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Using Smartphone for Measuring the Magnetic Field Produced by the Current Flow in a Single Straight Line

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ABSTRACT

In this study, we design and build an experimental kit to use a smartphone to measure magnetic fields in accordance with Ampere's Law. The Phyphox application was used to measure the magnetic field created by a single straight-line current flow. We provide a method for removing the noise from the other electrical equipment in our experiment as well as the Earth's magnetic field. Air has a permeability of about 1.164 - 1.233 $\times 10^{-6}$ $N A^{-2}$.

Keywords: Ampere's Law; Magnetic field; Permeability; Magnetometer application; Phyphox application

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Introduction

As one of basic sciences, physics takes part widely in daily life phenomena and serves as the grounds for most technological achievements [1]. It is the keystone of theoretical knowledge and experimental skill for various science and engineering applications. However, some students still struggling in learning physics due to the negative attitude against the abstract content with mathematical equations and the lack of user friendly laboratory tools. In order to improve students' understanding of physics, schools have to provide and develop learning management systems [2]. It is crucial to support students in summarizing experiment findings on their own and making connections between various ideas [3]. In digital society, Physics educators may consider using smartphones, which are available in modern life, as a useful learning tool, potentially increasing student engagement and accessibility via mobile technology in the classroom [4]. The magnetic field that permeates every area of an electrical conductor where current flows and surrounds our daily lives. Because of the strength of the current flow, there are tiny values of this magnetic field that occur within the range of the Earth's magnetic field. This field is generated by the electric current flowing through the conductor described by Ampere's law [5], one of the fundamental laws of electromagnetism. A magnetic field encircling a conductive wire carrying an electrical current is described by Ampere's law, but even in our immediate surroundings, the Earth's magnetic field exists everywhere and can obstruct the measurement of the magnetic field created by currents of a comparable amplitude. The Ampere's Law experiment, being commonly used in physics investigations, measures the magnetic field generated by current flowing through a coil or solenoid that has a magnetic field magnitude greater than that of the Earth. Many solenoid computations of Ampere's law were used as a guide to help students appreciate this empirical role, although this process caused greater confusion for some students. In the study conducted by Nicolas Silva, a clear linear relationship between the magnetic field and the number of turns in a current-carrying coil was established, consistent with electromagnetic theory. Using an iPad and the MagnetMeter-3D Vector Magnetometer app, the research demonstrated that as the number of turns in the coil increases, the magnetic field strength also increases proportionally. This experiment reinforces the theoretical expectation and provides practical insight into the relationship between coil geometry, current, and magnetic field strength. The results showed a strong linear correlation with a slope of approximately 0.74 μT per turn, highlighting the importance of precise coil construction and measurement setup for accurate results. Further research could explore the effects of varying current values and distances between the coil and the sensor to expand on these findings [6]. The research demonstrates the feasibility and accuracy of using smartphone sensors to measure magnetic fields, offering a practical and accessible tool for physics education and experimental applications. Despite the challenges in precisely locating the magnetic field sensor within the smartphone, the study successfully employed a weakly magnetized iron piece and various applications to pinpoint and utilize the sensor for measurements. The experiments conducted align closely with theoretical predictions, especially at lower currents, validating the reliability of smartphone sensors for such scientific inquiries. This method, while less precise than traditional laboratory equipment, provides a valuable alternative for educational purposes, enabling students to engage with and understand magnetic fields using everyday technology. The ability to export data for further analysis enhances its applicability, making it a versatile tool for both classroom and independent learning environments [7]. In 2015, Arribas et al. [8] demonstrated that using smartphones with magnetometer applications for measuring magnetic fields provides an accessible and cost-effective approach for introductory physics laboratory practices. The results confirmed that the magnetic field's intensity inversely follows a cubic relationship with distance, aligning with theoretical predictions.However, they set the magnetic field intensity in mili-Tesla range. This method not only validates theoretical concepts but also fosters active learning and engagement among students. By leveraging widely available technology, the experiment facilitates practical, hands-on experience in experimental design and data analysis, highlighting the potential of smartphones to enhance physics education and make scientific exploration more interactive and relatable. Smartphone sensors are increasingly being used for precise measurements. These sensors enable direct measurement of physical quantities, provided that specific applications, most of which are free, are downloaded beforehand. These applications display measurements on the smartphone screen, store the data, and even graph the results [9-14]. Our experiment is designed to demonstrate Ampere's Law, which states that the magnetic field created by a single straight line's current is comparable to the Ampere's Law figure found in many introductory physics texts.

