Measuring the magnetic field of Earth (approx. 1.5 h) (11/10/15)

Introduction

Magnetic fields can be produced *by* moving charges (such as currents) and in turn produce forces *on* moving charges. In this lab you will estimate the strength of Earth's magnetic field by comparing it to the magnetic field produced at the center of a coil of wire carrying a measured current.

Equipment

- dip needle
- 2 banana-to-alligator cables
- dip needle instruction sheet
- tangent galvanometer
- HP power supply
- string to measure coil circumference
- compass
- meter stick
- level (non-magnetic)

Theory

Although the origin of Earth's magnetic field is not well understood, it is generally believed that it is due to electrical currents circulating in its molten iron core. The pattern of Earth's magnetic field is similar to that which would result from a bar magnet or *magnetic dipole* located at the center of Earth. The geographic North Pole of Earth is actually its magnetic "south" pole. Therefore, the north pole of a compass needle (which is itself a magnetic dipole) will point north.

Molecules, atoms and elementary particles, such as electrons, have small *magnetic moments* which produce weak, localized magnetic fields. These are due to the intrinsic magnetism of the protons, neutrons and electrons as well as the circulation of electrons. In most cases the magnetic moments of the atoms and molecules of a material are randomly aligned so that on average there is no net, macroscopic magnetic field from the material. A permanent magnet is a material in which the atoms and/or molecules are aligned so as to produce a net magnetic field. A simple bar magnet typically has a north pole at one end and a south pole at its other end (and so is a *magnetic dipole*). Opposite poles attract each other and 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 (usually red or white) and will point towards Earth's North Pole (i.e. 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 microscopic internal magnetic moments will align with the externally imposed magnetic 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 for example, is not magnetic.

An electromagnet uses an electric 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 around the loop, the thumb will point in the direction of the magnetic field inside of the loop.

Procedure

Direction of Earth's magnetic field:

First you will use a "dip needle" to find the direction of the Earth's magnetic field so you can later calculate its horizontal component. Make sure the dip needle is not being influenced by any nearby magnets, steel objects or current source which could interfere with this measurement. (You can do this by moving the dip needle closer to and farther from any suspected influences and observing.)

First, make sure the dip needle banana plug connector is fully inserted into the hole in the vertical black rod on the stand so it does not sag, then rotate the plastic scale to lie in a horizontal (i.e. level) plane. Your "dip needle" can now be used as a compass to determine which direction is north. Rotate the base of the apparatus to align the direction of the axis of the banana plug connector (i.e. 270° on the plastic scale) with the direction of the dip needle (i.e. magnetic north). Is this direction in reasonable agreement with what you believe to be "north"? (Discuss with other students.)

Next, while holding the base of the dip needle support stand in place, rotate the dip needle assembly about the axis of its banana plug connection until the plastic scale is in a vertical plane, so the needle can "dip" downward. Once the needle comes to rest, make a sketch of the dip needle (on last page). Read the angle of dip, measured from the horizontal (i.e. from 270°), and record it on your sketch. This angle is known as the "local inclination" or "magnetic dip angle". It should be about 70° in our region. If your dip angle is less than 60° or greater than 80°, you should consider carefully repeating the measurement, possibly at a different location. As you can see, the magnetic field of Earth actually points downward as well as north-south, indicating that the source of the field is located deep below the surface.

Magnetic field produced at the center of a coil

Measure the diameter (or circumference) of the wire coil on your tangent galvanometer, then calculate and record the radius (last page). Set a small compass on the center platform of the tangent galvanometer such that the north-south direction of the compass case is aligned *in the plane of the coil*. Rotate the tangent galvanometer until "N" on the compass case is in the same direction that the compass needle is pointing.

With the power supply off, connect the banana plug ends of your patch cords to the + and – terminals of your power supply. Then, while being careful not to change the orientation of your tangent galvanometer, connect the alligator clips across the 15-turn terminals.

Before turning your power supply on, turn the current adjust knob all the way down (i.e. counterclockwise), and turn voltage adjust knob all the way up. Turn the power supply on and slowly increase the current using the current adjust knob while watching the compass needle and the current display on the power supply. Turn the current up and down a few times and observe what happens.

Next, turn the current adjust all the way down again and switch the leads. Slowly increase the current to 2 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° the current-produced ***B*** field (B_{coil}) should be equal to the *horizontal* component of Earth's magnetic field (B_{earth}).

Carefully adjust the current until the compass needle points 45° from North (i.e. either NE or NW). (See Fig. 1) (If you suspect the compass is sticking tap it *lightly*.) Turn the current up and down a few times to see how reproducible the value of this 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 rotate the compass needle 45° the other way? (If the current for each direction is not (nearly) equal then your coil may not be aligned with magnetic 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° 3 times for each direction of current. Turn the current down to zero between each trial and make sure the compass isn't sticking.

Turn the power supply down again and connect the leads to the tangent galvanometer across the 10-turn terminals. Repeat your measurements for the current required to turn the needle 45° each way. Make three measurements for each direction.

Repeat using 5 turns of wire.

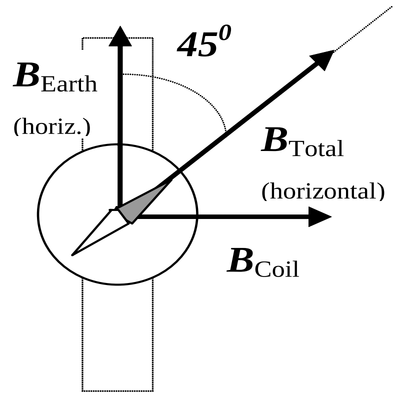

Figure 1: Current in the coil produces a magnetic field which deflects the compass needle (in horizontal plane).

Summarize your observations in your report.

Analysis

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

<u>Preliminary Analysis. (Answer in your report)</u>

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

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

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 these ratios 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:

$$B_{coil} = N\frac{\mu_0 I}{2R},$$

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 μ_0 is called the permeability of free space. Its value is:

$$\mu_0 = 1.26\times10^{-6}\ tesla\cdot meters/ampere.$$

The SI standard unit for magnetic fields is called the tesla (T). The direction of the magnetic field depends on the direction of the current and is determined using the right-hand rule.

Using the above expression calculate the average values of B at the center of the coil for each case (i.e. number of turns) and record them in the table as the theoretical values for B_{coil}.

Is the magnetic field required to rotate the compass 45° the about same in each case? Should it be?

What component of Earth's B field is the coil's field equal to when the angle is $\pm 45^0$?

Write an expression for this *component* of B_{Earth} and equate it to the average calculated value of B_{coil}: (hint: Use your measured dip angle.)

Solve for, calculate and record your estimated for B_{Earth}.

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?

Does your calculated value of B_{Earth} compare reasonably well with $5x10^{-5}$ T, the value listed for this area? If not, discuss possible reasons for the disagreement.

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 setup. 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.

Inclination (dip angle) of Earth's magnetic field:

Sketch of dip needle (in vertical plane): Dip angle = ___________

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_{coil} (Show calculations)
1	5					
2	5				1.00	
3	5					
1	10					
2	10					
3	10					
1	15					
2	15					
3	15					

Calculations:

Calculated value for B_{Earth} = ___________

The value for B_{Earth} in this area is roughly $5x10^{-5}$ T. How does your value compare?