

Smartphone use in a physics project on magnetic field measurements

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Abstract. This paper presents a detailed teaching and experimental project on magnetism designed for high school students. The project aims to help students to measure magnetic fields using the “Phyphox” smartphone application and explore how magnetic field strength depends on various physical quantities such as distance, electric current, number of coil turns, and especially the size of the electromagnet core. As a practical example, the project proposes using a permanent magnet and a homemade or laboratory coil, with a variable core made from bundles of iron nails. The paper explains the theoretical background, experimental setup, data analysis and offers guidelines for constructing relevant magnetic field dependencies. Special attention is given to the usability and educational advantages of the “Phyphox” application for high school students. The paper concludes with pedagogical evaluations and recommendations.

Keywords: project, measurement, magnetic field, phyphox, smartphone, sensors, experiment high school physics, core size dependence, physics teaching tools

1 Introduction

Physics education in high schools often focuses heavily on theory, leaving limited space for hands-on experimental work. However, student engagement and understanding improve significantly when they can actively participate in experiments that connect theory to real world observations. Magnetism is an ideal topic for such activities, as it allows for simple yet meaningful experiments that reveal fundamental physical principles. The integration of smartphones into physics education represents an innovative approach to experimental learning.

On the other hand, another greatness of the smartphone is that we can measure with different sensors. This is a great advantage because can avoid the dependence on other instruments [1]. With their widespread availability, advanced sensors and user-friendly applications, smartphones have transformed into powerful tools for data collection and analysis in scientific investigations. This project focuses on utilizing smartphones in

magnetic field measurements, providing students with hands-on experience in exploring magnetic phenomena through accessible and cost-effective means.

Today the use of magnetic sensors is spreading very quickly, that finds application in automotive, industrial and aerospace. At first time, magnetic sensors were used in navigation for industrial areas [2].

“Phyphox” application can be used for a wide range of experiments, which enable users to access and record data form various sensors including microphone, camera, accelerometer, sensors for magnetic field strength, illumination, or brightness sensors, a gyroscope, GPS receiver and sometimes even temperature, pressure and humidity sensors [3].

“Phyphox” application brings an experimental observation and measurements aid that helps a physics teacher to conduct experiments, which makes it fun conducting a practical study. This app has today been downloaded by over 1.5 million people and is translated into 17 foreign languages, making science education around the world more attractive. Many of Phyphox’s sensors are present inside smartphones, unlike camera, which is located on the surface and is more easily accessible. “Phyphox” provides tools and intructions for all academic levels of education, from the lowest to the highest.

Among the sensors that can be used to observe different physical phenomena and that are installed inside a smartphone (See Fig. 1):

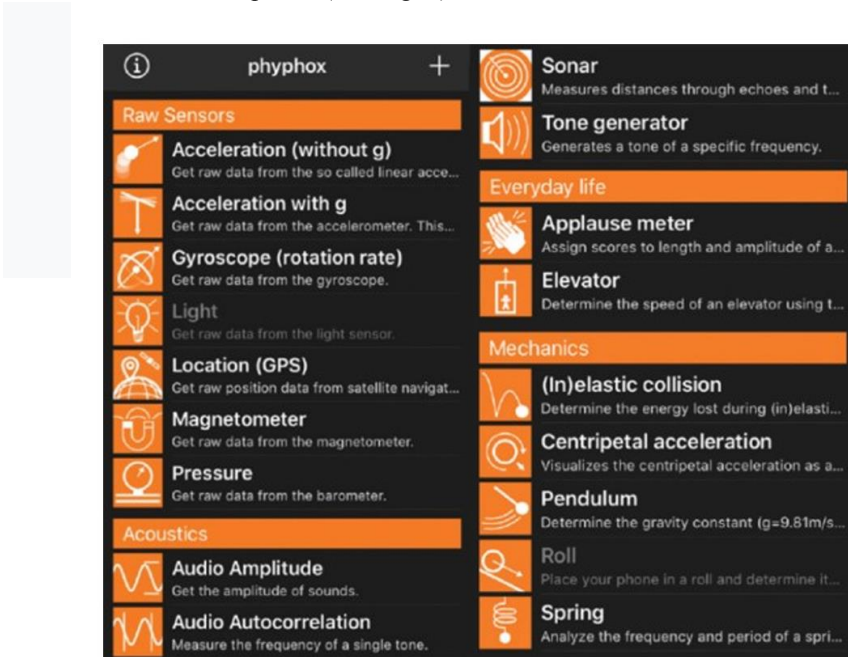


Fig. 1. View of the “Phyphox” application, where the list of some of the sensors of a smartphone is shown.

