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# Exploring the magnetic field strength of a solenoid using the magnetometer of a smartphone

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## Abstract

This paper investigated the magnetic field strength of a solenoid using the magnetometer of a smartphone. There were three experiments: magnetic field strength versus current; magnetic field strength versus number of turns; and magnetic field strength vs distance between smartphone and solenoid. The result of the experiment has found that magnetic field strength and current and magnetic field strength and number of turns have direct relationship to one another and conformed with the Ampere's Law. Meanwhile, the magnetic field strength vs distance between smartphone and solenoid has an exponential relationship. This paper recommended to verify the permittivity of free space by revising the experimental set-up. From educational uses to practical applications, it provides the teaching and learning process with a convenient tool for measuring magnetic field strength at various points with incredible precision and accuracy with minimal effort required.

**Keywords**: magnetic field strength, solenoid, magnetometer, smartphone learning, physics teaching

## INTRODUCTION

As technology advances and becomes more accessible, new opportunities have emerged to explore science from a different perspective. Smartphones now come with magnetometers that can measure the strength of magnetic fields, making it possible for us to measure the field strength of a solenoid using just our phone. The use of smartphone is this field have limited literature [1]. Others are in the local language like of [2]. This research used a solenoid to calculate its magnetic field strength and relationship with current and distance. The solenoid's magnetic field was measured using the magnetometer of a smartphone. A solenoid is an electromagnetic coil that when energized produces a controlled magnetic field. The controlled magnetic field enables a solenoid to be used in a variety of applications such as door locks, electric motors and valves [2].

A solenoid is a type of electromagnet, consisting of a long coil of wire that creates a uniform magnetic field when an electric current is passed through it. The magnetic field is strongest near the centre of the solenoid and decreases as you move away from it. Inside the solenoid, the lines of force form closed loops and the direction of the magnetic field follows the right-hand rule; when you hold your right hand with your thumb pointing in the direction of current flow, your fingers will curl around in the same direction as the lines of force within the solenoid.

The objectives of this experiment are: (1) measure the magnetic field of a solenoid using the magnetometer of smartphone at varying voltage and current; (2) measure the magnetic field of a solenoid using the magnetometer of smartphone at varying distances; (3) determine the relationship among magnetic field strength and current and magnetic field strength and distance; 4) and determine the relationship between the number of turns of a solenoid and the magnetic field strength on the solenoid.

This project provided an interesting way to bridge theoretical physics with real-life applications, while also acquainting us with basic principles of electromagnetism. The magnetometer in a smartphone has proven to be an invaluable tool for classroom learning, as it provides an accurate and easy-to-use measurement of magnetic field strength. Furthermore, magnetometers are becoming increasingly popular in STEM education due to their ability to quickly measure and visualize data [4]. With just a few clicks of a button and without having to deal with manual measurements or installations of expensive instruments, students and teachers alike can access real-time data about the magnetic field around them. [4] argued that this hands-on learning opportunity helps lead to a better understanding in these fields. This makes it much easier for teachers and students alike to explore theories related to magnetism. Moreover, this new hype is vital when it comes to designing new materials or studying theories related to magnetism.

## Theoretical Background

The magnetic field inside of a current-carrying solenoid is uniform and directed along the axis of the solenoid. This is because the turns of wire that make up the solenoid all produce their own magnetic field, and each field adds to the overall strength of the magnetic field. The direction of this field is determined by Lenz's law, which states that it will be in such a way as to oppose any changes in the magnetic field. This means that when electric current passes through the coils, the direction of its associated magnetic field will be opposite to any change caused by moving charges outside of the coil. As a result, each turn of wire contributes to an increasing overall magnetic field that is directed along the axis of the solenoid.

The magnetic field inside of a current-carrying solenoid can be described by this equation:

$$B = \mu_0 n I \qquad [1]$$

where B is the magnetic field strength, $\mu_0$ is the permeability of free space which is equal to $4\pi \times 10^{-7}$ $NA^{-2}$, n is the number of turns per unit length, and I is the current.

This equation 1 shows that the magnetic field inside of a current-carrying solenoid is directly proportional to both the number of turns per unit length and the magnitude of current. Therefore, increasing either one will result in an increase in magnetic field strength.

Since n is equal to the number of turns (N) of the solenoid divided by the length (L) of solenoid, the equation would become

$$B = \mu_0 (N/L)\, I \qquad [2]$$

Equation 2 tells us that number of turns and magnetic field strength are directly proportional to one another when the length of the solenoid and the current flowing are constant. This is means that increasing the number of turns increases the strength of the magnetic field. This is because each additional coil increases the total magnetic flux, which strengthens the applied B-field. In other words, doubling the number of turns doubles the strength of the magnetic field [6]. This phenomenon is made possible due to Ampère's law, which states that a "long straight wire carrying electric current produces a circular magnetic field in its surroundings." As more coils are added to a solenoid, its equivalent single-turn wire also grows proportionally longer, which amplifies the circular magnetic field it creates even more.

Moreover, the relationship between magnetic field strength and distance in a solenoid can be expressed as an inverse cubic law [7]. This means that the magnetic field strength decreases as the distance from the axis of the solenoid increases, proportional to the cube of that distance. This is due to the fact that the magnetic field emanating outward from a current-carrying wire decreases with distance, and since a solenoid is composed of many such wires wound together in a series, this effect is further exaggerated in each successive winding.

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## MATERIALS AND METHODS

The materials used in the experiment are shown in table 1. These materials are readily available in a standard classroom laboratory. As this experiment involved electricity, safety precaution was needed. The low voltage power supply offers electrical shock protection however there still a need to wear shoes. The coil can offer high temperature so protective gloves are needed.

There are three experiments in this paper. First is the effect of varying current to the magnetic field strength and second is the effect of distance to the magnetic field strength. For experiment one, the independent variable is the current and the dependent variable is the magnetic field strength. For experiment two, the dependent variable is the magnetic field and the independent variable is the distance between the smartphone and the solenoid. Finally, in experiment 3, the number of turns of the solenoid is the independent variable and the magnetic field was the dependent variable.

**Table 1.** The materials and their function

| **Material/Equipment** | **Function** |
|---|---|
| Low voltage power supply | To supply current to the solenoid |
| Three Solenoid | This act as the conduit for the magnetic field |
| Electricity Multimeter | To measure the amount of current passing through the solenoid. |
| Ruler | To measure the distance between the smartphone and the solenoid. |
| Smartphone with PhyPhox | The magnetometer of this application and smartphone measured the magnetic field strength. |

The control variables were the environmental condition of the laboratory, type of multimeter and type of smartphone. The table where this experiment was conducted was clear enough to cancel some magnetic interference (e.g., from metal). There were acquired values from the interference of the Earth's magnetic field on the smartphone. These are considered zero error and this was subtracted to the value observed on the smartphone.

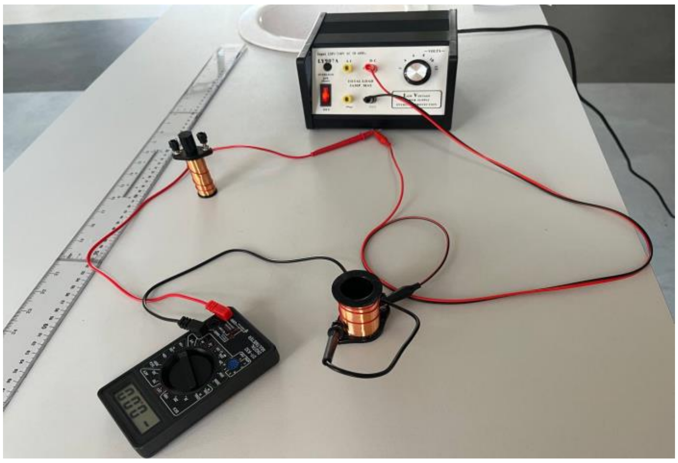

**Figure 1** The apparatuses were setup to determine the magnetic field strength, *B* of a solenoid. The *B* was measured using the magnetometer of a smartphone

The magnetic field strength was measured using the smartphone magnetometer with the help of PhyPhox application. The solenoid was positioned east or west in order for the earth's magnetic field not interfere with the measurement [2]. Hence, the y-axis was controlled to measure zero Tesla or very near to this value.

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The experiment one is about the effect of varying voltage to the magnetic field. The voltages were set from 2 volts to 12 volts. There were also six recorded current and six recorded magnetic field strength. The relationship was taken for the magnetic field and current. This was plotted in a graph using Microsoft excel. If a straight graph is formed, the relationship between B and I based on equation 1 is true.

On experiment two looked into the relationship between magnetic field strength measured and distance between the solenoid and smartphone. The solenoid was positioned at various length from the smartphone and measured the magnetic field strength at this position. There were six positions and recorded six different B. These two were plotted and should form a decreasing graph.