The purpose of this research was to create and develop an experimental kit for the measurement of magnetic fields according to Ampere's Law using a smartphone with the Phyphox [15] application allowing us to detect the magnetic field produced by a straight wire conductor with current. This experimental kit would make it easier for students to understudy the magnetic field surrounding us and enjoy learning how to learn the Ampere's Law.

Theoretical background

The Ampere's law can be expressed as the line integral of the magnetic field (B) encompassing a closed loop (l), multiplied by the sum of the currents (I) flowing through the loop [5]. The integral from is $\oint \vec{B}\cdot d\vec{l} = \mu_0 I$, where μ_0 is the permeability of free space. When considering the case of very long straight conductor with current influenced by a symmetrically rotating magnetic field, there is a circular path of radius (*r*) around the conductor as the center, giving the equation

$$B = \frac{\mu_0 I}{2\pi r}. \quad (1)$$

From equation (1), the relation of the magnetic field versus $\frac{1}{r}$ has a slope of $\frac{\mu_0 I}{2\pi}$. In our experiment, we aim to find the permeability of free space.

Experimental set up

In our experiment, the smartphone (iPhone 7 Plus) with a magnetic field sensor [7] was used with the Phyphox application on the 'Magnetometer" setting, as seen more details in www.Phyphox.org. The smartphone's magnetometer app was used to collect and examine data of 3D magnetic field in micro-tesla range, which is in the same range as the Earth's magnetic field. The simple circuit is shown in Figure 1. The single straight copper wire with a diameter of 0.2 mm was connected to a transformer, and an AC current source was used in this experiment.Besides, an additional resistance load was included in this circuit for the safety condition.

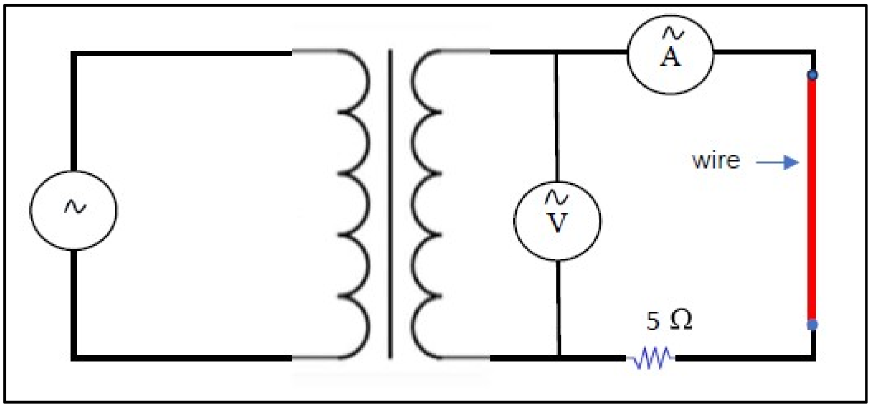

Figure 1 The electrical circuit used in the experiment.

To reduce the disturbing of ambient magnetic field, we exerted an acrylic table sized 60 *cm* x 60 *cm* x 30 *cm*, as shown in Figure 2. The experiment table consisted of a straight line of coper wire 60 cm long. None ferromagnetic materials were used to form this table.

