EXPERIMENT III

Determination of the Earth's Horizontal Magnetic Field Using a Vertical Current-Carrying Wire and a Compass

Objective

This experiment aims to investigate the magnetic field produced by a straight current-carrying wire and to determine the horizontal component of the Earth's magnetic field using compass deflection.
At the end of the experiment, students should be able to:

- observe that an electric current produces a magnetic field,
- determine the direction of the magnetic field using the right-hand rule,
- measure the deflection angle of a compass needle,
- calculate the horizontal component of the Earth's magnetic field,
- compare the experimental result with the expected order of magnitude.

Experimental Materials

- DC power supply, preferably 3 V to 12 V, Straight copper wire mounted vertically, Ammeter, Variable resistor or rheostat, Switch, Compass, Meter ruler, Connecting wires, Stand and clamps.

Theoretical Background

When an electric current flows through a straight conductor, a magnetic field is produced around the conductor. The magnetic field lines are concentric circles centered on the wire. The direction of the magnetic field is found using the right-hand rule: if the thumb points in the direction of the current, the curled fingers show the direction of the magnetic field.
For a long straight wire, the magnitude of the magnetic field at a distance r from the wire is

$$B_w = \frac{\mu_0 I}{2\pi r}, \tag{1}$$

where B_w is the magnetic field produced by the wire, I is the current through the wire, r is the perpendicular distance from the wire axis to the compass needle center, and $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{T\,m/A}$ is the permeability of free space.
A compass needle aligns itself with the horizontal component of the Earth's magnetic field. In this experiment, this component is denoted by B_E. When there is no current in the wire, the compass points in the magnetic north–south direction.
A vertical wire produces a magnetic field that is tangential to a circle centered on the wire. Therefore, at the compass position, $\vec{B}_w$ is perpendicular to the radial line joining the wire axis to the compass center. For the tangent relation to be valid, $\vec{B}_w$ must be perpendicular to $\vec{B}_E$. Hence, the radial line from the wire to the compass center must be parallel to the initial north–south compass direction.
Important: With the switch open ($I = 0$), first allow the compass needle to settle in the north–south direction. Then place the vertical wire so that its axis lies on this north–south line at a measured

distance r from the compass center. This ensures that, when current flows, the magnetic field of the wire at the compass position is perpendicular to the Earth's horizontal magnetic field. The wire does not produce a magnetic field when $I = 0$.

When current flows, the wire field $\vec{B}_w$ is perpendicular to the initial compass direction. The compass then aligns with the resultant field

$$\vec{B}_{\text{net}} = \vec{B}_E + \vec{B}_w.$$

Thus,

$$\tan\theta = \frac{B_w}{B_E}, \tag{2}$$

where θ is the deflection angle measured from the initial north–south direction. Using Eq. (1) in Eq. (2), the horizontal component of the Earth's magnetic field becomes

