**EARTH’S MAGNETIC FIELD**

**Short description:**
In this experiment, you will produce a magnetic field in the coil $B_{\text{COIL}}$ and combined it with the Earth magnetic field $B_{\text{EARTH}}$. Looking at the position of a compass needle will allow you to determine the intensity of $B_{\text{EARTH}}$.

**Equipment:**
- Earth magnetic field apparatus
- Pasco power supply
- Coil compass
- Ruler

**Theory:**
Magnetic fields can be produced by permanent magnets (e.g., bar magnets) and by currents in wires. The magnitude of the magnetic field at some distance $x$ along the perpendicular axis through the center of the coil is given by

$$B_{\text{COIL}}(x) = N \frac{\mu_0}{2} \frac{r^2}{(x^2 + r^2)^{3/2}} I \quad (1)$$

where $I$ is the current in the coil, $N$ the number of turns, $r$ the radius of the loop, and $\mu_0 = 4\pi \times 10^{-7}$ T⋅m/A = 0.4π μT⋅m/A. Moreover, magnetic fields add vectorially, and this must be accounted for in any measurement of magnetic field. In this experiment, we will orient a coil such that its field is perpendicular to the Earth's magnetic field. If we measure the angle of the total magnetic field $B_{\text{TOT}} = B_{\text{COIL}} + B_{\text{EARTH}} \quad (2)$

as a function of coil current, then the value of the Earth's field can be estimated.

A bar magnet in an ordinary compass is characterized by its magnetic moment $\mu$ (not to be confused with $\mu_0$). The moment can be compared to a current loop which has a moment $\mu = NIA$, where $N$ is the number of turns, $I$ is the current and $A$ is the area of the loop. A bar magnet is torqued by magnetic field, $B$, with the torque, $\tau$, given by

$$\tau = \mu B \sin \theta_{\mu B} \quad , \quad (3)$$

where $\theta_{\mu B} = \theta_\mu - \theta_B$ is the angle between the direction of $\mu$ (from the S-geographic pole to the N-geographic pole) and the magnetic field direction. This torque will cause the magnet to align in the direction of the magnetic field, that
is the equilibrium angle will have $\theta_\mu = \theta_b$. The compass needle is a bar magnet which aligns in the direction of the Earth’s field.

If we align the coil such that it produces a field perpendicular to the Earth's field, the total magnetic field vector will be at an angle to the Earth's magnetic field direction, as is shown in the diagram. With the normal to the coil perpendicular to the Earth's field, the relation

$$\tan \theta_\mu = \frac{B_{\text{COIL}}}{B_{\text{EARTH}}}$$

(4)

can be used to determine $B_{\text{EARTH}}$

**Procedure**

**PART I.**

1) Look at the coil assembly (similar to that shown to the right). **NOTE:** Do not place the coil directly over the table leg, as the proximity of the ferrous metal leg adversely affects the results; also keep electronic devices away from the coil. Connect the coil to the DC power supply and adjust the voltage output of the power supply to 12V. At the base of the coil there is a $R = 20$ Ohm resistor connected in series. Take the coil compass and move it around the coil to determine the direction of the magnetic field $B_{\text{COIL}}$ at various points inside and outside the loop.

2) The two diagrams below give two views of the coil, make a sketch and indicate the magnetic field lines and the current. Include arrows on the field lines showing the direction of the field.

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[Diagram showing magnetic field lines and current direction]
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3) Trace the direction of the current from the power supply around the loop. Is the direction of the magnetic field in the center of the loop consistent with the current direction? (Use the ‘right-hand rule’ to determine the field direction given the current direction.)

4) What happens to the field direction when you reverse the current through the loop? (You reverse the current by switching the leads to the power supply.)
5) Rotate the coil such that $B_{COIL}$ points 90° away from North. Set the voltage to zero and look at the compass needle mounted at the center of the coil. Should the compass needle rotate if you start to increase the current (by varying the voltage on the power supply)?

Gradually increase the current (by varying the voltage 0 - 12 Volts), how is your prediction verified?

PART 2.

6) With the current set to zero, the compass needle should point in the direction of the Earth’s magnetic field. Does it point north?

If not, consider the direction of the compass as the ‘effective’ North direction for your set up.

7) Orient the base such that the protractor on it is aligned with the compass needle along 0°. Rotate the coil such that $B_{COIL}$ is perpendicular to $B_{EARTH}$ and have the coil compass set at the center of the coil which corresponds to $x = 0$ in Eq. (1). The magnitude of $B_{COIL}$ depends on the current that runs through the coil. By varying the amount of current, you can change the magnitude of $B_{COIL}$ and therefore the direction of the total magnetic field $B_{tot}$ acting on the compass needle. Given that $\theta_B$ is the angle of the compass needle from north, what value of $\theta_B$ gives for $B_{COIL}$ and $B_{EARTH}$ to have the same magnitude?

$$\theta_B = _____$$

8) Adjust the voltage until $\theta_B$ reaches this value. Using the Ohm law (resistance $R = 20$ Ohm), find this current

$$I = _______$$

9) From Eq. (1) calculate $B_{EARTH}$. Use $N = 20$ and measure $r$, the radius of the loop.

$$r = _______$$

$$B_{EARTH} = _______$$

10) To get a more precise value of $B_{EARTH}$, measure the angles $\theta_R$ to the right and $\theta_L$ to the left side of the coil. To do so, set the coil compass on the plastic support 5.0 cm away to the left (right) of the center to the coil and read the angle on the protractor mounted on the compass. Then take their average value $\theta_B$. Repeat for different values of the coil current $I$ obtained by setting different voltages.

<table>
<thead>
<tr>
<th>$V$ (Volts)</th>
<th>$I$ (amps)</th>
<th>$B_{COIL}$ (μT)</th>
<th>$\theta_R$ (deg)</th>
<th>$\theta_L$ (deg)</th>
<th>$\theta_B$ (deg)</th>
<th>$\tan \theta_B$</th>
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To calculate $B_{COIL}$ use the equation (1) with $x = 5.0$ cm.
11) Plot $B_{\text{COIL}}$ vs. $\tan \theta_B$ using Excel. Fit with a linear trendline and find the slope. From Eq. (4), the slope of the line is your measured value of the Earth's field.

$$B_{\text{EARTH}} = \text{(slope)} = \underline{\text{_____________}} \, \mu\text{T}.$$  

**PART 3.**

12) Compare your measured value of $B_{\text{EARTH}}$ (found in step 11) with the expected value given by NOAA website (http://www.ngdc.noaa.gov/geomag-web/) or google “NOAA Magnetic Field Calculators”. Select the tab “Magnetic Field” (the third from the left). Lookup the latitude and longitude of Tuscaloosa by input the zip code and clicking “Get & add Lat/Lon”. Then click at the bottom left “Calculate”. This web site gives the horizontal, the vertical component as well as the total field. Which component should you be comparing your result to?

$$B_{\text{EARTH}} \text{ (NOAA)} = \underline{\text{_____________}} \, \mu\text{T}.$$  

13) Does the vertical component tend to rotate the magnet left or right, or would it tilt it up or down?

14) What is the percentage discrepancy between your measurement and the expected value from the NOAA website?

$$\% \text{ Error} = \frac{|\text{measured} - \text{expected}|}{|\text{expected}|} \times 100 \% = \underline{\text{_________}}$$  

**TURN OFF THE POWER SUPPLY**