Earth's Magnetic Field

Goal: To measure the Earth's local magnetic field and to investigate the magnetic field of a permanent magnet with a Hall sensor.

Lab Preparation

Earth's magnetic field can be resolved into separate horizontal and vertical component fields: $\vec{B}_e = \vec{B}_h + \vec{B}_v$. This experiment first measures the horizontal component, $\vec{B}_h$. The direction of $\vec{B}_h$ is towards magnetic north and determines the direction a compass points.

Measurement of $\vec{B}_h$ will be done by the deflection magnetometer method (sometimes called the tangent magnetometer method). A known magnetic field, $\vec{B}_{coil}$, is created between some coils and arranged to be horizontal and perpendicular to $\vec{B}_h$ as shown in Figure 1a.

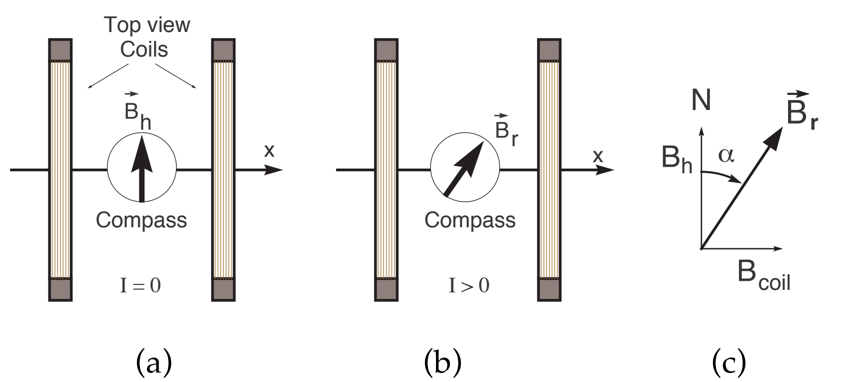


Figure 1

Let $\vec{B}_r$ (Figure 1b) be the resultant of the two horizontal fields $\vec{B}_h$ and $\vec{B}_{coil}$. Let α be the angle between this resultant field, $\vec{B}_r$, and the horitontal Earth's field, $\vec{B}_h$ as shown in Figure 1c. Then

$$\tan\alpha = \frac{B_{coil}}{B_h}.$$

When the current is off (so there is no $\vec{B}_r$), $\vec{B}_{coil}$ is zero so that $\alpha = 0$ and a magnetic compass indicates the direction of $\vec{B}_h$. When the current is on, a magnetic compass will indicate the direction of the net or resultant field $\vec{B}_r$, so that by knowing α and the magnitude $\vec{B}_{coil}$ one can calculate $\vec{B}_h$.

In the last part of the experiment the magnetic field of a standard bar magnetic will be measured. The Hall effect will be used to find this field. In the Hall effect, when an electric current is driven through a small piece of semiconductor in a magnetic field, a voltage appears perpendicular to the direction of current flow. This 'Hall voltage' is proportional to the magnetic field.

Equipment

Helmholtz coils are formed by a pair of identical coils with separation equal to their radius, Figure 2.

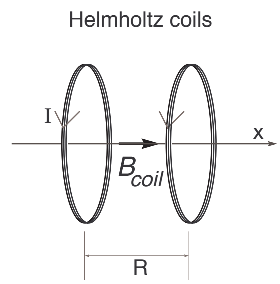


Figure 2

Helmholtz recognized that coils of this nature carrying a current I circulating in the same sense produced a magnetic field midway between the coils that is especially uniform. The field along the axis midway between the center of both coils is directed along the axis and has a magnitude

$$B_{\text{coil}} = \frac{8\mu_o N}{\sqrt{125}R} I = C_{\text{coil}} I.$$

where $\mu_o = 4\pi \text{ x } 10^{-7}$ Tm/A, R is the average radius of the turns of wire in each coil, N is the number of turns of each coil, and $C_{\text{coil}} = \frac{8\mu_o N}{\sqrt{125}R}$.

A Hall sensor probe is shown below in Figure 3. This probe will be used to measure the magnetic field of a bar magnet.

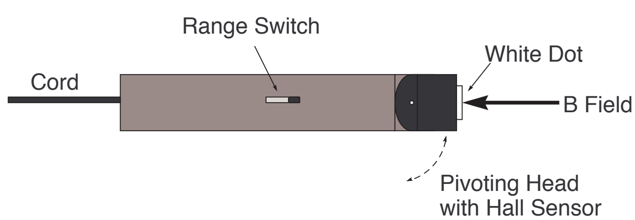


Figure 3

Procedure

I. Measuring the local horizontal component of the Earth's magnetic fields.

A. Determine the constant C_{coil} for your Helmholtz coils. The number of turns in one of the coils should be marked on the apparatus. The radius of coil is equal to the distance between the coils as shown in figure 2. To measure the radius make two different measurements - one from the outside to outside of the coil and one from the inside to the inside of the coil. Express the value of C_{coil} in units of mT/mA (note for example that 5 mT/mA is the same as 5 T/A but it is more convenient to write mT/mA since the current will be measured in milliamps).

B. Connect the circuit as shown below in Figure 4. Lay out the circuit so that the Helmholtz coils are not close to the power supply or current meter (use long leads, preferably twisted together, between the Helmholtz coils and the switch). The double-pole-double-throw (DPDT) switch is wired so the current in the Helmholtz coils can be reversed easily (note in the diagram that there is a wire that connects post 1 and post 4 as well as a wire that connects post 2 and post 3 that you need to put in). Set the decade resistance box to 3000 Ω. Do not yet apply any power to the circuit.