“Phyphox” is free to use, compact in size (around 6.7 MB) and suitable for both Android and iOS devices, making it widely accessible to students and educators to produce valid and reliable data [4].

Among the sensors offered by modern smartphones, the magnetometer is essential for measuring the strength and direction of magnetic fields. However, it is important to note that the magnetometer is continuously influenced by internal electronic circuits of the smartphone itself. As a result, the [5] “Phyphox” application incorporates calibration

features, enabling users to adjust for these interferences and improve the accuracy of their measurements. Typically, this involves rotating the smartphone in space until the magnetic field values stabilize, ensuring that the sensor readings are as reliable as possible.

This project is designed to guide students through a series of magnetic field investigations using the smartphone magnetometer via “Phyphox”. The experiments address key questions in electromagnetism and help illustrate fundamental concepts such as the variation of magnetic field strength with distance, current intensity, number of turns in a coil and core size. Specifically, the experiments include:

- Measuring the magnetic field of a single magnet:

The absolute magnetic induction is recorded at various distances between the smartphone and the magnet, demonstrating the inverse relationship between field strength and distance.

- Comparing magnetic fields of one versus two magnets:

By repeating the distance experiment with two identical magnets, students can observe how the magnetic field increases when the number of magnets increases and compare data sets through graphical analysis.

- Exploring the magnetic field of a coil:

Coils with 100, 200 and 300 turns are investigated to determine how magnetic induction depends on the current and the number of turns. Using a variable resistor (rheostat), the current is adjusted and corresponding magnetic field strengths are recorded and graphed.

- Studying the effect of core size:

The influence of inserting different numbers of steel nails into the coil (as a ferromagnetic core) is examined. This highlights the linear relationship between the size of the core and the resulting magnetic field strength.

- Analyzing the magnetic field of a solenoid:

A solenoid with known characteristics (485 turns per meter, 0.3 Ω resistance, 1 mH inductance) is used to study how magnetic field strength varies with current. This provides practical confirmation of theoretical linear relationships predicted by electromagnetic theory.

Throughout these experiments, “Phyphox” enables the recording and visualization of data, including the absolute value of the magnetic induction and its components along the x, y and z axes. The ability to export and analyze data in graphical form allows students to deepen their understanding of physical laws and relationships and to compare their experimental results with theoretical expectations.

In conclusion, this project demonstrates how smartphones can serve as mobile physics laboratories, bridging the gap between theory and practice in an interactive and engaging manner. By using widely available technology, educators can provide rich experimental experiences without the need for expensive or complex laboratory equipment. The experiments in this project not only reinforce key concepts in electromagnetism but also foster critical thinking, data analysis skills and curiosity about the physical world.

2 Theoretical Background

For using a smartphone to measure the magnetic field, some basic principles of physics and technology are used, including some special sensors and the basic concepts of the magnetic field. One of the basic principle which is used in this project is magnetometer like sensor of magnetic field, part of “Phyphox” application which is always exposed to the internal electronic fields of smartphone circuits. “Phyphox” application tries to get calibrated magnetic field results from results given by the sistem.

This application presents the value of the magnetic field induction according to three components (x, y and z), the absolute value of the magnetic induction as well as the corresponding graphs for each component.

We are focused only on the absolute value of the magnetic field induction.

The main physics equations that can be used in this experiment are: Lorentz force, The Hall Effect, Bio-Savart Law, Faraday's law [6].

