

# Measuring the magnetic field of the earth

## **Introduction**

Magnetic fields,  $B$ , can be produced by *moving* charges (such as currents) and in turn produce forces on moving charges. In this lab you will measure the magnetic field produced at the center of a coil of wire carrying a current and compare it to the earth's magnetic field.

## **Equipment**

Dip needle, compass, tangent galvanometer (coil), DC power supply, cables, ammeter (or use internal readout on Hewlett-Packard supplies).

**Note: steel lab tables and chairs will interfere with the Earth's field. If the lab benches are steel, this experiment must be conducted on the floor away from steel tables and chairs.**

## **Theory**

A magnetic moment is the source of the magnetic field. The simplest type of magnetic moment is the *magnetic dipole*: magnetic field lines go from the North pole to the South pole.

The Earth has a permanent magnetic moment. The geographic North Pole of the earth is actually its magnetic "south" pole since the north pole of a compass needle will point North.

Atoms can have small *magnetic moments* which produce small magnetic fields. These are due to both the intrinsic magnetism of the protons, neutrons and electrons and to the circulation of the electrons about the nucleus. In most cases the magnetic moments of the atoms are randomly aligned so that on average there is no net magnetic field for the material.

A permanent magnet is a material in which the atoms are aligned so as to produce a net magnetic field. A simple bar magnet typically has a North and South pole at its ends. Opposite poles attract each other, like poles repel.

A compass is generally a needle shaped permanent magnet mounted on a pivot so that it can rotate to show the direction of an external field. The North pole of the compass is often painted red and will point towards the Earth's North Pole (which is its south magnetic pole) since opposite poles attract.

Magnetic materials are materials that can produce an *induced* magnetic field in the presence of an external field because their atoms are able to realign the internal magnetic moments with the external field. An example is a *ferromagnetic* material such as iron or steel. Ferromagnetic materials are attracted to either pole of a permanent magnet because of their induced magnetic moment. Not all metals are ferromagnetic: Aluminum is not magnetic.

An electromagnet uses a current to create a magnetic field. The direction of the field is determined by the right-hand rule. For a current loop if the fingers of the right hand curl in the direction of the current the thumb will point in the direction of the magnetic field through the inside of the loop.

## **Procedure**

### **The Earth's magnetic field:**

Here you will use a "dip needle" to find the direction of the Earth's magnetic field and calculate its horizontal component. Instructions for the dip needle are found inside its box.

Take the dip needle to a position away from the steel lab tables, which will interfere with this measurement.

First align the protractor horizontally and find North. Note this position for future reference.

Align the dip needle so that the needle and its support are aligned along North. Then rotate the protractor to let the dip needle point downward. The Earth's field actually points downward into the Earth since the position of the magnetic North pole is downward. Record the downward angle that the dip needle makes with the horizontal direction.

Make a sketch of the dip needle and indicate the angle measured. Use the angle to find the *horizontal* component of the Earth's field. Use the value of  $5 \times 10^{-5}$  Tesla for the total Earth's field. This is a typical value the local conditions may vary or the building and steel furniture may distort the Earth's field.

### **The magnetic field produced at the center of a coil**

**WARNING:** TURN DOWN the power supply every time you connect or disconnect leads. DO NOT let the current exceed 5 Amps. (The Hewlett-Packard supplies are limited to 3 Amps)

Measure the radius of the wire in your coil. Set up the coil with the compass at the center of it so that the plane of the coil is aligned North. The compass needle should point North. Rotate the casing of the compass until the North label also points North.

DO NOT TURN ON THE POWER SUPPLY YET. If the power supply does not have an internal current read-out, place the ammeter on its highest setting (for example, 20 Amps). Connect the ammeters so that a lead goes from the + terminal of the power to the Ground or - input of the Ammeter and a second lead goes from the Amp terminal of the ammeter to one of the knobs on the coil --- the ammeter should be *between* the power supply and the coil so that it measures the current going towards the coil. MAKE SURE THAT THE AMMETER IS NOT CONNECTED DIRECTLY ACROSS THE POWER SUPPLY. Connect the other lead from a second knob on the coil (across the terminals marked 15 turns) to the ground on the power supply. If the power supply has a current indicator, you can simply connect it directly to the coil.

Turn up the power supply slowly to test your set-up, do not let the current exceed 5 Amps. As you change the number of turns (coils of wire) used re-test to make sure that you never exceed 5 Amps. (Note: if the current will not increase the supply may be set in a current limiting mode: ask your instructor for help).

Turn the current back down again. Now watch the compass needle as you *slowly* turn up the current (keeping it below 5 Amps). You may need to tap the compass to make sure the needle doesn't stick. Turn it up and down a few times and observe what happens.

TURN THE POWER SUPPLY DOWN and switch the leads. Turn the current slowly up to 3 to 5 Amps while observing the compass needle. What has happened? Make a sketch and record your observations in a section labeled **Observations**.

