Magnetic Field of a Solenoid

Prelab

LR Write experiment title, your name and student number at top of the page.

LR **Prelab 1:** Write the objective of this experiment.

LR **Prelab 2:** Write the relevant theory of this experiment.

LR **Prelab 3:** List the apparatus and sketch the setup.

! Have these ready to be checked by lab staff at the door on the day of your lab.

Introduction

This experiment aims to investigate the magnetic field produced by a solenoid, by flowing current through a metal slinky, and compare the magnetic field produced to that of an ideal solenoid.

To do so, Ampere's Law is introduced and investigate the dependence of the magnitude of magnetic field B at the centre of a solenoid with the current I and it's dependence on the number of turns of the coil.

Introduction

When current is passed through a conductor, a magnetic field is produced.

For magnetic fields with high symmetry, **Ampere's Law** plays an important role. With magnetic fields that are more difficult to determine with Biot-Savart, Ampere's Law can simplify the matter similarly to Gauss' Law for electric fields.

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{enc}$$

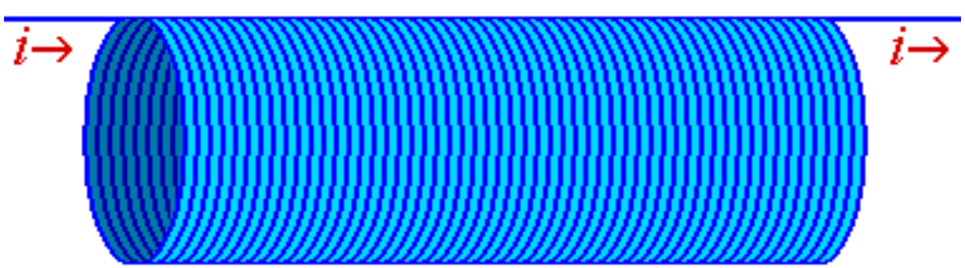
Magnetic field is a vector and has units of tesla (T). Ampere's Law is dependant on the enclosed current through a loop I_{enc}, and is calculated using a line integral around a closed loop.

Introduction

A solenoid is composed of a number of turns of a conducting material, arranged in a cylindrical fashion.

Solenoids are commonly used in electronics and electromagnets as a way to create a uniform magnetic field, which means having a constant magnetic field in some region of space.

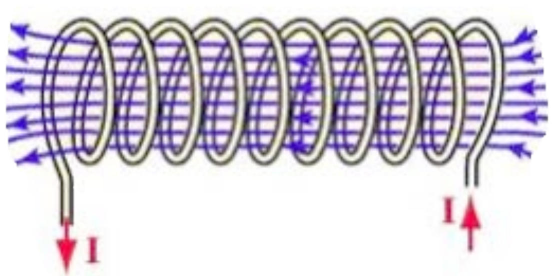
In our case, a Slinky is used as an example of a solenoid. Flowing current through the Slinky creates a magnetic field similar to a solenoid.



Introduction

For an ideal solenoid, the magnetic field is produced completely inside the solenoid and is constant along the length.

The field produced inside a solenoid is parallel to the axis as shown.



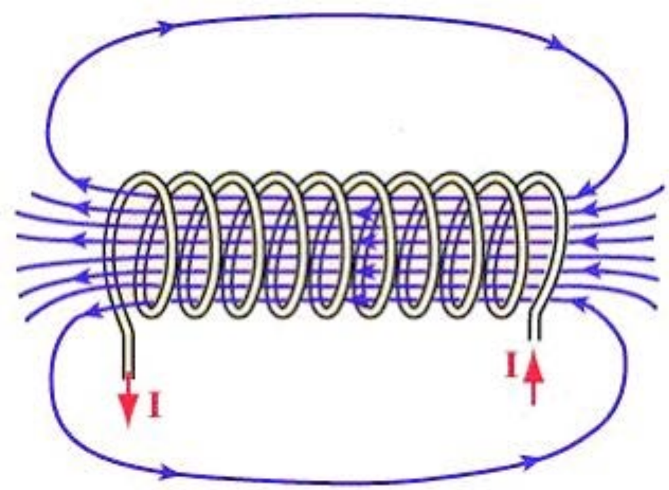
The magnetic field inside an *ideal solenoid* with **number of turns** N, **length** L, and **current** I may be calculated from Ampere's law and has magnitude

$$B = \frac{\mu_o N I}{L} = n\mu_0 I ,$$

where n is the **number of turns per unit length** and μ_o is the permeability of free space with value $4\pi \times 10^{-7}\ Tm/A$.

Introduction

For an ideal solenoid, the coils must be parallel and in close proximity in order to sum the field inside the coil and cancel the field outside. Considering the magnetic field produced from each individual coil, and how the magnetic field vectors interact, it can be shown why these conditions are necessary.



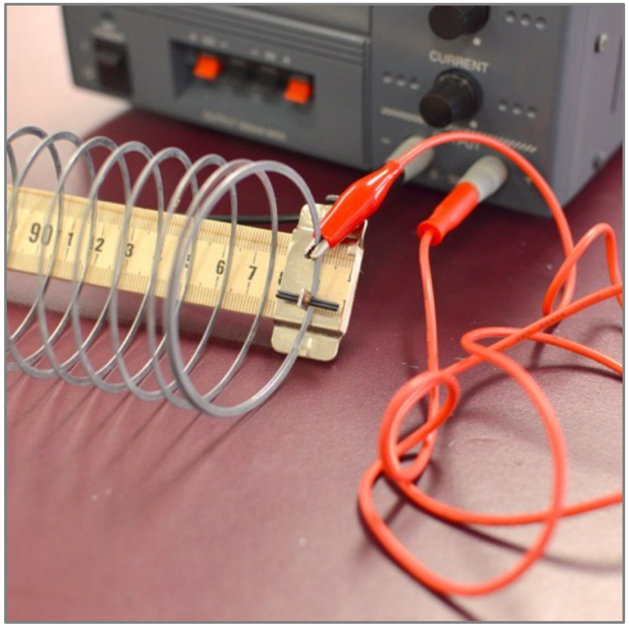
For a *real solenoid*, however, magnetic field is not constant at the ends and some field exists outside the solenoid. We'll look more closely at these conditions in this experiment.

Apparatus and Setup

You have been provided with the following equipment:

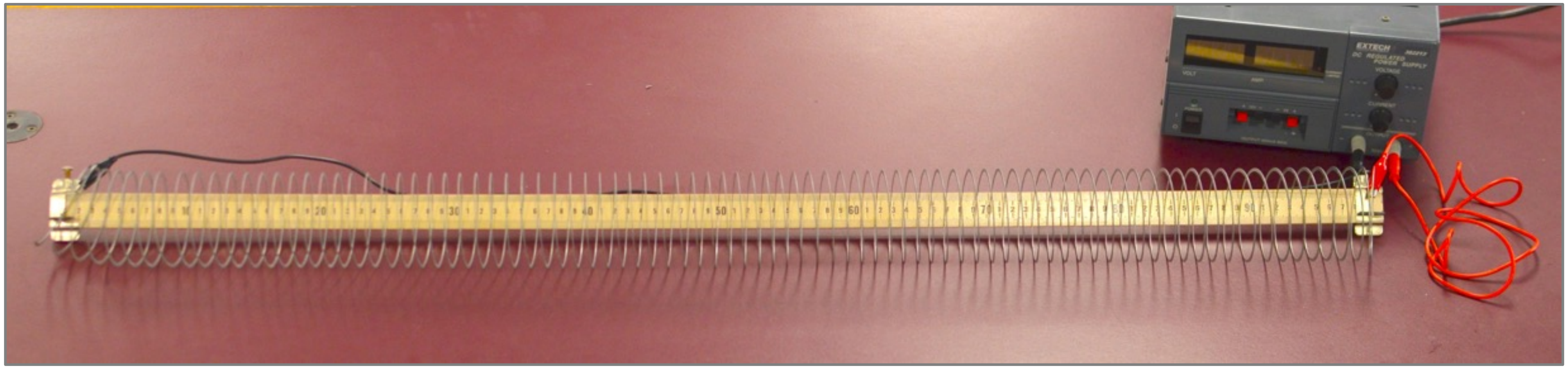
- Magnetic field sensor
- Leads with alligator clips
- Metre stick clamps
- Slinky
- Metre stick
- Power supply

Apparatus and Setup



Attach the slinky to the metre stick using the silver clamps as shown. Have the clamps adjusted to the very ends of the meter stick and hook a single coil or two of the slinky onto the pins of the clamps. Tighten the clamp screws to affix them to the meter stick.

The alligator clips attach to the coil and may be used to hold the slinky to the clamps. Connect the wires to the power supply.



The Magnetic Field Sensor

The magnetic field sensor uses a Hall effect transducer to measure the magnetic field.

The magnetic field sensor should be plugged into **Channel 1** on the LabPro.

Set the switch on the sensor to either **LOW** or to **6.4mT**.

The sensor measures magnetic fields parallel to the normal of the white dot on the tip of the sensor.

Magnetic Field Measurements

Important note:

All moving charges produce a magnetic field. Meaning, anything carrying electricity will also produce a magnetic field.

When we attempt to take measurements of a magnetic field, we need to be aware of any other possible items that may be a source of magnetic field. Also, the magnetic field due to the Earth is also a concern.

To ensure we are measuring the field we intend to, being the magnetic field generated by the solenoid, there is a particular process that must be followed.

Click here to open Logger Pro.

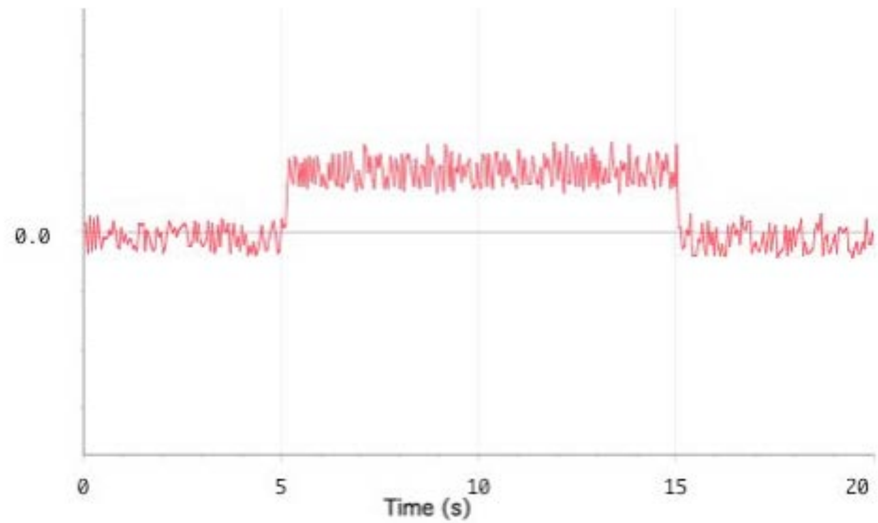
Data Collection

To take measurements:

- Turn the power supply **on** and adjust the voltage and current dials until you have the desired current (**to a maximum of 2.0 A**).
- Turn the power supply **off**.
- Insert the magnetic field sensor at the location you wish to measure the field.
- Click the **Experiment** then **Zero** (to zero contributions from the Earth's field and surroundings).
- Wait 5 seconds to ensure the field is truly zeroed.
- Begin data collection, switch power on, off, stop data collection. Hold each step for 5 seconds or so.

! **Repeat these steps in this order for all data collection.**

Data Collection



Data collected should look similar to the plot above.

The first few seconds should average to approximately zero. The step in measured field indicates when the power supply is turned on, and the value should return to zero once the supply is turned off. This ensures that you are not measuring any external fields.

Part I: Data Collection

In this part of the experiment, we'll become familiar with how to take measurements with the magnetic field sensor and gain an understanding of the magnetic field produced by a solenoid.

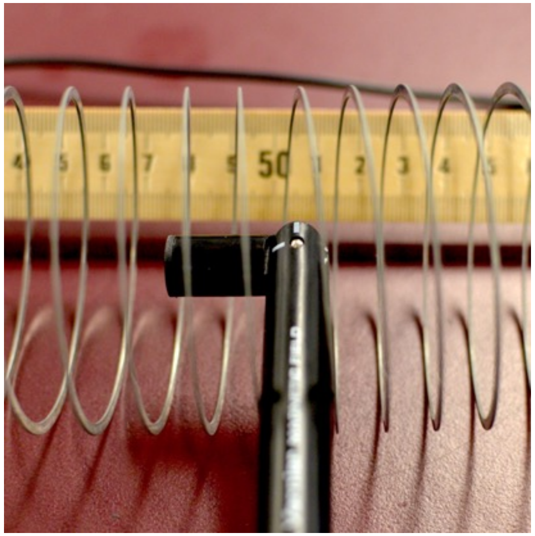
The sensor measures magnetic fields parallel to the normal of the white dot on the tip of the sensor.