1. Bio-Savart Law (describes magnetic field created by an electric current at a point in space):

$$\mathbf{B} = \frac{\mu_0}{4\pi} \int \frac{Id\mathbf{l} * \hat{\mathbf{r}}}{r^2} \quad (1)$$

2. Lorentz force equation:

$$\mathbf{F} = q * \mathbf{v} * \mathbf{B} \quad (2)$$

3. The Hall Effect:

$$V_H = \frac{I * B}{n * q * t} \quad (3)$$

4. Magnetic field intensity:

$$|B| = \sqrt{B_x^2 + B_y^2 + B_z^2} \quad (4)$$

The formula that “Phyphox” uses to show the average value of magnetic induction in microtesla.

5. Faraday's law of electromagnetic induction:

$$\varepsilon = -N \frac{d\phi_B}{dt} \quad (5)$$

Some of the theoretical results we can expect are: different values of magnetic field intensity from the distance of the magnet, how does the dependence of the magnetic field on electric current change, the dependence of the [7] magnetic field of a coil on the size of the core, the dependence of the magnetic field induction on the current passing through the solenoid.

3 Theoretical Experiment Setup / Methodology

The “Phyphox” application has demonstrated itself to be useful and impressive for physics teaching, which can be downloaded very quickly on any Android/IOS smartphone and is free of charge. There are many experiments already available for it online and helps a physics teacher conduct experiments with low cost and more accurate data [8].

An important role by using smartphone has mobile applications, that process and analyze experimental data over the years [9].

Magnetometer in smartphones is always exposed to internal fields electronics of smartphone circuits. This leads to incorrect results. So “Phyphox” tries to get calibrated magnetic field results from the result that the system gives.

There are also cases when no data may be received, as it is not yet calibrated (for example when the smartphone has just been turned on).

In this case, the smartphone should be rotated several times during the experiment until the displayed values are almost unchanged. This helps to calibrate the sensor as best as possible.

How to use the “Phyphox” application magnetometer?

- First, the “Phyphox” application is opened and then the Magnetometer column is clicked (See Fig. 2)

- Then click the “MULTI” menu on the bar at the top of the page.

- Once we are in the “MULTI” menu, we prepare the conditions of the experiment which can be modified in the “setting” menu symbolized by (3 dots), on the upper right.

- Then select “Timed Run” to set the initial wait seconds and preview duration.

Usually the time of set to wait it is 3 seconds and the preview is done after 10 seconds. This means that the moment we start the experiment (start measuring) it will take 3 seconds for the measurement to start and after 10 seconds it will end automatically.

This application presents the magnetic field induction value according to 3 components (x, y, z), the absolute magnetic induction value as well as the corresponding graphs for each component. We are focused only on the absolute value of the magnetic field induction.

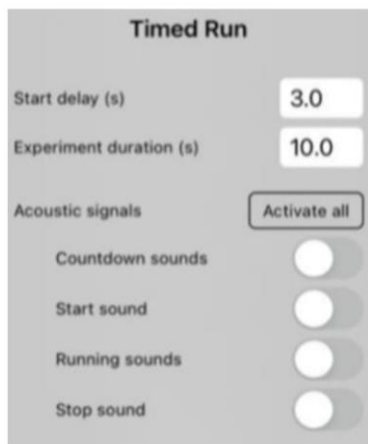
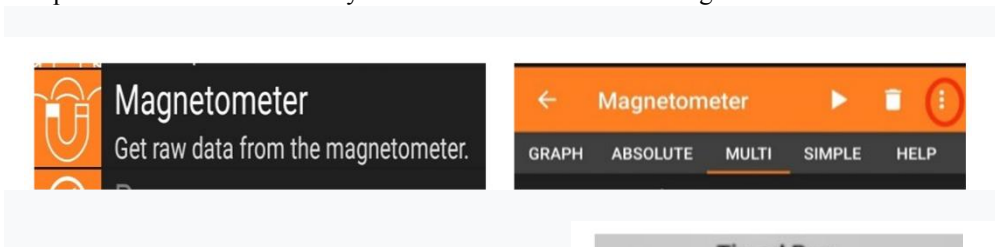


Fig. 2. Steps for using “Magnetometer” in the “Phyphox” application

The instruments we used are: smartphone (magnetic field sensor-magnetometer), magnet, solenoid (100, 200, 300 spirals) which has these elements: voltmeter, ampermeter, resistance, magnetic needle and ruler, then we took another coil and placed a certain number of nails in it (20 pieces) and finally we got a solenoid, whose characteristics are: 485 number of spirals per meter, maximal current is 8A, ohmic resistance 0.3 Ω , inductivity 1mH. We used all these instruments in this experiment where we wanted to determine the absolute value of magnetic induction from different parameters, applying the magnetometer sensor, part of “Phyphox”.

