**Effect of coil diameter on the performance of an electromagnet**

Student ID: ABC-345 Word Count (excluding data) = 1687 words

My **research topic** is to investigate the effect that different diameters of a solenoid have on the performance of the electromagnetic field at the end of the solenoid.

I use five different diameters from 1.8 cm to 8.55 cm and I make a coil with copper wire. I measure the magnetic field using my Smartphone and the *Phyphox* app.

**Schematic of Solenoid**

|  |  |
| --- | --- |
| Diagram  Description automatically generated | An electric current flows through the wires. The magnetic field of a coil reinforces with other coils into parallel field lines in inside and at the ends of the solenoid. The blue lines are magnetic field lines. I measure the magnetic field at the end of the solenoid. |
| https://www.researchgate.net/figure/Magnetic-field-in-solenoid-9\_fig3\_312587018 | |

**Background**

The known **equation** for the interior of a solenoid is from a physics textbook.

**Magnetic Field *B* in the Interior of a Solenoid**

|  |  |
| --- | --- |
|  | *B* = magnetic field, micro-tesla, *μ*T  *μ* = permeability of space, 8.85 x 10–12 C2 N–1 m–2  *N* = number of turns  *I* = current, (A) amperes  *r* = radius of solenoid, cm  *d* = 2 *r*, diameter of solenoid, cm |
| Page 693 (equation 19.4) in Physics: Algebra/Trig by Eugene Hecht (Brooks/Cole Publishing) | |

Keeping the number of turns and voltage constant, we see an inversely proportion relationship between the magnetic field and the diameter of the solenoid. My experiment will confirm this.

My **hypothesis** is that the greater the diameter of the coil, the lower the strength of the magnetic field, hence the performance of the solenoid.

**Materials:** Copper wire, 30 metres; Vernier caliper Luther Digital Caliper at 0.01 mm least count; Smartphone and *Phyphox* app to measure magnetic field (<https://phyphox.org/>) at 1 μT least count; cardboard tubes with diameters of 1.8, 3.2, 4.05, 5.05 and 8.55 cm; DC power supply 0-12 V; assorted wires and appropriate tools.

**Safety:** Inspect wiring before use to avoid electric shock; use small voltage, 4 volts; do not perform lab with others in the room; locate power switch for easy turn off in case of fire; reuse wire as not to waste it.

**Method Steps**

1. Solenoids of diameters (1.8, 3.2, 4.05, 5.05, 8.55) cm were prepared by rotating the copper wire around the different cardboard tubes, 50 turns each diameter.
2. The solenoids were removed from the cardboard tubes.
3. Both ends of the solenoid wire were rubbed with sandpaper to remove the insulating coat of the wire.
4. A voltmeter was connected to the DC power supply to ensure the accuracy and consistency of the voltage each trial at 4 volts exactly.
5. The solenoid was connected to the DC power supply by connecting wires.
6. The Smartphone with the *Phyphox* software was put facing the solenoid and directed to the middle of the solenoid with distance of 0.5 cm far from the solenoid.
7. The DC power supply was switched on and the reading of the magnetic field was taken after 4 seconds and recorded in the raw data table.
8. The DC power supply was turned off directly after the reading was taken.
9. Steps 4 to 9 were repeated 2 more times for the same diameter of the solenoid.
10. Steps 3 to 9 were repeated for the remaining 4 diameters.
11. Used wire was rotated back on the main tube of the copper wire and was restored for future experiments.

|  |  |
| --- | --- |
| **Independent Variable**  This is the diameter of the coils in the solenoid. Five values were used: 1.8, 3.2, 4.05, 5.05 and 8.55 cm.  Here is a photograph of my experimental set up. Note the coil, the Smartphone, power supply and wires.  **Dependent Variable**  This is the magnetic field *B* generated by the solenoid, measured in micro-tesla, *μ*T. | Diagram  Description automatically generated |

The Smartphone was placed at the open end of the wire solenoid. The magnetic field lines are parallel inside the solenoid and by putting the sensor at the end of the solenoid we can assume the measurements will be accurate.

**Controlled Variables**

|  |  |  |
| --- | --- | --- |
| **Controlled** | **How to control** | **Possible Effect** |
| permeability of space | Use the same copper wire in all measure-ments. | If the permeability were to change, higher or lower resistance, then the *B* field would change. |
| Number of turns | This number must remain constant for all diameters; it is kept at 50 turns. | If the turns vary, then the magnetic field varies. |
| Current | The same voltage is used for all coils. | If the voltage changed, then magnetic field would change. |
| Temperature | The power supply was turned on for only 5 seconds in each trial. | When the wire temperature increases the resistance increases, and so less reliable results. |