Place the tip of magnetic field sensor **inside the solenoid at the midpoint.**

Follow data collection instructions.

Measure the magnetic field with:

- white dot facing the negative terminal
- white dot facing the positive terminal
- white dot facing the ceiling
- white dot facing the floor



Analysis

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Lab Report 1: What direction is the white dot on the sensor pointing, relative to the axis of the solenoid, when the largest positive field measurement is registered when the power supply is on? Specify if it is perpendicular or parallel to the axis and which terminal the white dot is facing.

!

Perpendicular to the axis means that the white dot is facing either the ceiling or the floor.

CP

Have an instructor check your results and sign your lab report.

Part II: Data Collection

In Part II, collect magnetic field measurements to illustrate how the field varies around the solenoid.

Determine the relative magnitude of the magnetic field:

- Along the inside length of the solenoid.
- At the ends of the solenoid.
- Just outside the solenoid.

Sensor position: For your measurements, hold the sensor so that it is facing in the direction whereby you measure the largest positive field.

You can find the average magnetic field by **highlighting the region when the power supply is on** and clicking **Analyze** then **Statistics** in Logger Pro.

Part II: Analysis

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Lab Report 2: From your results, describe the magnetic field of a solenoid. Include answers to the following questions:

a) Is the magnetic field constant along the length of the solenoid?
b) Is there variation at the ends?
c) Is the field weaker (or zero) outside the solenoid?

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Lab Report 3: Based on your findings, can your solenoid be considered ideal? Explain.

Part III: Data Collection

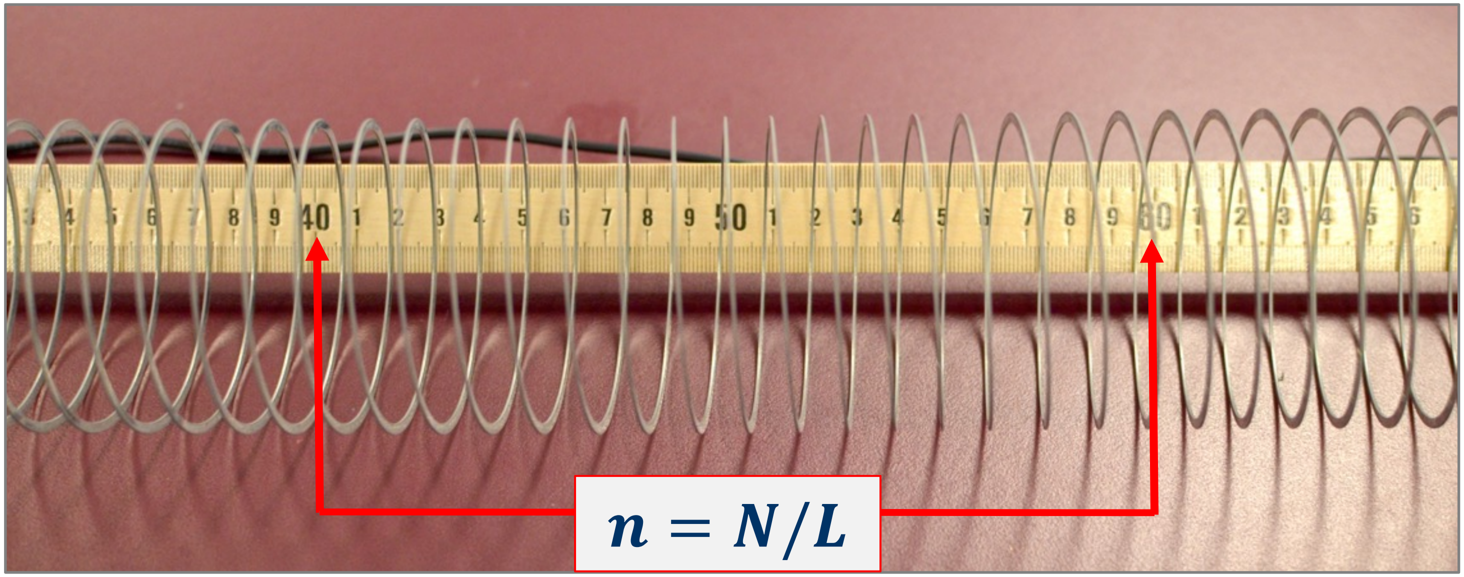
Using the same measurement technique, we will now attempt to determine the dependence of the magnetic field produced by the solenoid and the physical dimensions of the coil. To determine this dependence, we will **vary the solenoid length and measure the field dependence.**

Set the current to approximately 1.5 A.