First we got a smartphone and a magnet, then measured the absolute value of the magnetic field without the influence of the magnet and using a ruler we determined the distance of the magnet from the smartphone, by placing the magnet at different distances, we performed 8 measurements and found the average value of B . We repeated the same procedure with 2 magnets and noticed that the more magnets we use the more the value of B increases.

In the second case, we took a coil (100, 200, 300 spirals) which we placed at a distance from the smartphone that we measured with a ruler and through the resistance in the circuit we changed the current in the coil where we measured the induction of the magnetic field.

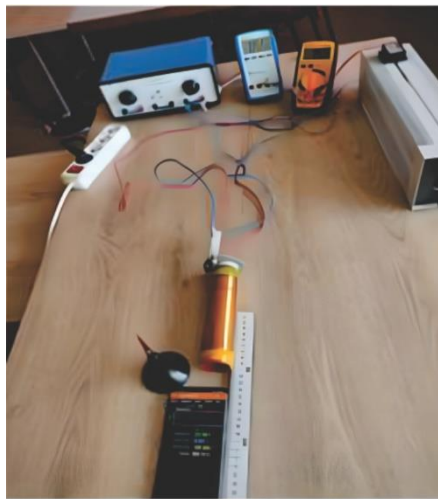


Fig. 3. Scheme for studying the dependence of the magnetic field of a coil on the electric current passing through it

In the third case, we determined the dependence of the magnetic field on the number of nails inside the coil, we used a coil with 200 spirals and have placed a different number of nails inside it (1-20 nails), for each number of nails the application measures the magnetic field at the same distance from the coil and for the same magnitude of current in it. From this we have noticed that for every nail we add to the core of the coil, the value of B increases by $2\mu\text{T}$.

In the last case we have a solenoid, its characteristics are: 485 number of spirals per meter, maximal current is 8A, ohmic resistance $0.3\ \Omega$, inductivity 1mH and determined the linear dependence of the magnetic field of the solenoid on the intensity of the current passing through it.

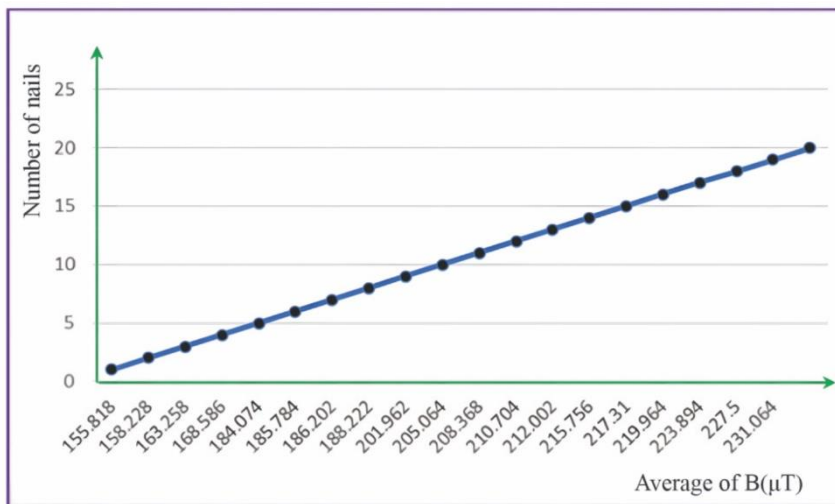


Fig. 4. Graph of the dependence of the magnetic field near the end of a solenoid on the intensity of the current passing through it

4 Results

Dependence of the magnetic field on the distance from the magnet (1 magnet)							
Distance (cm)	5	10	15	20	25	30	35
Measurements of B	418.2	207.9	112.1	78.5	63.4	55.0	51.9
	417.9	208.3	111.4	78.1	64.1	55.1	51.7
	418.3	208.2	111.3	78.9	63.3	54.8	51.5
	418.9	208.4	111.3	78.2	63.6	54.2	51.8
	418.7	208.3	112.3	78.4	64.1	54.8	51.3
	418.5	208.8	111.0	78.8	64.2	54.6	51.5
	418.1	208.9	111.9	78.0	63.3	54.5	50.7
	417.8	208.8	112.3	78.9	63.8	54.8	50.9
Average of B μT	418.3	208.4	111.7	78.5	63.8	54.7	51.4

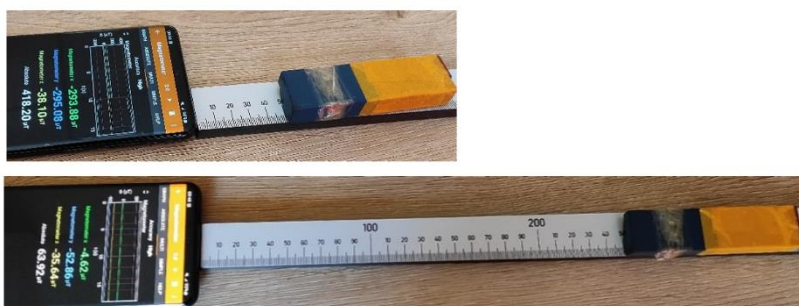


Fig. 5. Dependence of magnetic field on distance (1 magnet)

Dependence of the magnetic field on the distance from the magnet (2 magnets)							
Distance (cm)	5	10	15	20	25	30	35
Average of $B(\mu\text{T})$	1141.3	385.6	171.9	113.7	83.0	67.5	59.4



Fig. 6. Dependence of magnetic field on distance (2 magnet)

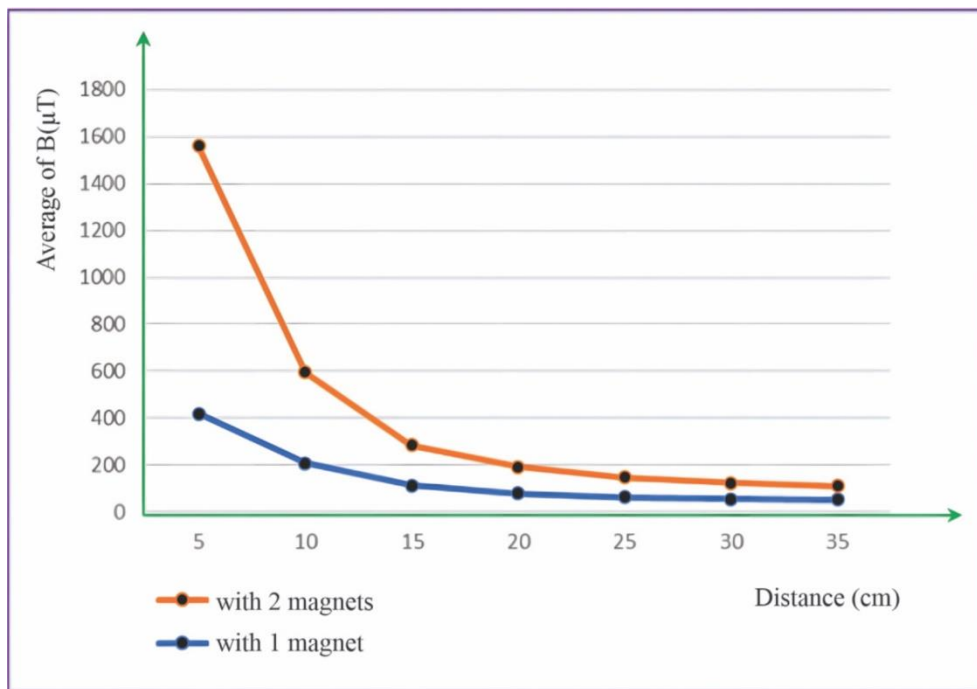


Fig. 7. Graphs of the dependence of the magnetic field from the distance for two magnets and one magnet