$$B_E = \frac{\mu_0 I}{2\pi r \tan\theta}. \tag{3}$$

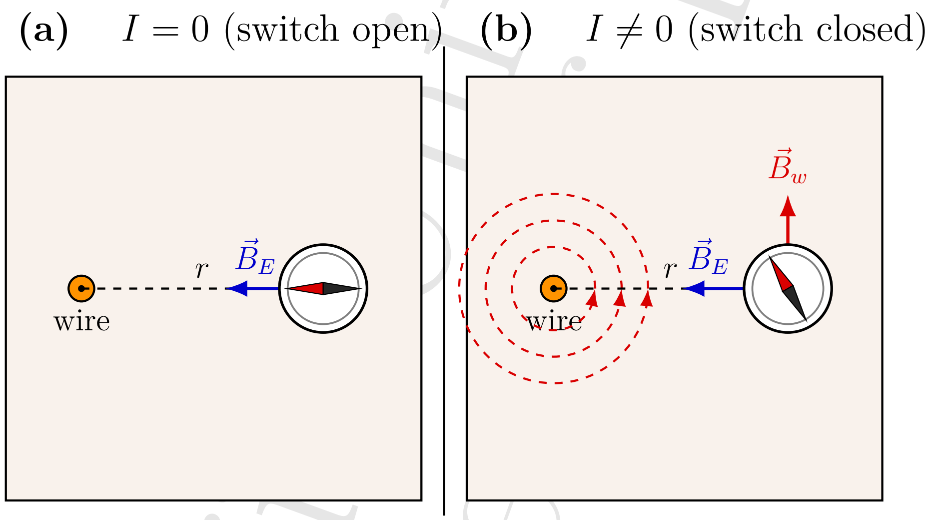
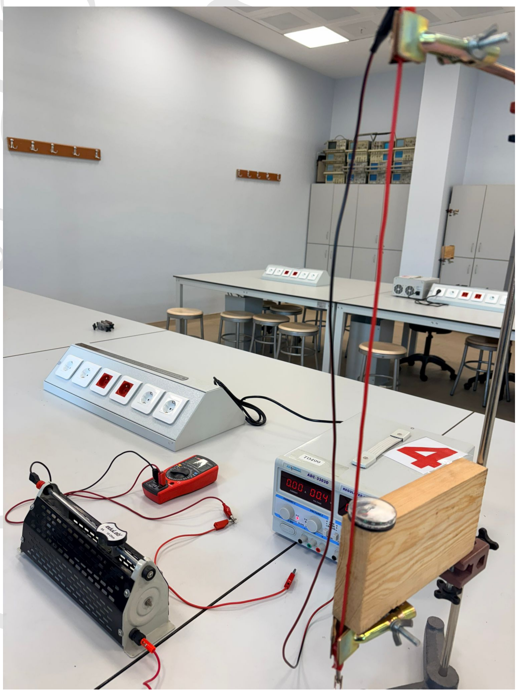


Figure 1: Top view of the vertical current-carrying wire and compass experiment.



Procedure

1. Assemble the circuit by connecting the DC power supply, switch, rheostat, ammeter, and vertical wire in series.
2. Keep the switch open. Place the compass horizontally on the table and allow the needle to settle.
3. Mark the initial north–south direction indicated by the compass needle.
4. Place the vertical wire on this marked north–south line, at a known distance r from the compass center. In other words, the line joining the wire axis and the compass center should be parallel to the initial compass needle.
5. Measure r from the center of the wire to the center of the compass needle.
6. Close the switch briefly and adjust the current to a chosen value.
7. Record the current I shown by the ammeter.
8. Measure the deflection angle θ from the initial north–south direction.
9. Open the switch to avoid unnecessary heating of the wire.
10. Repeat the measurement for several different current values.
11. Reverse the current direction and observe that the compass deflection reverses.

Suggested Experimental Values

For a visible compass deflection, the magnetic field of the wire should be of the same order as the horizontal component of the Earth's magnetic field. A practical range is

$$r = 1.0\,\text{cm to } 3.0\,\text{cm}, \qquad \text{and} \qquad I = 0.5\,\text{A to } 2.0\,\text{A}.$$

For example, if $I = 1.0\,\text{A}$ and $r = 1.0\,\text{cm}$,

$$B_w = \frac{4\pi \times 10^{-7}(1.0)}{2\pi(0.010)} = 2.0 \times 10^{-5}\,\text{T} = 20\,\mu\text{T}.$$

This is comparable with the expected horizontal component of the Earth's magnetic field. The total magnetic field of the Earth is usually of the order of $25\,\mu\text{T}$ to $65\,\mu\text{T}$. In this experiment, the compass responds mainly to the horizontal component. A reasonable expected value for the horizontal component in northern Türkiye is approximately

$$B_E \approx 25\,\mu\text{T}.$$

Experimental results may differ due to local magnetic disturbances.

EXPERIMENT REPORT

Name: **Surname:**

Student ID: **Group:** **Date:**

Observation Table: The measurements recorded in this table are used to determine the horizontal component of the Earth's magnetic field based on the experimental setup.

Table 1: Measurements for calculating the horizontal component of the Earth's magnetic field.

