Experiment F

Earth’s Magnetic Field Measurement

**Experimental Objectives:** To measure the local Earth magnetic field and the field of a current-carrying circular coil of wire.

**Apparatus:** Compass, circular coil of wire, power supply, wires, ammeter.

**Fundamentals:** The magnitude of the magnetic field at the center of a circular coil of wire ($B_c$ in Fig. 1) depends on the coil current ($I$), the coil radius ($R$) and the number of loops that make up the coil ($N$)

$$B_c = \frac{N\mu_0 I}{2R} \quad (1)$$

Recall the SI unit for magnetic field is the Tesla (T) and $\mu_0 = 4\pi \times 10^{-7}$Tm/A is the magnetic permeability of free space.

**PROCEDURES**

**Procedure for Measuring the Earth’s Field:**

1. With the power supply OFF, connect its 6 VDC, 5.0 A output to the coil to form a complete circuit (do NOT bypass the resistor). Make sure there is an ammeter in the circuit to measure the current.

2. Place the compass on the supporting block at the coil's center, and orient the plane of the coil so it is in the N-S direction (Fig. 3). Now the plane will contain the horizontal component of the Earth’s local field (labelled $B_h$ in Fig. 3).

The field direction is given by a source right-hand rule: place your thumb in the direction of the current and wrap your fingers around the wire. Your finger direction gives the magnetic field direction at the center (Fig. 1). For our coil, $R = 10.5$ cm and $N = 200$ loops.

The magnetic field ($B_c$) on the $z$-axis of the coil (Fig. 2) has the same direction as the field at the center, but is less strong. It can be shown that the magnetic field decreases as the axis distance $z$ increases according to

$$B_z = \frac{B_c}{\left(1 + \frac{z^2}{R^2}\right)^{3/2}} \quad (2)$$

(continued)
Procedure for Measuring the Earth’s Field:
(continued)

3. Turn on the power supply and gradually increase the coil’s current. As you do so, notice that $B_c$ will increase, thus increasing the angle $\theta$ as shown in Fig. 3.

4. Measure the current for $\theta$ from 15° to 75° in steps of 10-15°. (Keep $I \leq 100$ mA.) [If you can’t reach 75°, record up to 60°.]

Procedure On the $z$-axis ($B_z$):

Start with the coil current that gave the angle of 60° in the previous procedure. Call this angle $\theta_1$. Using the tall support block move the compass along the $z$-axis until the angle between its direction and the coil’s plane drops to 45° (i.e. $B_z = B_h$). Call this $\theta_2$ (see Fig. 4). Record the distance $z_0$.

Fig. 4. Moving Along the z-Axis, $B_z$

$B_c$ $B_h$ $\theta_1 = 60^\circ$

$z_0$

(top)

$B_h$ $\theta_2 = 45^\circ$

$B_z = B_h$

Procedure for Determining the Coil’s Magnetic Field Shape:

Using the swivel mini-compasses, map the coil's field pattern. Make a sketch including not just on the axis, but above and below the coil and in its plane, both inside and outside the coil.

REPORTS AND ANALYSIS

Report and Analysis for Determining the Earth's Local Magnetic Field:

1. For each current, use Eq. 1 to find $B_c$.

2. From Fig. 3, $\tan \theta = B_c/B_h$ or $B_c = (B_h) \tan \theta$. Since $B_h$ is constant, plotting $B_c$ (vertical axis, $y$) versus $\tan \theta$ (horizontal axis, $x$) should yield a straight line with a slope of $B_h$. (Recall that $y = Ax$ is a line.) Use your best-fit line to determine $B_h$. Be sure to include enough significant figures in your fitted values of slope and intercept.

3. Using the dip-angle compass (your instructor will provide this), determine the dip angle near your apparatus. Use this to determine the total local Earth magnetic field, $B_E$. (HINT: $B_h$ from above is only the horizontal component.) Due to electric circuits in the laboratory, the presence of magnetic materials, etc., this total field for $B_E$ may or may not be the same as the Earth’s field ($B_E$ should be about $4.84 \times 10^{-5}$ T or 0.0484 mT). Your value should, however, fall between 0.04 mT and 0.06 mT. Does it?

Report and Analysis on the $z$-axis:

1. Using Eq. 2 and trigonometry, one can show (see Problem 3) that the theoretical value for $z_0$ is

   \[ \frac{z_0}{R} = \left( \frac{\tan \theta_1}{\tan \theta_2} \right)^{2/3} - 1 \]  

   (3)

   Using your angular values show that $z_0/R = 0.665$. Now use your $R$ to find $z_0$. Compare this to your experimental result.

   Follow-Up Questions: (Your instructor may or may not require these in your report.) Be sure to show your work.

   A. Using the manufacturer’s numbers for the coil, show in Equation 1 that
\( \frac{N \mu_0}{2R} = 1.20 \times 10^{-3} \text{ T/A} = 1.20 \text{ mT/A}. \)

Interpret this result physically.

**B.** What coil current would produce a center magnetic field strength at the center of 0.20 mT?

**C.** If you face the coil, and the magnetic field at its center points away from you, which direction is the current in the coil?

**D.** If you are facing the coil, and the current is counterclockwise, what is the direction of the magnetic field in the plane of the coil outside the area of the coil?

**E.** Starting with Eq. 2, derive the result in Eq. 3. HINT: \( B_h \) is the same for both angles.

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