Dependence of the magnetic field on electric current (coil with 300 spirals)					
Current (mA)	5	10	15	20.5	25
Measurements of B	58.9	73.5	91.0	109.9	129.9
	58.1	73.4	91.2	109.8	129.1
	58.2	73.5	91.4	109.3	129.1
	58.8	73.4	91.7	110.9	129.2
	58.2	73.7	91.0	109.5	129.5
	58.3	73.6	91.5	109.7	130.0
	58.5	73.2	91.7	109.4	129.9
	58.8	73.0	91.7	109.1	129.1
Average of B (μT)	58.5	73.4	91.4	109.6	129.5

Dependence of the magnetic field on electric current (coil with 200 spirals)					
Current (mA)	5	10	15	20.5	25
Average of B (μT)	58.7	72.2	87.1	106.5	120.6

Dependence of the magnetic field on electric current (coil with 100 spirals)					
Current (mA)	5	10	15	20.5	25
Average of B (μT)	56.0	65.2	76.0	87.3	105.0

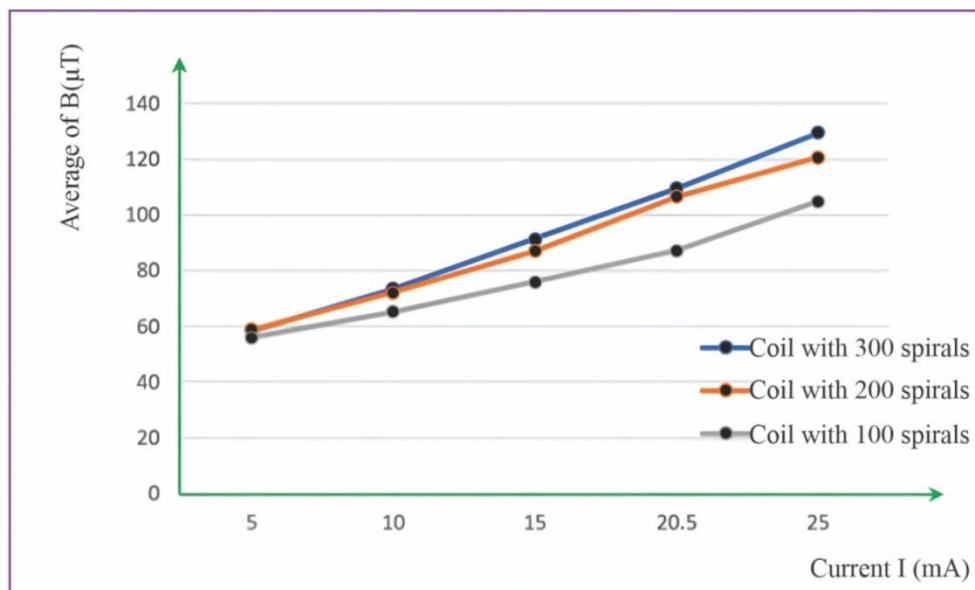


Fig. 8. Summary graphs for all three coils

Dependence of the magnetic field on the number of nails in the core (coil with 200 spirals)

Number of nails	1	2	3	4	5	6	7	8	9	10
Measurements of $ B \mu T$	156.4	157.9	163.4	169.0	184.4	185.7	186.2	187.8	202.0	206.0
	155.6	159.1	163.4	168.5	183.9	186.3	186.8	188.8	202.1	204.6
	155.5	158.1	162.8	168.8	184.3	185.9	186.0	188.1	201.9	204.8
	155.7	158.2	163.2	168.3	183.7	185.7	186.0	188.3	201.8	205.0
	155.9	157.9	163.6	168.3	184.2	185.4	186.0	188.1	202.0	204.9
Average of $ B \mu T$	155.8	158.2	163.3	168.6	184.1	185.8	186.2	188.2	202.0	205.1

Number of nails	11	12	13	14	15	16	17	18	19	20
Measurements of $ B \mu T$	208.3	211.6	211.8	215.6	217.5	219.9	223.6	227.5	231.2	234.0
	207.9	210.2	212.1	215.4	217.1	220.9	223.8	228.1	231.7	233.7
	208.4	209.8	212.1	216.3	217.4	220.7	224.2	227.2	230.9	233.2
	208.5	210.9	211.7	215.4	217.3	219.1	223.6	227.7	230.6	233.6
	208.9	211.0	212.3	216.0	217.3	219.2	224.2	226.9	230.9	234.2
Average of $ B \mu T$	208.4	210.7	212.0	215.8	217.3	220.0	224.0	227.5	231.1	233.7