## RESULTS AND DISCUSSION

### Magnetic Field Strength against Current

According to equation 1, there is a linear relationship between current and the magnetic field strength running through a solenoid. As the current increases, the magnetic field strength increases proportionally. The graph of the magnetic field strength versus current is plotted to verify on this theory as shown on figure 2 and figure 3.

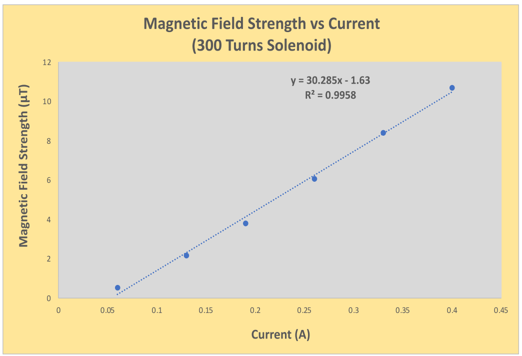


**Figure 2** The data shown between magnetic field strength and current has revealed a direct relationship. This used a solenoid of 300 turns

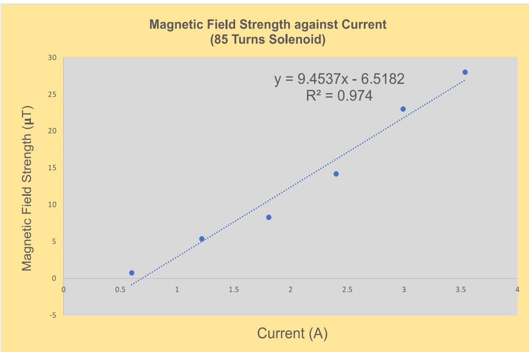


**Figure 3** Using the 85-solenoid, data presents a direct relationship between magnetic field strength and current has revealed

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Both figures 3 and 4 showed a direct relationship between current and magnetic field. This is because the current creates a circulating electric field in the solenoid, which in turn produces a magnetic field. This proved the effectiveness of the smartphone's magnetometer in measuring the magnetic field strength of the solenoid used. The data precision is also high with $R^2$ of 0.974 and 0.9958. A similar result using a different magnetometer application was found by [2]. His paper is written in Thai language and was conducted in Thailand. [8] also used a magnetometer of a smartphone to measure the magnetic field strength of a solenoid and found that magnetic field strength is proportional to the current flowing.

## Magnetic Field Strength and Number of Turns

The magnetic field strength of a solenoid is proportional to the number of turns. That is, the more turns of wire in a given solenoid, the higher the magnetic field strength at its center. Magnetic field strength can be increased by adding more length (thus more turns) of wire to the solenoid.

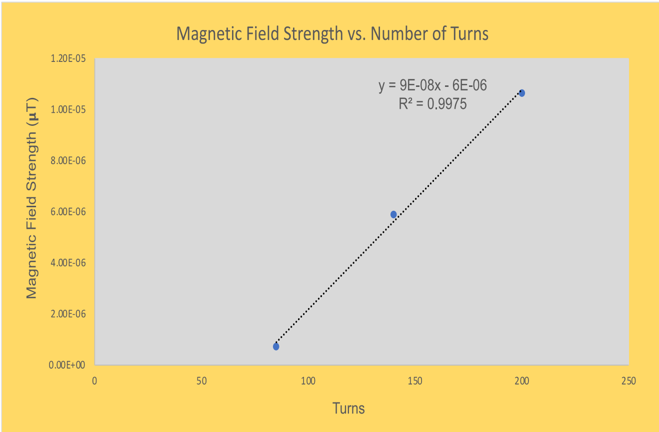


**Figure 4** The magnetic field strength versus the number of turns projected a straight-line graph as predicted by equation 2

There were three laboratory solenoids used, 85 turns, 140 turns, and 200 turns. The current and the length of the solenoid were kept constant on this part of the experiment. As observed from figure 4, the graph featured a straight-line prognosis with regards to magnetic field strength over the number of turns of the solenoid. This only suggest that the experiment was able to correctly follow what equation 2 is theorizing. The values data were also precise as the $R^2$ is 0.9975. The use of the magnetometer of a smartphone to take the relationship between number of turns and magnetic field strength was also tried by [2] and similar result was found.

## Magnetic Field Strength and Distance

The magnetic field strength of a solenoid is inversely proportional to the distance from its center. In other words, as you move away from the center of the solenoid, the magnetic field strength decreases. [7] suggested that this relationship is inverse cubic law. This is due to the magnetic field lines produced by a solenoid spreading out over distance and becoming weaker at greater distances from their source.