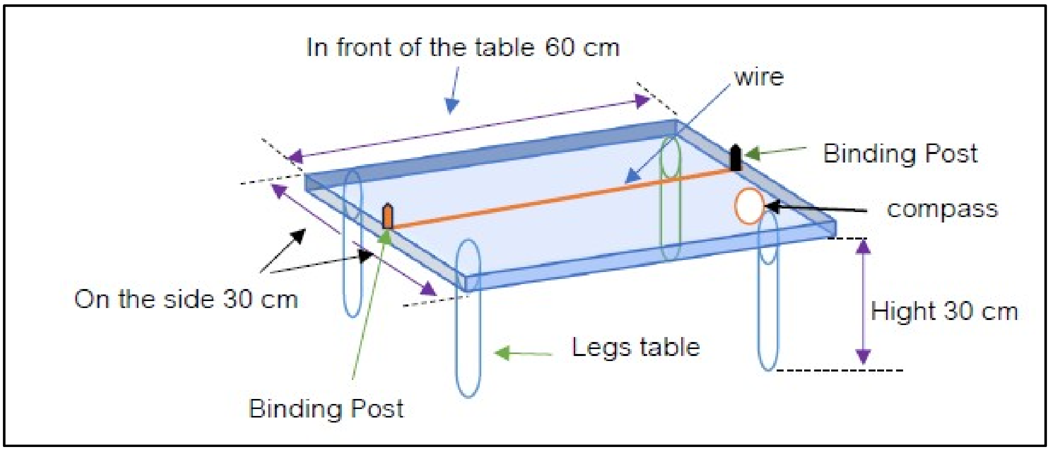

Figure 2 The acrylic table used for this experiment.

Data collection

Firstly, we assembled the equipment by putting it within the position of the smartphone's flash (iPhone 7 Plus) with the electrical wires positioned between them, starting at 1 - 8 *cm* apart. Then the current flow in circuit was set up by choosing a 20 *W* 5-ohm resistor. During the measurement, the head of the smartphone kept facing North at zero-degree angle. The magnetic field was detected on a table with the wire centered and towards the x-axis at 8 points (1 *cm* apart at each point). The Phyphox application was ready set for beginning the experiment until completing the measurement process. Then the data was collected and available to transmit through 'export data' command by selecting the 'excel' command for navigating these data to pc. Finally, the magnetic field intensity dataset could be analyzed using Microsoft Excel.

Data analysis

In the experiment, the currents with I_{peak} =0.775, 1.128, 1.974, 3.000 and 3.698 *A* were usedby seting3 of 5-ohm resistors for seriesand parallecircuitz.For each experimental dataset, there existed 3 direction of the Earth's magnetic field that interfered with the experiment. To reduce some components of the Earth's magnetic field, the acrylic table was set up in the North-South direction. The measurement of the magnetic field on the experimental table was done by setting the wire as the center and measuring 8 positioning points. There were 4 lines of data at each point, representing the magnetic field in the x-, y-, z-directions, and the total magnetic field. Figure 3 represents the data from each point with 1 *cm* away from the wire with a current of $I_{peak} = 1.974$ *A*. According to the alignment of the experimental table in N-S magnetic poles, there was a constant magnetic field in y-direction. The minimum value of each line was not zero because there was the disturbance of the envelopment, such as the Earth's magnetic field. As a result of Ampere's law, the magnetic field occurring from the current can be equal to $B_x = \left|B_x^{\max} - B_x^{\min}\right|/2$.