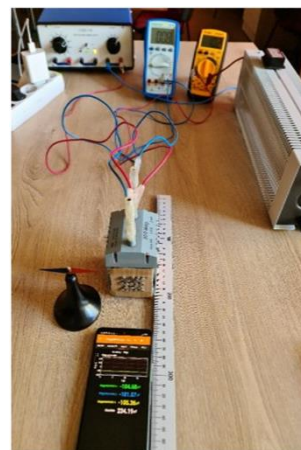
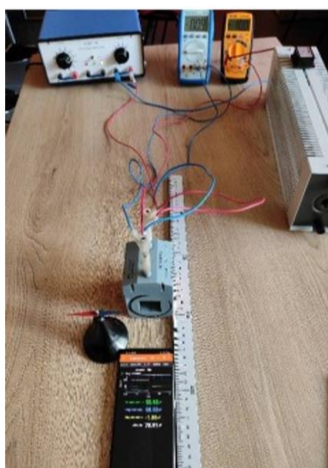


Fig. 9. Coil and scheme used to study the dependence of the magnetic field on the size of the core. In three cases, the coil is seen, empty and with different number of nails it.

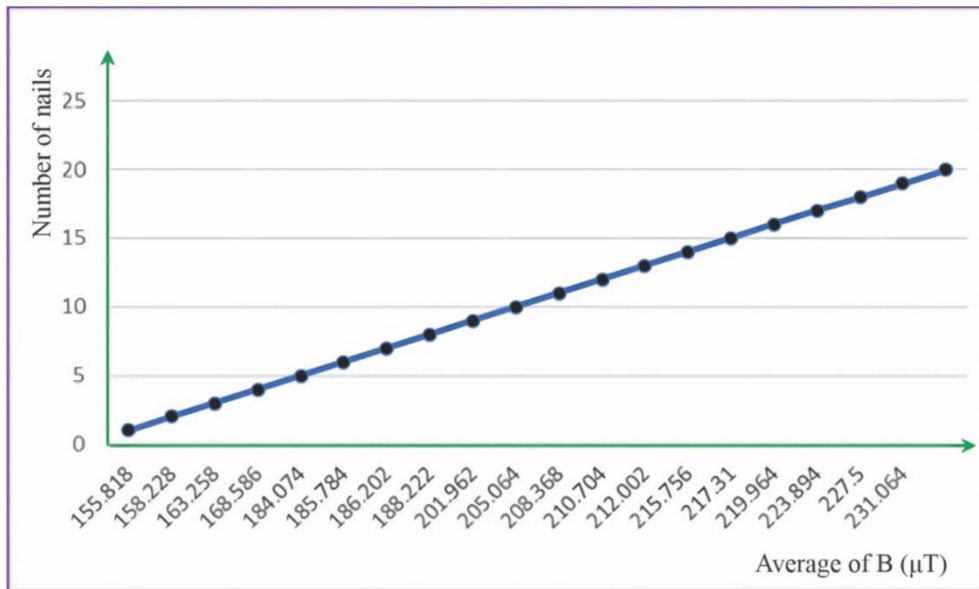


Fig. 10. Graph of the dependence of the magnetic induction on the size of core (number of nails)

The dependence of the magnetic field induction of the solenoid on the intensity of the current passing through it				
Current (mA)	5	10.5	15.5	20.4
Measurements of B	40.4	57.4	84.0	111.6
	40.2	57.0	83.4	112.2
	41.1	47.0	84.8	112.1
	40.3	57.5	83.8	111.8
	40.9	57.2	83.7	112.4
Average of B (μT)	40.6	55.3	83.9	112.0



Fig. 11. Solenoid and scheme for the study of its magnetic field depending on the electric current