Place the field sensor at the center of the coil, near the 50cm mark, and oriented to measure the highest positive magnetic field.

The field sensor position and orientation, as well as the current, will **remain the same** for upcoming measurements.

Part III: Data Collection



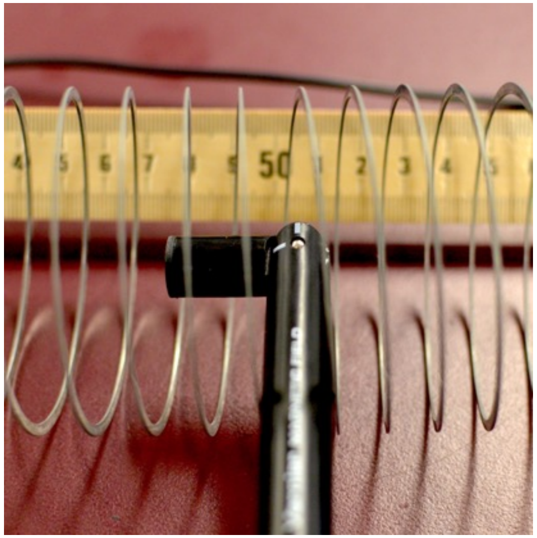
Lab report 4:

a) Count the number of coils of your solenoid between the 40 and 60 cm mark on your meter stick. Include an uncertainty estimate.

b) Calculate $n \pm \delta n$.

Part III: Data Collection

Measure the magnetic field at the center of the coil near the 50 cm mark.



Click **Experiment** and **Store Latest Run**. This will allow use to overlay new data.

Alter the length of the coil so that the clamps are at approximately the 20 and 80cm marks.

Collect magnetic field data as before

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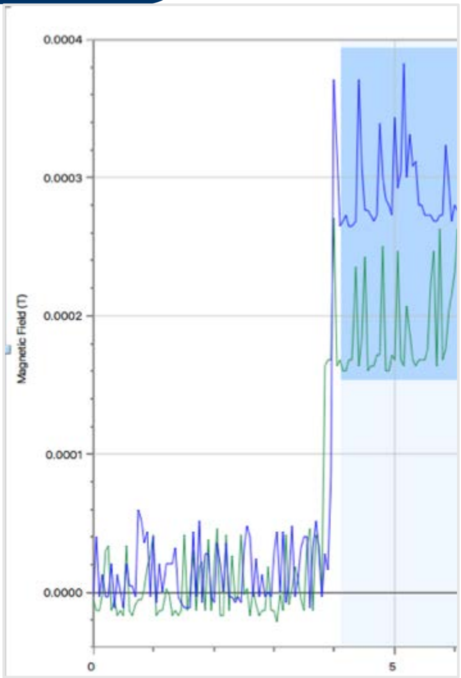
Lab report 5:

a) Count the number of coils of your solenoid between the 40 and 60 cm mark on your meter stick as before. Include an uncertainty estimate.

b) Calculate $n \pm \delta n$.

Part III

You find the average magnetic field by highlighting the region of magnetic field collected only when the power supply is on and clicking **Analyze** then **Statistics** in Logger Pro for each run.



Add a title to your graph by right-clicking, under **Graph Options**.

P

Print your Logger Pro graph displaying **all data**.

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Lab Report 6: Using your values of $n \pm \delta n$ from the previous questions, determine the theoretical magnetic field magnitude $B \pm \delta B$ and compare those to the magnetic field values from your data? Do the values agree within uncertainty?

Summary & Conclusion

LR **Lab Report 7:**

a) How did altering the length of the solenoid affect the magnetic field measurement?

b) Does the equation $B = \mu_0 n I$ support these findings? Explain

LR **Lab Report 8:** Briefly summarize your experiment, in a paragraph or two, and include any experimental results.

LR **Lab Report 9:** List any sources of experimental uncertainty and classify them as random or systematic.

! Include your prelab, printed data, and all analysis with your report.