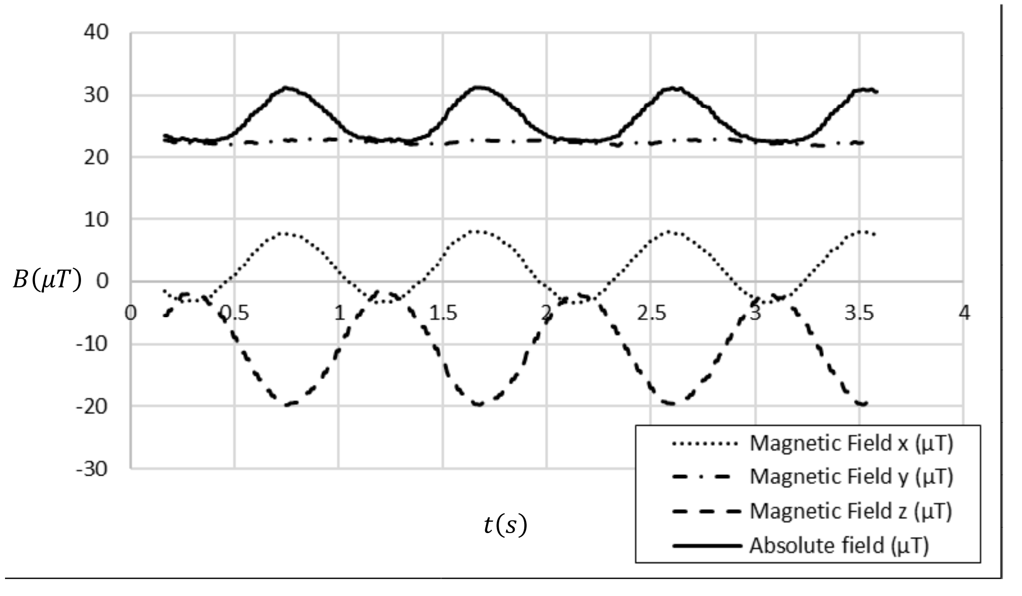

Figure 3 Data from point, 1 cm from wire with current $I_{peak} = 1.974$ *A*.

After finishing the required data collection obtained the relationship of the magnetic field (B_x) inversely proportional to $\frac{1}{r}$ for various currents, such as $I_{peak} =$ 0.775, 1.128, 1.974, 3.000 and 3.698 A, as shown in Figure 4.