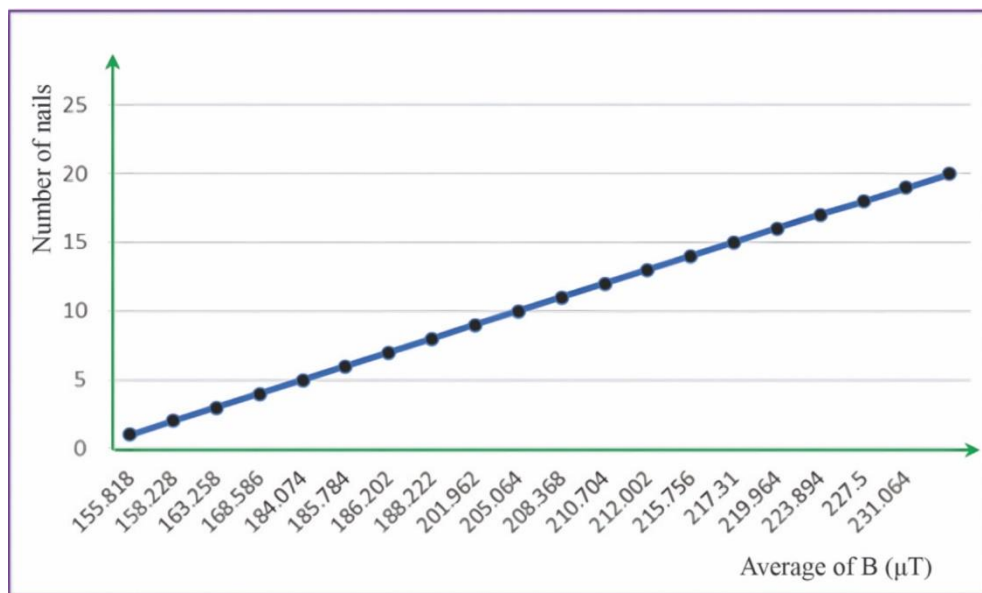


Fig. 12. Graph of the dependence of the magnetic field near the end of solenoid on the intensity of the current passing through it

5 Analysis and Discussion

From the experimental results we see that the value of the magnetic field will increase if we increase number of magnets and decrease the distance between the smartphone and the magnet, or for every nail we add inside the coil, the magnetic field will increase again. By comparing these results, which will be very close to theoretical expectations, we will see that when the smartphone approaches the magnet, the value of B will increase.

Some of the uncertainties in this experiment may be:

1. Due to incorrect sensor calibration, high or low values may appear.
2. Small variations in measurement due to invisible movements, vibrations.
3. Placing the magnet carefully using known distances.
4. Conducting repeated measurements to test the stability of the results.

Some of the common mistakes are:

1. Any metal object like iron near the smartphone can distort the measurement.
2. The presence of nearby electronic devices (such as laptops, speakers) can create additional magnetic fields.
3. The values may be inaccurate if the magnetometer is not properly calibrated (the smartphone must be rotated several times during the experiment).
4. Uncontrolled hand movement can change our measurement values.

Some of the limitations of the device are:

1. Not all smartphones have accurate or functional sensors.
2. Lack of knowledge on the part of users regarding the placement of sensor on the smartphone.
3. "Phyphox" application does not automatically calculate magnetic field changes that occur over the time.

6 Conclusion

Some of the main findings in this experiment are:

The dependence of the magnetic field on the distance, on the electric current, on the number of nails in the coil.

The magnetic field will increase due to several factors:

1. The large presence of magnets.
2. The large number of spirals.
3. The large number of nails inside the coil.

From this experiment we conclude that the value of the magnetic induction in the coil has a linear dependence on the intensity of the electric current passing through it and the number of nails placed inside the coil.

The initial purposes of the experiment have been successfully achieved, the experimental results are consistent with theoretical expectations.

Some of the purposes of the experiment were: measurement of the absolute value of magnetic induction, the influence of the proximity of the magnet on the gradual increase of magnetic field, the magnetic field decreases with distance.

Some of the possible improvements and future directions would help us not only increase the quality of the data but also in a deeper understanding of the magnetic field.

Here are some of the possible improvements:

1. More accurate sensor calibration.
2. Fixed magnetic holder (will increase accuracy).
3. Distance measurement for every 1cm.
4. Isolation from interference.

Future directions:

1. Analyzing the x, y and z components of the field to understand its direction in space.
2. Placing materials such as iron, aluminum between the magnet and the phone to see the protective effect.

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