**Raw and Processed Data**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Solenoid Diameter *d*  ±0.001 cm | Magnetic Field *B*, *μ*T | | | |
| Trail 1 | Trial 2 | Trail 3 | Mean Value |
| 1.800 cm | 887 | 885 | 889 | 887.00 |
| 3.200 cm | 584 | 589 | 590 | 587.67 |
| 4.050 cm | 465 | 482 | 481 | 481.50 |
| 5.050 cm | 325 | 323 | 326 | 324.67 |
| 8.550 cm | 98 | 95 | 94 | 95.67 |

**Sample Calculation**

To find the average of repeated measurements, for example, with 1.8 cm diameter:



**Diameter Uncertainties**

The absolute uncertainty in the Vernier caliper is ±0.001 cm. I divide this value by the measured value, multiplied by 100, to find the percentage of uncertainty. For example:



|  |  |
| --- | --- |
| Solenoid Diameter | Percentage Uncertainty |
| 1.800 cm | 0.056% |
| 3.200 cm | 0.031% |
| 4.050 cm | 0.025% |
| 5.050 cm | 0.020% |
| 8.550 cm | 0.012% |

These values are too small to pay attention to so I can ignore them.

**Magnetic Field Uncertainties**

By taking an average of repeated values, any uncertainty here cancels out.

**Graph Analysis**

A graph with a line

Description automatically generated

**Conclusion**

My hypothesis was confirmed: I have proved that the magnetic field reduces as the diameter increases. Indeed, my graph shows an inversely proportional curve with a very high R2 value also confirming my theory. The uncertainties were a small fraction of a percent (0.01% to 0.05%) so we can ignore them. The inversely proportional function is highly precise and justified.

There are no obvious outliers in the data. The range of data was justified by the amount of time and work needed to produce the five diameters. My results are thus accurate. The graph also shows that the points chosen were on a satisfactory scale so that I could recognize and could impose a specific trend line to answer the research question.

The trend line equation (where) *y* = *B* and *x* = *d*) is for my data is *y* = –513.5 ln(x) + 1185.5 with a correlation of R2 = 0.9965.

**Evaluation**

The uncertainties calculated are very low, for example the highest percentage uncertainty in the diameter was 0.056 % which is a very low number indicating the precision of the conclusion acquired.

There were no incongruous results collected or outliers because the chosen data range was far away from one another which did not allow any overlapping of results and data point were respectively away from each other. This shows that the data range chosen was able to give an accurate result and showed a correct trend.

The graph also shows that the points chosen were on a relatively satisfying scale so that the points are easily recognized and could impose a specific trend to help in answering the investigation's research question.

**Strengths**

The magnetic field strength was measured using a highly advanced software (Phyphox) which helped in providing the most accurate results. A gauss meter could have been used but it would not have given these precise data because the gauss meters measures only to 1 decimal place.

The copper wire used in the experiment was thick enough to compensate with the current and voltage that were supplied for all the trials as there are some other wires that get burnt in the process if not of high quality.

Another strength was the controlled variables was easily controlled and that is guaranteed in my experiment because nothing can cause fluctuation in the controlled variables in the experiment. The controlled variables were the number of turns which were counted several times.

**Weaknesses and Limits**

The 5 increments used for the diameter were not enough to determine the relation between the diameter of solenoid and the magnitude of magnetic field because the curve was flattening out so the magnitude of magnetic field might be constant after a certain diameter.

A systematic error in my experiment is that the current might have risen because when I left the voltage to pass in the solenoid for a lot of time so that the resistance increased hence the current also increases and that might have affected the result by making the results a bit higher. This could be avoided by opening the DC power supply quickly and take the reading of the magnetic field then close the power supply again before taking

the reading for another trial. By this, it will be assured that the solenoid does not gain kinetic energy resulting in more resistance hence, higher current.

Another systematic error is that the wire used had insulation on it which created some extra resistance hence the values obtained were less accurate. To overthrow this error, a wire with no insulation could be used as this will decrease the resistance and make the quantitative data have more accuracy.

A systematic error was also that the solenoid was coiled by hand, this resulted in uneven parts and some turns were not accurately the same diameter, as well as not all turns were perfect circles, hence the accuracy of the results was decreased. A solution for this error would be using solenoids that are coiled by a machine that will enhance the accuracy of the shape of the solenoids and give accurate results.

A random error is that only three trials have been carried out and that decreases the precision of the experiment. This meant that if there was an outlier in possible way to take an average. To come up with a solution, more trials could be done to get a more precise mean of data

Another random error is that the device measuring the magnetic field was not put precisely in the same place relative to each diameter of the different solenoids and that might have affected the reading of the magnetic field. To overthrow this error, two stands of adjustable heights would be needed, one to put the solenoid on and the other to put the devise that measures the magnetic field. Then the height of the stand is adjusted that it makes the measuring device as close as possible to the center of each solenoid being measured and at the same distance far from each solenoid.

**—end—**

06 August 2024