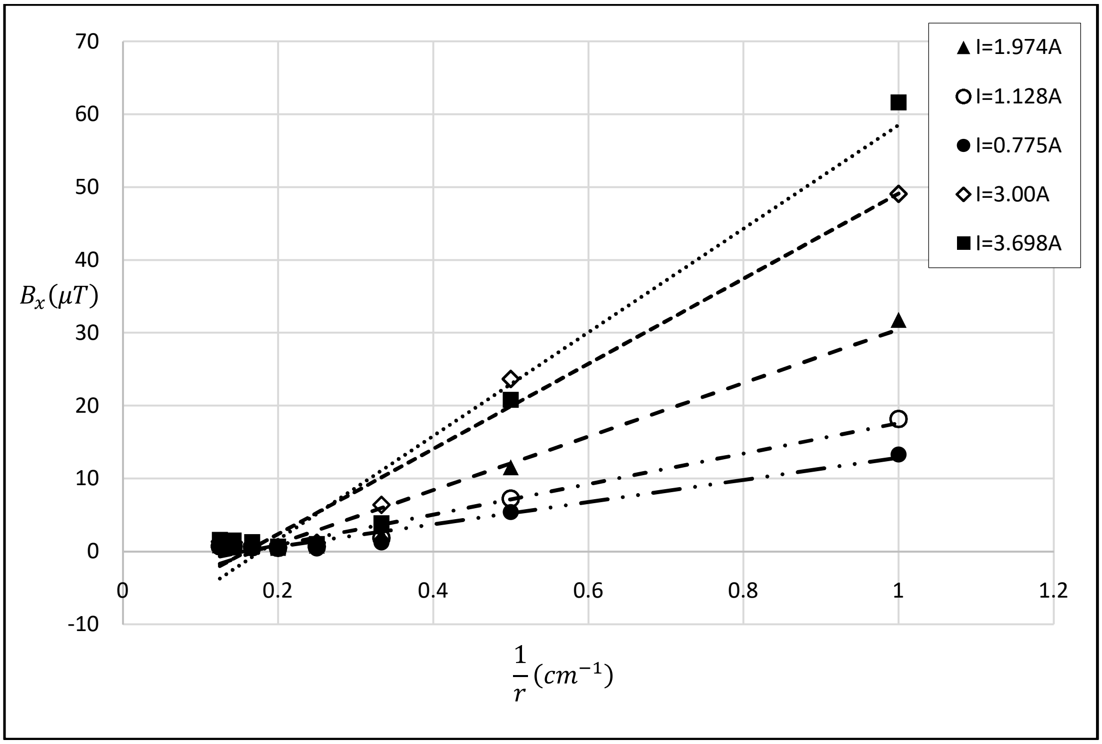

Figure 4 The magnetic field (B_x) versus $\frac{1}{r}$ and the linear fitting curve.

Results and discussion

The obtainable results shown in Figure 4, were linearly fitted along with Ampere's law in equation (1), the slope was equal to $\frac{\mu_0 I_{peak}}{2\pi}$ with $\mu_0 = \frac{2\pi}{I_{peak}} \cdot slope$, allowing us to find the permeability of air. By comparing to the standard vacuum permeability, $\mu_0 = 1.2566 \times 10^{-6}$ NA^{-2} the experimental results are shown in Table 1.

Table 1 The permeability of air from our experiment

I_{peak} (A)	slope $(T \cdot m)$	μ_0 $(N \cdot A^{-2})$	Error (%)
0.775	15.236×10^{-8}	1.233×10^{-6}	1.67
1.128	20.912×10^{-8}	1.164×10^{-6}	8.59
1.974	36.790×10^{-8}	1.170×10^{-6}	7.96
3.000	58.423×10^{-8}	1.221×10^{-6}	2.84
3.698	71.134×10^{-8}	1.207×10^{-6}	4.22

Because, the magnetic field is in micro-Tesla range and we try to keep experiment in the same situalion of Ampres single wire experiment so the error value of the vacuum permeability have beenscatter and only the error value of 3.000 is consistent with the theory.

Conclusion

In our experiment, we created and developed an experimental kit for measuring magnetic fields based on Ampere's Law using a smartphone. From the measurements, we found that the permeability of free space could be determined, although there was some deviation due to the magnetic field values obtained from the magnetometer. The measuring magnetic field produced by the current flow in a single straight-line by the Phyphox application was done. The noise from the Earth's magnetic field and the other electrical instrument from our experiment were excluded then the permeability of air was achieved about 1.164 - 1.233 x$10^{-6}$$NA^{-2}$. We realised that the Earth's magnetic field might interfere with our measurements since the magnetic field produced by a single straight-line wire was in the micro tesla region. Positively, our study could demonstrate how to use a smartphone to measure the magnetic field in the micro tesla region. The alternating magnetic field was found by the application of alternating current. The magnetic field output figure from current should display the difference in magnetic field strength from the earth's magnetic field. With this method, Ampere's law would be theoretically deployed for electromagnetic knowledge transfer with challenging and interesting experiment for students, providing them with a clear picture of the rigid theory with enjoyable hands-on experiment. This teaching and learning approach was keen and smart for all learners apart from the difficult content in Physics textbook. With this concept, it can be applied to various scenario and situation, such as in the case of the known permeability of air, the unknown current source can be obtained. Additionally, Phyphox was open source [16] with the ability to add some instrument and technique stimulating the users can go far beyond the basic physics to more complex academic content. In summary, the use of smartphones proves to be a powerful teaching & learning aid which improves student's engagement with active learning process and digital accessibility via mobile phone technology in the real life. This approach served as a practical tool, can merge the abstract knowledge to the real experiment with the positive perception and enthusiastic experience for promoting the life-long learning [4,15,17].

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