Instructions :

- Duration : 2 Hours
- Part One : Understand the relationship between electric current and magnetic field.
- Part Two : Measure the magnetic effect of Eddy current on the free fall of a magnet in conductive tubes.

Part One : Study of the Magnetic Field Created by an Electric Current

1 Introduction

Oersted's experiment demonstrated for the first time that an electric current can create a magnetic field. This lab aims to explore this relationship by measuring the magnetic field generated by a current-carrying wire. In the first experiment we investigate the properties of the magnetic field generated by a current by using a smartphone with a magnetometer. According to the Biot-Savart Law, the intensity of the magnetic field B decreases with the distance from infinite long wire as:

$$B = \frac{\mu_0}{2\pi}\frac{I}{R}$$

We will use the Phyphox app on a smartphone to measure the magnetic field at various distances and for different currents. A useful byproduct of this experiment consists in measuring with good precision the location of the sensor inside the smartphone, which in current models is usually placed close to the top left corner of the phone.

2 Materials

- Conducting connecting wires.
- An adjustable DC power supply.
- A smartphone with the Phyphox app installed.
- Ruler and scotch tape.

3 Preliminary Questions

3.1 Schematic of the experiment

Lay one or two meters of conductor wire on a table, ensuring it is straight for a reasonably long stretch, approximately 0.5 to 1 meter. Secure the wire to the table using scotch tape. Connect the wire to the terminals of a DC supply, making sure to route any excess wire as far away as possible from the section lying on the table (see figure 1).

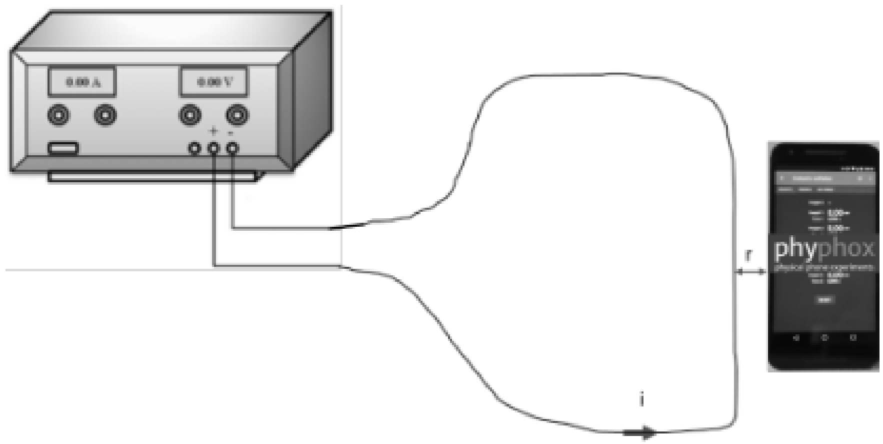


Figure 1: Schematic of the experiment with on the left a DC supply and on the right, at a distance r, a smartphone with the PhyPhoc app.

The resistance of 10 meters of typical banana plug wire (electrical wire) is a fraction of an Ohm. Therefore, to achieve a current of about 1A, a voltage of approximately 1V is enough. If you have a multimeter, you can measure the current directly. If necessary, you may add a resistor in series with the circuit, ensuring that its power rating is sufficient to handle the current. Verify that a stable current is flowing through the circuit by checking the display on the DC power supply or by using a multimeter.

To start data acquisition in Phyphox, select the appropriate sensor and then tap the small play triangle located at the top right corner of the screen. Observe the measured magnetic field over time, comparing the readings when the circuit is closed and when it is open. You should notice a clear difference between the two states.

3.2 Representation of the magnetic field

1. Sketch the magnetic field lines around a straight current-carrying wire.
2. Describe the orientation and shape of the magnetic field lines.

4 Measurements to be taken

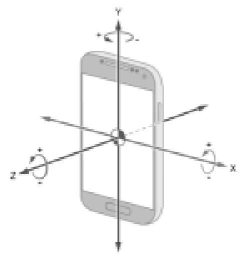
The magnetometer in the smartphone, which is a very small solid-state sensor utilizing the Hall effect, measures the magnetic field in the vicinity of its sensor. When current flows through the wire, the phone's sensor will detect the combined magnetic field of the Earth and that produced by the current. Therefore, before proceeding, we need to determine the Earth's magnetic field, which must be subtracted from the total measured field to obtain the magnetic field generated by the current.

Place the smartphone to the right of the wire, ensuring the long side of the smartphone is parallel to the wire and at the smallest possible distance from it. Measure the three components and the magnitude of the magnetic field for a fixed duration when the circuit is open ($I = 0$) Calculate the average and derive the uncertainty from its distribution. Let's call this measurement $B_0(r)$, where is the distance between the wire and the left side of the phone.