The direction of the magnetic field produced by the coil is perpendicular to the plane of the coil. Thus if the compass needle originally points North and the coil is aligned so that this is in the plane of the coil, you should observe that the compass needle rotates as the current-produced ***B*** (magnetic) field becomes stronger. When the needle has turned 45 degrees the current-produced ***B*** field ( $B_{\text{coil}}$ ) should be equal to the *horizontal* component of the Earth's field ( $B_{\text{earth}}$ ).

Carefully adjust the current until the compass needle points 45 degrees from North (this should be either NE or NW). Tap the compass if necessary to make sure it isn't sticking. Turn it up and down a few times to see how reproducible the current is. Make a note of the current used. **TURN THE POWER SUPPLY DOWN** and switch the leads --- how much current does it take to turn 45 degrees the other way? If the current for each direction is not (nearly) equal then your coil may not be aligned with North.

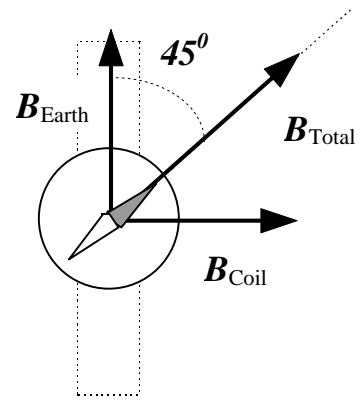
Once you are sure the plane of the coil is aligned with North, repeat your measurements for the current required to turn the needle 45 degrees 3 times for each direction of current. Turn the current down to zero between each trial and tap the compass to make sure it isn't sticking.

**TURN THE POWER SUPPLY DOWN** and switch the leads on the coil so you are using 10 turns of wire. **CHECK TO SEE HOW FAR YOU CAN TURN UP THE POWER SUPPLY WITHOUT EXCEEDING 5 AMPS.** (With fewer turns the resistance is less and so the current will be higher for the same voltage setting.)

Repeat your measurements for the current required to turn the needle 45 degrees each way. Make three measurements for each direction.

Repeat using 5 turns of wire.

Summarize your observations in your report.



**Figure 1: Current in the coil produces a magnetic field which deflects the compass needle.**

### **Analysis**

When the compass needle turns to 45 degrees the field produced by the coil should be equal to the *horizontal* component of the Earth's field.

#### **Preliminary Analysis. (Answer in your report)**

How reproducibly could you measure the currents required to turn the needle 45 degrees?

Average the currents measured for the different numbers of turns and for the two directions. Record in the table.

Is the magnetic field required to turn 45 degrees the same in each case? (What is the coil's field when the angle is  $\pm 45^\circ$  ?)

Calculate 1) the ratio of the current required for 15 turns to the current required for 5 turns and 2) the ratio of current required for 10 turns to current needed for 5 turns. Record in the table.

How does the current required compare to the number of turns?

Theoretically the magnetic field produced at the center of the coil should be

$$B = N \frac{\mu_0 I}{2R}$$

where N is the number of turns of wire in the coil, I is the current and R is the radius of the coil. The constant  $\mu_0$  is called the permeability of free space and is equal to

$$\mu_0 = 1.26 \times 10^{-6} \text{ Tesla} \cdot \text{meters} / \text{Amperes}$$

The standard units for magnetic field are Tesla. The direction of the magnetic field depends on the direction of the current. The right-hand rule is used: if the fingers curve in the direction that the current moves around the coil, the thumb points in the direction of the magnetic field.

**Further Analysis. (Answer in your report)**

If  $B$  is constant (and the radius is constant) how must the current,  $I$ , change as the number of turns in the coil changes?

Does this agree with your observations? If not exactly, is the trend right?

For each number of turns, use the average current for that number of turns to calculate the theoretical magnetic field produced at the center of the coil.

Compare to the expected value. Is the result within the accuracy with which you could reproducibly measure the currents? If not, discuss possible reasons.

Make two sketches of the coil showing the two directions for the current. Use the right-hand rule to predict the direction of the magnetic field in each case and indicate this on your sketch.

**Report**

Your report should include a cover page, Introduction, data and observations. Your introduction should include a sketch of your experimental set-up. You should write sections labeled Observations, Preliminary Analysis and Further Analysis answering the questions posed in each section. Answers must always be complete sentences which can be read independently of the handout. For your Conclusion summarize your results and discuss any random or systematic discrepancies in your data.

**The Earth's magnetic field:**

Sketch:

Calculation:

Total B of Earth very approximately =  $5 \times 10^{-5}$  Tesla  
(local  $B_{\text{Earth}}$  may vary)

Horizontal component of  $B_{\text{Earth}}$  = \_\_\_\_\_

**The magnetic field produced at the center of a coil**

Radius of coil = \_\_\_\_\_

Trial	Number Turns, N	Current - 45 degrees CW	Current - 45 degrees CCW	Average Current, I	Ratio of Measured Current to the Current Measured for 5 turns of wire	Theoretical $B_{\text{coil}}$ (Show calculation)
1	5				1.00	
2	5					
3	5					
1	10					
2	10					
3	10					
1	15					
2	15					
3	15					

Calculations: