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The Magnetic Field in a Slinky

A solenoid is made by wrapping a tube with many turns of wire. A metal Slinky is the same shape and will serve as a solenoid. When a current passes through the wire, a magnetic field is present inside the solenoid. Solenoids are used in electronic circuits or as electromagnets.

In this lab you will explore factors that affect the magnetic field inside the 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, you can measure the magnetic field inside the coil. You will also measure μ0, the permeability constant. The permeability constant is a fundamental constant of physics.

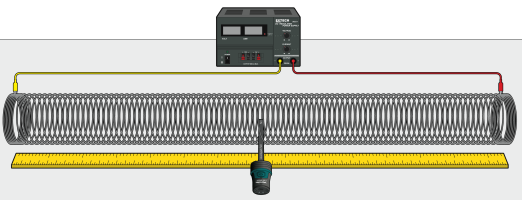


Figure 1

Objectives

* Determine the relationship between magnetic field and the current in a solenoid.
* Determine the relationship between magnetic field and the number of turns per meter in a solenoid.
* Study how the field varies inside and outside a solenoid.
* Determine the value of μ0, the permeability constant.

Materials

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct 3-Axis Magnetic Field

Extech Digital DC Power Supply

metal Slinky

meter stick

masking tape

connecting wires with clips

Initial setup

1. Set up the sensor.
   1. Launch Graphical Analysis.
   2. Connect the Gp Direct 3-Axis Magnetic Field Sensor to your Chromebook, computer, or mobile device.
   3. Click or tap Sensor Channels.
   4. Enable the Y magnetic field channel and disable the X magnetic field channel.
   5. Click or tap Done.
2. Set up the data-collection mode.
   1. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   2. Enter Current as the Event Name and A as the Units.
   3. Click or tap Done.
3. Stretch the Slinky until it is about 1 m long. The spacing between the coils should be 1–2 cm. Use a non-conducting material such as masking tape to hold the Slinky at this length.
4. Set up the circuit and equipment as shown in Figure 1.
5. Turn on the power supply, and adjust it so that the current is 2.0 A.

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|  |
| Figure 2 |

Preliminary questions

1. Hold the magnetic field sensor between the turns of the Slinky with the y-axis label at the center of the coil (see Figure 2). Rotate the sensor and determine which direction gives the largest positive magnetic field reading. What direction is the y-axis label on the tip of the sensor pointing?
2. What happens if you rotate the sensor so the y-axis label on the tip points the opposite way? What happens if you rotate the sensor so the y-axis label of the sensor is perpendicular to the axis of the solenoid?
3. Insert 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 maximum magnetic field at that point along the Slinky. How does the magnetic field inside the solenoid seem to vary along its length?
4. Check the magnetic field intensity just outside the solenoid. Is it different from the field inside the solenoid?

Procedure

Part I  How is the Magnetic Field in a Solenoid Related to Current?

For the first part of the experiment you will determine the relationship between the magnetic field at the center of a solenoid and the current flowing through the solenoid. Data will be collected in Events with Entry mode. Each time you click or tap Keep during data collection, the sensor reading will be displayed. You will then enter a value and click or tap Keep Point to complete the data point.

1. Turn off the power supply to stop all current in the solenoid.
2. Position the magnetic field sensor between the turns of the Slinky near its center, lengthwise. Rotate the sensor so that the y-axis label points directly down the long axis of the solenoid in the direction that gives the largest positive magnetic field reading. The y-axis label of the sensor should still be at the center of the coil, as shown in Figure 2. This will be the position for all of the magnetic field measurements for the rest of this part.
3. Zero the Magnetic Field Sensor to remove readings due to Earth’s magnetic field, any magnetism in the metal of the Slinky, or the table. Click or tap the Y Magnetic Field meter and choose Zero.
4. Now you are ready to collect magnetic field data as a function of current.
   1. Turn on the power supply.
   2. Adjust the power supply so that it is set to 0.0 A.
   3. Start data collection.
   4. Hold the sensor still and click or tap Keep. Enter 0.0 as the current and click or tap Keep Point to store the data pair.
   5. Increase the current by 0.5 A. Click or tap Keep and enter 0.5 as the current. Click or tap Keep Point.
   6. Repeat this process until you collect data for 2.0 A, and then stop data collection.
5. Answer the Analysis questions for Part I before proceeding to Part II.

Part II  How is the Magnetic Field in a Solenoid Related to the Spacing of the Turns?