Magnitude $B_0(r) =$ __________

! If you don't move your phone, this value should not change.

4.1 Distance variation



Then, close the circuit, and measure the average $B(r)$ and the uncertainty of the field again, in the same conditions.

1. Set the current to a fixed value (e.g. 1.5 A).
2. Look at the x- and y-components measured (which are parallel, respectively, to the short and long sides of the phone). Can you develop a sense of the shape of the field lines from their values? **What about the component z perpendicular to the display?**
3. Record the values of the three spatial components and the magnitude of the magnetic field at different distances (e.g., 1cm, 2cm, 3cm, ...). To do so, move the wire, not the phone. From each distance r, report the value of the three spatial axis B_x,B_y,B_z and the magnitude B_I of the of the field produced by the current $B_I(r) = B(r) - B_0(r)$.

Distance (cm) **r**	Magnetic Field (µT - x) $\mathbf{B_x(r)}$	Magnetic Field (µT - y) $\mathbf{B_y(r)}$	Magnetic Field (µT - z) $\mathbf{B_z(r)}$	Magneti Field Magnitude (µT) $\mathbf{B_I(r)}$
0.5				
1				
1.5				
2				
3				

4. Plot a graph of B_I as a function of distance for a fixed current.

5. Try linearising the relationship existing between B and r to find an appropriate function of B as $\alpha r + \beta$. Find α and β from your data, and compare with your expectations.
6. **Optional:** Can you find the distance of the sensor into the phone, from the left side of the smartphone? Can you imagine a set of measurements to be done in order to obtain its distance from the top side, such that you can exactly locate it inside the body of your phone?

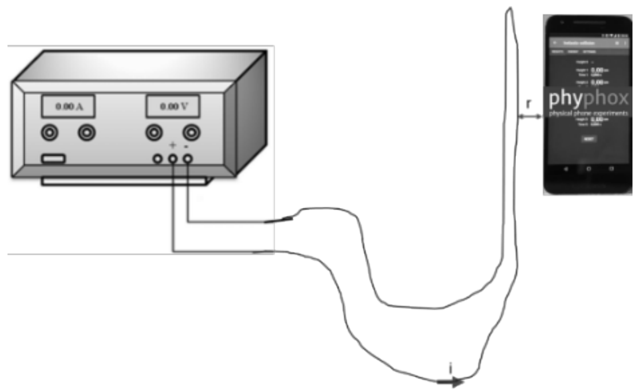
4.2 Current Variation

1. Fix the distance between the wire and the smartphone (e.g., 1 cm).
2. Vary the current intensity (e.g., 0.5 A, 1 A, 1.5 A, 2 A) and report the magnetic field for each current value for the three spatial components and the magnitude.
3. Repeat the procedure with the voltage polarity reversed

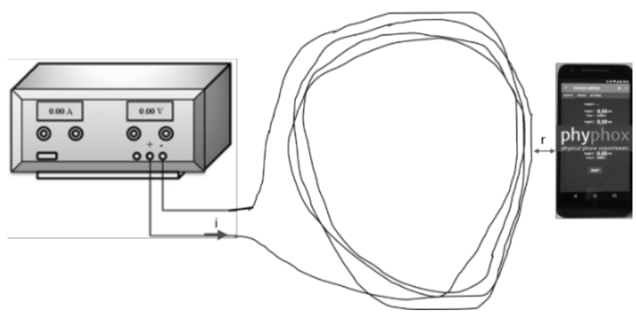
Distance (cm) **r**	Magnetic Field (μT - x) $\mathbf{B_x(r)}$	Magnetic Field (μT - y) $\mathbf{B_y(r)}$	Magnetic Field (μT - z) $\mathbf{B_z(r)}$	Magneti Field Magnitude (μT) $\mathbf{B_I(r)}$
0				
0.5				
1				
1.5				
2				
-0.5				
-1				
-1.5				
-2				

4. Plot a graph of the magnetic field magnitude as a function of current for a fixed distance.

5. Discuss the obtained graphs with theoretical predictions based on the Biot-Savart Law.
6. Discuss any discrepancies and propose possible explanations (e.g., measurement errors, external magnetic interferences,. . .).
7. **Round Trip with the Wire:** Configure the wire to make a round trip and measure the resulting magnetic field at a fixed distance for a fixed current. Discuss your observation.



8. **Multiple Wires with the Same Intensity:** Use multiple parallel wires carrying the same current or a loop and measure the resulting magnetic field at a fixed distance. Discuss your observation.



