Physics 121: Measurement of the Earth’s Magnetic Field

1 Introduction

The Earth’s magnetic field is well known and is ever present, affecting any experiments in which relatively small magnetic fields are involved. In this lab, we will use our knowledge of the magnetic field created by currents to measure the Earth’s magnetic field in our lab.

At a given location on the Earth’s surface in the northern hemisphere, the direction of the Earth’s magnetic field is in the general direction of the Earth’s north pole, but directed downward at an angle \( \theta \) (called the “dip angle”) below the horizontal. As shown in Figure 1 the total \( B \) field vector is related to the horizontal component \( B_H \) and the dip angle by

\[
B = \frac{B_H}{\cos \theta}.
\]

(1)

In this lab we will only measure the horizontal component.

![Figure 1: The relationship between the Earth’s magnetic field \( B \) and the horizontal component \( B_H \) at the Earth’s surface in the northern hemisphere.](image)

We will measure the strength of the horizontal component of the earth’s magnetic field using a simple device called a tangent galvanometer. We will place a small magnetic compass at the center of a circular coil of wire. A power supply provides an electric current that produces a magnetic field at the center of the coil where the compass is located.

The \( B \) field of the current at the center of the coil is directed perpendicular to the plane of the coil (given by the third right-hand-rule) and, as explained in class, its magnitude is given by

\[
B_{\text{coil}} = \frac{\mu_0}{4\pi} \frac{2\pi NI}{R}
\]

(2)

where \( N \) is the number of turns of wire in the coil, \( I \) is the conventional current, and \( R \) is the radius of the coil. With the plane of the coil aligned parallel to the Earth’s magnetic field, the field of the coil \( B_{\text{coil}} \) will be perpendicular to the direction of \( B_H \). The Earth’s field \( B_H \) tries to align the compass needle toward magnetic north, while \( B_{\text{coil}} \) tries to align it along the east-west line.
The resultant orientation of the needle is in the direction of the net field, somewhere between these directions. The angle $\alpha$, shown in Figure 3, through which the needle is deflected away from the direction of $B_H$ gives a measure of the strength of the field $B_{\text{coil}}$ relative to the strength of the horizontal component of the earth’s magnetic field $B_H$. In fact,

$$\tan \alpha = \frac{B_{\text{coil}}}{B_H}. \quad (3)$$

![Diagram of compass needle deflection](image)

Figure 2: The deflection of the compass needle due to the magnetic field of the coil perpendicular to the horizontal component of the earth’s magnetic field.

By calculating $B_{\text{coil}}$ from the data and reading the deflection angle of the compass, from the equation above we can obtain a value for $B_H$.

2 Procedure

1. Read from the coils, and record on your data table, the values of the coil’s radius, $R$, and the number of turns of wire, $N$. (Attached at the back is a sample data table with spaces that you can use to enter your data. In the end, though, you will need to make your own data table in Excel, so you may want to start with Excel at this point.)

2. Place the compass at the very center of the coil, let the needle settle, and turn the coil so that the north-south direction is in the plane of the coil.

3. Carefully rotate the compass until the ends of the compass needle are aligned with 0° and 180° on the compass scale.

4. Connect the circuit described below. IMPORTANT: do NOT turn on the power until your instructor has checked your circuit (or you can blow a fuse in the meter).

5. Connect the ‘+’ socket in the power supply to the left-most socket in the coils. Connect the middle socket in the coils to the resistor. Connect the other end of the resistor to the ‘Com’
socket in the meter. And, connect the 'mA' socket in the meter to the ' '-' socket in the power supply. Turn the dial on the meter to the milliamps setting, but do not turn on the meter yet.

6. HAVE YOUR INSTRUCTOR CHECK YOUR CIRCUIT before continuing.

7. Turn on the power supply and set the current so that the compass deflects through $40^\circ$. (You may need to tap on the compass lightly to make sure that the compass needle is not binding and moves freely.) Turn off the current, and perform the measurement again to see if it is repeatable. Read the angle at both ends of the compass needle to ensure that your reading is not affected by a poor viewing perspective. Discuss with your partner the best way to measure the angle accurately and how to estimate the uncertainties in the angle measurement.

8. Turn off the power supply, reverse the leads and repeat the last step. Adjust the current to get to the same angle. Do you get the same current? If not, calculate the average of your two currents and set half the difference as the uncertainty.

9. Record your angle and average current, with uncertainties, in your data table.

10. Repeat for four other angles. For each angle, remember to get a measurement of the current in each direction; after measuring the current for a given angle, turn off the power supply, switch the leads into the power supply, turn it back on, and turn up the power slowly to get back to the same angle.

11. For each angle value, average the currents and record the data in your data table.

3 Analysis

1. Using Equation (3), make a plot in Excel from which you can infer $B_H$ and an uncertainty. (Hint: if you plot a straight line whose slope equals $B_H$, then you can use the Regression Analysis tool in Excel to get an uncertainty, as well as a measure of $B_H$.)

2. As a comparison analysis, calculate and record $B_H$ for each trial. Also determine and record the uncertainty for each value by propagating the uncertainties in the measurement (as explained by your instructor).

3. Calculate the average of the values you obtained for $B_H$ from the five trials and enter the result on the line provided on the data sheet. Calculate the uncertainty in the average ($\sigma/\sqrt{N}$) and list it as well.

4. Compare your inferred values and uncertainties for $B_H$ from the graphing method and by averaging all the individual trials. Which method do you find more enlightening?

5. Compare your value for $B_H$ with accepted values (as can be found by Googling “Magnetic Field Earth Schenectady”) and comment on the agreement.
4 Data

Radius of the coil $R = \_\_\_\_\_\_\_\_;$ Number of turns of wire $N = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_;$

Table 1: Measurements of compass deflection angle and current and inferred value of the horizontal component of Earth’s magnetic field.

<table>
<thead>
<tr>
<th>Trial</th>
<th>$\alpha$(deg)</th>
<th>$\Delta\alpha$(deg)</th>
<th>I(A)</th>
<th>$\Delta$I(A)</th>
<th>$B_H$(T)</th>
<th>$\Delta B_H$(T)</th>
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Average value and uncertainty of $B_H$ from graph = _________________

Average value and uncertainty of $B_H$ calculated from trials = _________________