$\pm$				
$\pm$	$\pm$				
$\pm$	$\pm$				
$\pm$	$\pm$				
$\pm$	$\pm$				
$\pm$	$\pm$				

## Calculations

Finish the data table, listing  $n$  and  $B$  with their uncertainties. In your lab report, show a sample calculation of  $n$  and its uncertainty.

Plot a graph of magnetic field  $B$  vs. the turns per meter of the solenoid  $n$ . There is no obvious reason why the uncertainty for  $B$  should be different for each length, so you may use the largest  $\delta B$  for all six lengths. However, the uncertainty of  $n$  should be less for longer lengths.

Theory says that the magnetic field  $B$  inside a long solenoid is  $B = \mu_0 n I$ , where  $\mu_0$  is the permeability of free space. What value does your graph indicate for  $\mu_0$ ?

## Uncertainty Analysis

Determine the uncertainty in  $\mu_0$  from the uncertainty of the slope. Which other quantity affects the uncertainty in  $\mu_0$ ?

## Conclusions

Summarize your results in sentences, referring to the purposes of this lab.

## Discussion

Find the absolute discrepancy between your experimental  $\mu_0$  and the reference value  $1.2566 \times 10^{-6} \text{ Tm/A}$ :

$$\text{Absolute discrepancy} = |\text{your value} - \text{reference value}|$$

Does your value agree with the reference value? If not, discuss the reasons of the disagreement. If they do agree, discuss which factor dominates your uncertainty.

Unless you are going to do the extensions below, return the wire leads and power supply, put the Slinky® back in its box, and shut down the computer.

**Optional Exercise: this may increase your mark by up to 1 but won't raise your mark above 10. Do only if you have the time!**

*Study how the field varies at different locations of the solenoid*

Take data on the magnetic field intensity vs. position along the length of the solenoid, for a solenoid length of 1.0 m. Check the field intensity at several distances along the axis of the Slinky® past the end. Make a rough plot of magnetic field  $B$  vs. the distance from the center, ranging between  $-0.6$  m and  $0.6$  m.

What is the magnetic field off-axis? Make a rough plot of magnetic field  $B$  vs. the distance to the axis of the Slinky® from 0 to 10 cm (just outside the coils).

With our setup, it is hard to keep the magnetic sensor at the same place and in the same orientation. How does it affect our measurement of  $\mu_0$ ?