5 Analysis and discussion

1. Discuss the obtained graphs with theoretical predictions based on the Biot-Savart Law.
2. Discuss any discrepancies and propose possible explanations (e.g., measurement errors, external magnetic interferences, etc.).
3. Explain how variations in distance and current affect the magnetic field.

Part Two : Study of Eddy currents

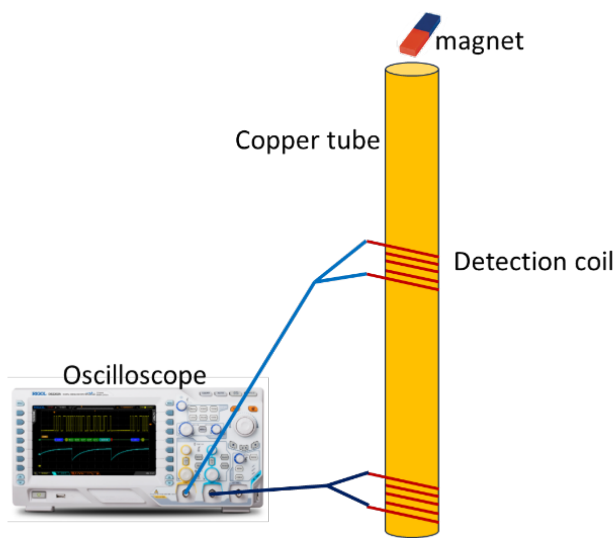
1 Introduction

Faraday's law of induction is a fundamental principle in electromagnetism that predicts how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF). This phenomenon is a cornerstone in the understanding of many electromagnetic devices. In this lab, we will investigate how different materials and configurations can influence the fall of a magnet through a tube, providing insights into electromagnetic induction.

2 Materials

- Various magnets
- Tubes of different materials and diameters
- Copper wire (enough to make two coils)
- An oscilloscope to visualize electrical signals

3 Experimental setup



3.1 Coil Preparation

- Wrap the copper or conducting wire around two distant points on the tube to create two coils with approximaltly 15-20 turns. These coils will be connected to the inputs of an oscilloscope to detect the passage of the magnet.
- Copper wires are covered with an insulating film to prevent short circuits. This protective film can be removed by carefully rubbing or scratching the end with a knife or scissors before connecting it to the oscilloscope.

- Using Lenz law, provide a short explanation of how the oscilloscope can be used to detect the passage of the magnet.

3.2 Oscilloscope Setup

- Connect the coils to the oscilloscope. Set the oscilloscope to an appropriate time scale to capture the signals generated by the falling magnet.

4 Data Collection

1. **Initial test:**
   - Drop the magnet through the vertical tube and observe the signals on the oscilloscope. Ensure the setup is working correctly and the signals are clear. Put your hand under the tube to catch the falling magnet (they can break easily if they hit the table)
2. **Measure Fall Velocity :**
   - For each type of tube, release the magnet and record the time it takes to travel between the two coils using the oscilloscope.
   - Repeat the measurement 3 to 5 times to get an average fall velocity and record the data.
3. **Vary Tube and Magnet Types:**
   - Test the fall velocity with tubes of different materials and diameters.
   - Use different types of magnets (varying in size, mass, and magnetic strength) to observe their influence on the fall velocity.
4. **Split Tube Test (Optional):**
   - If available, test the fall velocity with a tube that is split lengthwise. Observe any changes in the magnet's fall behavior.
5. **Data Collection:**

Tube Material	**Tube Diameter**	**Magnet Type**	**Average Fall Velocity** (m/s)
Copper	D1	Type A	
Copper	D2	Type B	
Copper	D1	Type A	
Copper	D2	Type B	
PVC			
Split copper tube			

5 Analysis

1. **Compare with Free Fall:**
    - Calculate the expected fall velocity under free fall conditions (without eddy currents) using the formula for free fall: $v = \sqrt{2gh}$, where h is the distance between the coils and g is the acceleration due to gravity.
    - Compare the measured fall times with the calculated free fall times.
2. **Discuss Eddy Current Effects:**
    - Explain how eddy currents affect the fall velocity of the magnet. Discuss why the effect is more working only in conductive materials.
    - Analyze how different factors (tube material, diameter, magnet type) influence the fall velocity.
3. **Split Tube Analysis:**
    - If tested, discuss the effect of splitting the tube on the fall velocity. Explain why the behavior might change.

6 Conclusion

- Summarize the main findings and try to provide a clear understanding of what is eddy currents and how they can slow down the free fall of a magnet.
- Discuss the importance of eddy curren:ts in practical applications and how they can be utilized.