Magnetic Field of the Earth

Theory
The earth has a magnetic field with which compass needles and bar magnets will align themselves. This field can be approximated by assuming there is a large bar magnet inside the earth as shown in Figure 1.

Generally, a compass is aligning itself with the horizontal component $B_x$ of the magnetic field. Incidentally, opposite poles of magnets attract each other; like poles repel each other. Thus, when compasses point toward the North Magnetic Pole of the earth, they are really pointing toward the equivalent of the south pole of a bar magnet.

We will use a coil (tangent galvanometer) carrying a known current to produce a magnetic field which will be perpendicular to the horizontal component of the earth's magnetic field. By measuring the direction of the resultant of these two fields, we can calculate the horizontal component of the earth's magnetic field.

The magnitude of the magnetic field produced by the current in the coil is given by

$$|\vec{B}_c| = \frac{N\mu_0 i}{2r} \quad (1)$$

where $N$ is the number of turns in the coil, $i$ the current in the coil, $r$ the radius of the coil, and $\mu_0$ the permeability of free space. The magnetic field will be in Tesla if $i$ is measured in amperes and $r$ in meters. The direction of this field at the center of the coil is perpendicular to the coil. The direction is such that if the thumb of your right hand points in the direction of the current while your right hand is wrapped around the coil, then the fingers of your right hand will point in the direction of the field.

When the field of the coil is horizontal and perpendicular to the horizontal component of the field of the earth, the two will combine to produce a resultant field $\vec{B}_r$ whose direction will be indicated by a compass at the center of the tangent galvanometer. Using the known magnetic field of the coil, the horizontal component of the earth's magnetic field can be calculated from the relationship.
\[
\frac{|\vec{\beta}_t|}{|\vec{\beta}_t|} = \tan \theta
\]  

(2)

where \(\theta\) is the angle between the resultant field and the coil field as shown in Figure 2.

A magnetic dip needle is essentially a compass free to rotate in a vertical plane (as opposed to a horizontal plane as a traditional compass does). If the plane of the dip needle is aligned with the horizontal component of the earth’s magnetic field, then the needle will align itself with the actual direction of the field at that point – not just a component of the field. If we call the angle that the dip needle makes with the horizontal \(\beta\), then the magnitude of the earth’s magnetic field can be calculated with

\[
|\vec{\beta}_t| = \frac{|\vec{\beta}_t|}{\cos \beta}
\]  

(3)

Apparatus
Magnetic Dip Needle, Tangent Galvanometer, DC Power Supply, Ammeter, Connecting Wires, Compass.

Procedure
Choose a location far from metal plumbing, electrical outlets and other metal objects. Connect the circuit as shown in Figure 3.

Before current is introduced, align the tangent galvanometer coils parallel to the earth's magnetic field. The needle on the compass in the galvanometer will be aligned with the coils when they are parallel to the earth's magnetic field.

Turn on the power supply and adjust the current in the circuit – note what happens to the compass needle as you do this. You need to take a series of readings in which you note the magnitude of the current in the circuit as well as the angle the compass needle makes with the normal to the coil (see Figure 2). The magnitude of the current depends on the number of turns that you are using in the coil. Therefore, a good approach might be to start with a large angle and work down from there so that you fill up Table 1. Under no circumstances exceed an angle of 75° or a current of 2A.

When done recording your values, turn off the power supply and place dip needle so that its plane of rotation is parallel to the coils of the coil.
the galvanometer. Record the angle that the dip needle makes with the horizontal $\beta$.

For each current calculate the magnetic field of the coil $B_c$. 

Table 1

<table>
<thead>
<tr>
<th>Number of Turns in the coil, $N$</th>
<th>Radius of the coil, $r$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

Angle below horizontal from dip needle, $\theta$ (°) __________

Analysis

1. Plot a graph of The Magnetic Field of the Coil ($B_c$) as a function of The Inverse Tangent of the Angle from the Normal ($1/\tan \theta$). Calculate the slope of the resulting curve. Record the slope here, and don’t forget units!

3. Use your slope and dip needle angle to calculate the magnitude of the earth’s magnetic field here in the lab. Use Equation 3.

4. Compare (%) your experimental values of the earth’s magnetic field with the accepted values. Do this for the magnitude as well as the angle.
**Pre-Lab: Magnetic Field of the Earth**

<table>
<thead>
<tr>
<th>Name</th>
<th>Section</th>
</tr>
</thead>
</table>

1. Find an accepted value of the earth’s magnetic field at the location of the laboratory online (try Google™). Find magnitude and angle (Be sure to record this value in the lab somewhere also so that you can compare it to your experimental values).

2. The magnetic field of the earth can be thought of as arising from what being in the earth?

3. The needle of a traditional compass aligns itself with what?

4. A magnetic dip needle aligns with what?

5. Is it really necessary for the plane of the dip needle to be parallel to the horizontal component of the earth’s field? Why or why not?

6. A current of 0.50A runs through a coil consisting of 20 turns. The diameter of the coil is 7.0cm. What is the magnitude of the magnetic field at the center of the coil?