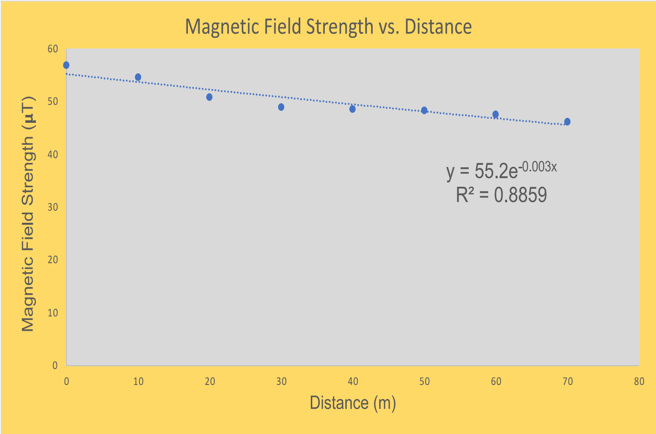


**Figure 5** The magnetic field strength of the solenoid with respect to distance was found exponentially decreasing with distance

The data gathered from this experiment showed that there is an exponential decay of the magnetic field strength with distance as shown in figure 5. This is not the same with the findings of [7] that the relationship between B and d is inverse cubic law. However, what is primarily established by the magnetometer of the smartphone is that the magnetic field is decreasing. Anyway, there is currently no equation relating the distance and magnetic field strength of the solenoid.

## DISCUSSION

The magnetic field strength of a solenoid can be measured by using the magnetometer that is found in most modern smartphones. This sensor measures the strength of Earth's geomagnetic field, which is used as a reference point to measure all other fields. The magnetic field strength of a solenoid was read in microtesla (μT). Most magnetometers on phones are accurate enough to measure the strength, though accuracy may vary depending on the model and manufacturer [9].

In experiment 1, the purpose was to measure the magnetic field and its relationship with the current. This was established when a straight-line graph emerged and this is supported by literatures. However, the value of the permittivity of free space was not successfully measured. There was a great error in the value which did not appear in this paper and this is considered as one of the limitations of this study. The sources of error probably are coming from the metals in the laboratory and classroom which interferes with the measurement. Although there were errors, this experiment proved the relationships in equation 1 and 2.

The magnetometer of a smartphone is limited in its ability to measure magnetic field strength generated by a solenoid due to the inherent accuracy and resolution limitations of the device. Additionally, the sensor is unable to measure very strong magnetic fields [10]. Therefore, if the solenoid generates a magnetic field that exceeds the detection capability of the smartphone's magnetometer, its field strength cannot be accurately measured.

The use of magnetometers in smartphones to measure the magnetic field strength of a solenoid can have a significant effect on students. Student can measure the magnetic field strength through a solenoid, with the use of magnetometer instead of relying solely on calculations or rough estimations. This would allow them to gain deeper insights into their studies and enable more accurate measurements. Furthermore, this application could also be used for teaching purposes. Students might be able to observe and analyze changes that occur when different coils are used for example. Although there were inevitable errors, the implication of this experiment for the teaching practice is significant. Through the use of simple materials and a smartphone, students have the power for see for themselves how the Ampere's Law works and of the solenoid as a whole. According to [11] teachers can demonstrate various concepts related to magnetic fields without additional bulky equipment.

## CONCLUSIONS AND SUGGESTIONS

The experiment conducted found that magnetic field strength and current is proportional to one another. This is the same with magnetic field strength and number of turns. Both of these findings conform with the Ampere's Law and related literature. Moreover, this paper revealed the exponential decay for magnetic field strength with distance from the smartphone and this is not in coherence with related literature. The area for improvement of the experiment conducted is how to measure the permittivity of free space properly. Educators and students who will use this experiment may take variety of readings of current or change the number of turns or the orientation of the smartphone. In doing so, they may change the experimental set-up and procedure.

Moreover, the magnetometer in a smartphone has proven to be an invaluable tool for classroom learning, as it provides an accurate and easy-to-use measurement of magnetic field strength. By using the magnetic field strength of a solenoid as a teaching resource, educational institutions can better illustrate the relationship between electric current and magnetism, thus furthering students' understanding of this central concept in electromagnetism. Using this data from a smartphone's magnetometer can help to build lasting connections between classroom lesson and real-world applications.

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