For the second part of the experiment, you will determine the relationship between the magnetic field in the center of a coil and the number of turns of wire per meter of the solenoid. You will keep the current constant. Leave the Slinky set up as shown in Figure 1. The magnetic field sensor will be oriented as it was before, so that it measures the field down the middle of the solenoid. You will change the length of the Slinky from 0.5 to 2.0 m, in order to change the number of turns per meter.

1. Change the event name and the units to create a graph of magnetic field vs. turns per meter.
   1. Click or tap Mode to open Data Collection Settings.
   2. Change the Event Name to turns/m and the Units to m. Leave the rest of the settings as they are.
   3. Click or tap Done.
2. Keep the number of turns the same, but change the length of the slinky to 0.5 m. If you need to, re-count the number of turns, and then calculate the number of turns per meter. Record these values in the data table.
3. With the power supply off and the magnetic field sensor in position, click or tap the Y Magnetic Field meter and choose Zero to zero the sensor and remove readings due to Earth’s magnetic field, any magnetism in the metal of the Slinky, or the table.
4. Collect the first data point.
   1. Turn on the power supply and adjust the power supply so that it is set to 1.5 A.
   2. Start data collection.
   3. Click or tap Keep and hold the sensor still. Enter the number of turns per meter that you calculated, and click or tap Keep Point to store the data pair.
5. Collect additional data.
   1. Change the length of the Slinky to 1.0 m but keep the number of turns the same. As before, re-count the number of turns if necessary, and then calculate the number of turns per meter. Record the values in the data table.
   2. Click or tap Keep and hold the sensor still. Enter the number of turns per meter that you calculated. Click or tap Keep Point.
   3. Repeat this step to collect data for 1.5 m and 2.0 m.
   4. Stop data collection when you have finished with the last point.
   5. Turn off the power supply.
6. Proceed to the Analysis questions for Part II.

Analysis

Part I  How is the Magnetic Field in a Solenoid Related to Current?

1. Count the number of turns of the Slinky and measure its length. If you have any unstretched part of the Slinky at the ends, do not count it for either the turns or the length. Calculate the number of turns per meter of the stretched portion. Record the length, turns, and the number of turns per meter in the data table.
2. Inspect the graph of magnetic field, B, vs. the current, I, through the solenoid. How is magnetic field related to the current through the solenoid?
3. If the points on your graph of magnetic field vs. current through the coils follow a generally linear path, fit a straight line to the data.
   1. Click or tap Graph Tools, , and choose Apply Curve Fit.
   2. Select Linear as the curve fit, and click or tap Apply. The linear-regression statistics are displayed.
   3. Record the slope and y-intercept of the regression line in the data table, along with their units.
   4. Export, print, or sketch your graph.
4. Inspect the equation of the best-fit line to the field vs. current data. What are the units of the slope? What does the slope measure?

Part II  How is the Magnetic Field in a Solenoid Related to the Spacing of the Turns?

1. How is magnetic field related to the coil density, n, measured in turns/meter of the solenoid?
2. If the points on your graph of magnetic field vs. number of turns per meter follow a generally linear path, fit a straight line to the data.
   1. Click or tap Graph Tools, , and choose Apply Curve Fit.
   2. Select Linear as the curve fit. Click or tap Apply to view the-regression statistics.
   3. Record the slope and y-intercept in the data table, along with their units.
   4. Export, print, or sketch your graph.
3. From Ampere’s law, it can be shown that the magnetic field, B, inside a long solenoid is



where μ0 is the permeability constant. Are your results consistent with this equation? Explain.

1. Assuming the equation in the previous question applies for your solenoid, calculate the value of μ0 using your graph of B vs. n. You will need to convert the slope to units of T•m from mT•m.
2. Look up the value of μ0, the permeability constant. Compare it to your experimental value.
3. Was your Slinky positioned along an east-west or north-south axis, or was it on some other axis? Does this have any effect on your readings?

Data Table

Part I

|  |  |
| --- | --- |
| Length of solenoid (m) |  |
| Number of turns |  |
| Coil density (m–1) |  |

|  |  |
| --- | --- |
| Magnetic field vs. current | |
| Slope |  |
| Intercept |  |

Part II

|  |  |  |
| --- | --- | --- |
| Number of turns | Length of solenoid (m) | Coil density (m–1) |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

|  |  |
| --- | --- |
| Magnetic field vs. coil density | |
| Slope |  |
| Intercept |  |

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? Does the result make sense? Explain your reasoning.
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, 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.
7. Use the graph obtained in Part I to determine the value of μ0.