Trial	I (A)	r (m)	θ (degree)	$\tan\theta$	B_E (T)
1					
2					
3					
4					
5					

Sample Calculation

For each trial, calculate the horizontal component of the Earth's magnetic field using

$$B_E = \frac{\mu_0 I}{2\pi r \tan\theta}$$

Then, calculate the mean value of the obtained B_E values.

$$\overline{B}_E = \frac{B_{E,1} + B_{E,2} + \cdots + B_{E,n}}{n} \tag{4}$$

Graphical Analysis

Since

$$\tan\theta = \frac{\mu_0}{2\pi r B_E} I$$

for constant r, a graph of $\tan\theta$ versus I should be approximately linear.
The slope m of the graph is given by

$$m = \frac{\mu_0}{2\pi r B_E} \tag{5}$$

Thus, the Earth's horizontal magnetic field may also be calculated from the slope:

$$B_E = \frac{\mu_0}{2\pi r m} \tag{6}$$

This graphical method is generally preferable to using a single measurement because random errors are reduced.

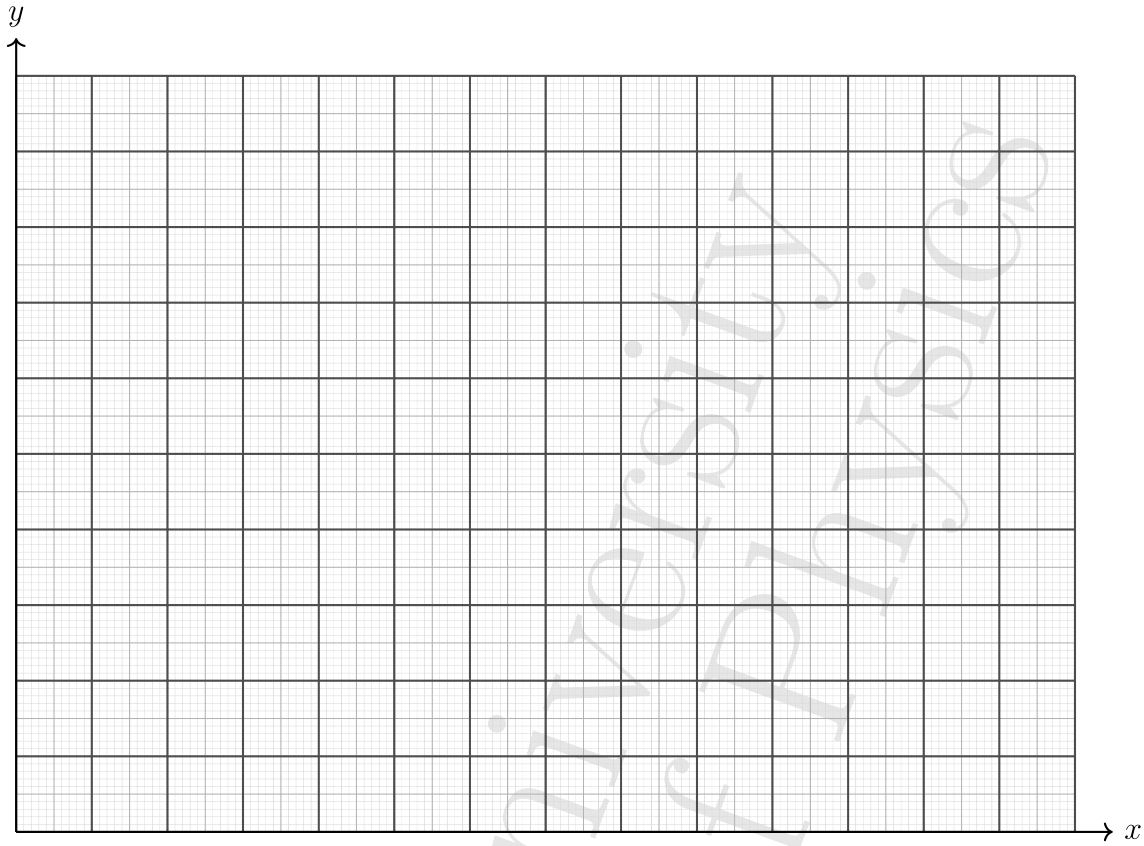


Figure 2: Graph of $\tan\theta$ versus current I.

Conclusion

Summarize the results, discuss their physical meaning, and compare them with theoretical expectations.

Prepared by
Prof. Dr. Necla ÇAKMAK
Assoc. Prof. Dr. A. Mustafa ERER
Assist. Prof. Dr. Ulvi KANBUR
Karabük University, Department of Physics, 2026