

# Physics 121 Lab 7: Finding the horizontal component of the magnetic field of the Earth

## Introduction

The Earth's magnetic field exhibits changes with time and is not uniform across the surface of the earth. It is not completely clear how the earth's magnetic field is produced. The most widely accepted view is that its origins are in the earth's core. The flow of the molten metals (mostly iron and nickel) generates electric currents that generate part of the earth's magnetic field. Additionally, the solar winds from the sun ionize the ionosphere and this adds to the magnetic field.

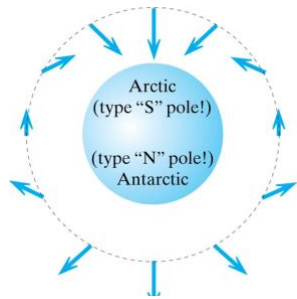


Figure 1. A very simplistic sketch of the geomagnetic field. (image from Matter & Interaction by Chabay and Sherwood.

A simple model of the field is presented on Figure 1. In Figure 1 the secondary field due the solar winds is not shown. The field, nonetheless, starts somewhere near the geographic south pole and ends near the geographic the north pole indicating that the geomagnetic poles are not exactly aligned with the geographic poles. The earth's magnetic field is, thus, nearly horizontal near the equator while it is nearly vertical near the poles. A compass placed on the surface of earth dips to align with the total field. In the northern hemisphere, the north-end of the compass directs downward at some inclination angle,  $\theta$  depending on its latitude. The magnetic field in the vicinity of your lab station comes mainly from the earth, but it is sometimes significantly modified by the presence of steel or magnetic materials in the building construction. In this lab you will measure the strength  $B_{\text{Earth}}$  of this field. The basic idea is to compare the unknown  $B_{\text{Earth}}$  with another magnetic field whose strength is known. Suppose that a known magnetic field  $\mathbf{B}$  is perpendicular to  $B_{\text{Earth}}$  as shown in Fig. 2. The two fields together produce a net field  $\mathbf{B}_{\text{net}}$  whose direction  $\theta$  relative to  $\mathbf{B}_{\text{Earth}}$  is given by

$$(1) \quad \tan \theta = \frac{B}{B_{\text{Earth}}}$$

If we know the strength of  $B$  and we can measure the angle  $\theta$  then the unknown  $B_{\text{Earth}}$  can be calculated. A compass needle at any location points in the direction of the net magnetic field, and can be used to measure  $\theta$ .

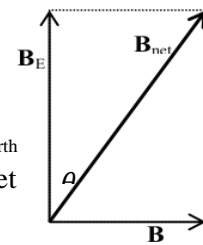


Fig. 2 Combining Magnetic Fields

In order to generate a known and controllable magnetic field  $\mathbf{B}$ , we will use a two circular coils of wire each with  $N$  turns, carrying current  $I$  and of radius  $R$ .

The magnetic field generated by such a current is shown in Fig. 3. At the center of the loop taken as the  $z$ -axis, the magnetic field has a magnitude given by

$$(2) \quad B_{\text{net},z} = \frac{8 m_0 N I}{\sqrt{125} R}$$

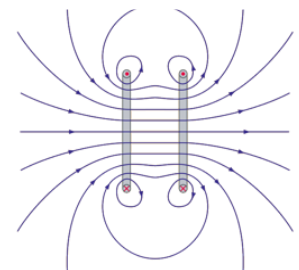


Fig. 3 Magnetic field of two circular coils of current.

where  $I$  is the current in the loop,  $R$  is the radius of the coils of wire, and  $N$  is the number of turns. The direction of the magnetic field at the center of the loop is perpendicular to the plane of the loop and follows the right hand rule.

## Preliminary

- a. Because the magnetic field at your lab station is mainly from the earth, you should expect that a compass needle points roughly north. Check that it does so. You may have to raise the compass a few inches above the surface of the table to avoid the effect of steel screws.
- b. Place the compass carefully at the center of the wire loop. A tiny gob of clay applied to the bottom of the compass will help hold it in place. Your instructor will describe how to align the wire loop and the compass. Note that the digital multi-meter is set to read current in mA. The 220 Ohm resistor in the circuit is intended to prevent the current from getting too large and burning out the fuse of the multi-meter. Try running a current through the circuit to see that the compass needle does indeed deflect.
- c. Now do things more carefully. Turn on the power supply and set the current so that the compass deflects through  $40^\circ$  and record the current. Do this as accurately as you can and then retry it from scratch. The difference between your two values for current is a measure of uncertainty. You should have a discussion with your lab partners about how best to measure angles accurately.
- d. Turn off the power supply and reverse the leads. Now repeat part c. Note that the compass deflects in the other direction. Are your currents different from those of part c? Defects in the manufacture of the compass can cause it to deflect differently in the two directions. This is also a source of uncertainty.
- e. You will be making several measurements of the kind that you just made. Here is a suitable method for handling measurement uncertainties. Take two measures of current on each side and find the average of the four measurements. Use the standard deviation of the mean (as calculated in Excel) to get the uncertainty in the current. [Your instructor can remind you how to calculate the standard deviation of the mean.] Make sure you write your final value for current with uncertainty in the correct format.
- f. Now that we know the current with uncertainty let's calculate the magnetic field generated by that current with uncertainty. Equation 2 above is the formula to use. But first, calculate the numerical value of the following constant

$$K = \frac{8m_o N}{\sqrt{125} R}$$

Knowing this constant, the magnetic field generated by the current loop can be calculated as  $B = KI$  and the uncertainty in  $B$  can be calculated as  $\Delta B = K\Delta I$ . Calculate those values and record them in the correct format.

- g. Now that we have a value for  $B$ , we can find  $B_{\text{Earth}}$  from a plot of  $B$  versus  $\tan \theta$  comparing with equation 1 and

$$\Delta B_{\text{Earth}} = \frac{\Delta B}{\tan \theta}$$

Calculate those values and record your measured value for the magnetic field of the earth with uncertainty in the correct format.

- i. One last thing, measure the distance between the centers of the coils and record this value on your data table somewhere.

#### Collect Data

For angles of 10, 20, 30, 40, 50 and 60 degrees collect the kind of data that you did for 40 degrees above. Equation 1 can be written as  $B = B_{Earth} \tan \theta$  so that a graph of  $B$  vs  $\tan \theta$  should give a straight line through the origin, and the slope of the graph should be  $B_{Earth}$ . Be sure you understand why! Considering all of your data record your value for  $B_{Earth}$  with uncertainty in the correct format. Print out your Excel results.