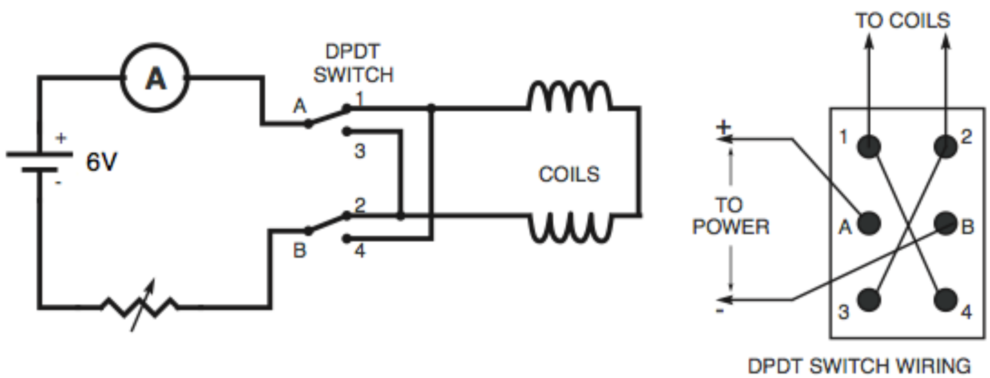


Figure 4

C. Place the magnetic compass on the post in the center of the Helmholtz coils. Align the coils so that the axis of the coils is perpendicular to the direction of the compass needle (placing a ruler on top of the compass as a sighting aid can help in this alignment). This will ensure that the magnetic field of the coil, $\vec{B}_{\text{coil}}$, is perpendicular to the horizontal component of the Earth's magnetic field, $\vec{B}_{\text{h}}$. **Have your lab instructor check your circuit.**

D. Turn on the current by closing the switch. Slowly reduce the resistance of the decade box, increasing current, until the compass has deflected to an angle, α, of 45°. Record the current in a table similar to the table below. Reverse the current direction by flipping the switch the other way and record the deflection angle in your table.

Repeat this process at two other values of current that give deflections of 30° and 60°. In each case record the current and the angle of deflection when the switch is flipped.

I (mA)	α_+	α_-	α_{av}	B_{coil} (mT)	B_h (T)
	45°				
	30°				
	60°				

E. Determine the average angle, α_{av}, the magnetic field produced by the coil, B_{coil}, and the horizontal component of the Earth's magnetic field, B_h. Ideally, the values for B_h listed in the last column should all be the same if the experiment were error-free. Find the average of your values of B_h. Take this average as your final result of the determination of B_h. Report your result in units of millitesla (mT). Typically B_h is ~.010 - 0.20 mT. Since the exact value is very sensitive to the presence of iron or steel in the vicinity, such as in the lab table and stools, the values can differ noticeably from table to table and even with position on any one table.

II. Measuring the Earth's vertical field component.

A dip needle can measure the direction that the Earth's magnetic field points below the horizontal (the magnetic inclination). Record the angle reading on the needle, θ.

III. Permanent magnet's field.

A. You will use a Hall sensor magnetic field probe to measure the magnetic field of a permanent magnet as a function of distance. Set up the probe, ruler, and permanent magnet on a block of wood as shown in Figure 5. The probes amplifier should be set to 6.4 mT.

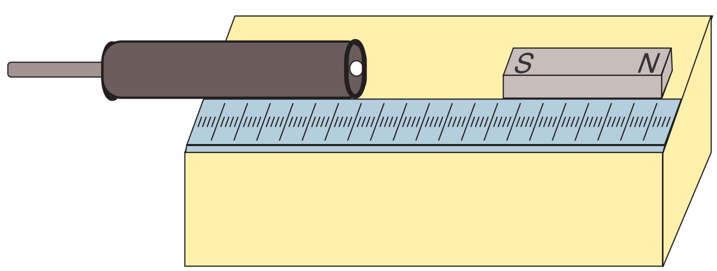


Figure 5

B. Open the "hall10" file. Remove the bar magnet far (at least one meter from the sensor) and zero the sensor (there is a "Zero" button next to the "Collect" button). This will automatically subtract any background magnetic field from subsequent readings.

C. Begin with the magnet's South pole $x = 250$ mm away from the sensor. You can slide the block and magnetic but try not to move the sensor. If need be, you can always zero the sensor again. Since the value of the magnetic field fluctuates you can "collect" data for 5 seconds and then find the mean (the average value) by using the "Statistics" button. Make a table for x and B values to record the values in the table.

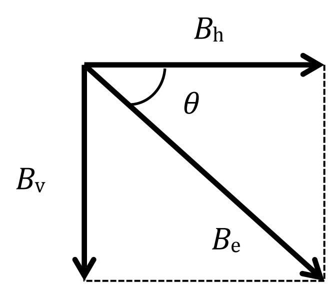
D. Continue to move the bar magnet closer in steps of 25 mm until $x = 100$ mm. Record the magnetic field at each position.

E. Use the "manual graph" file to plot a graph of B vs. x (magnetic field on the vertical axis. Print out a graph for your report.

*When finished with your lab clean up your lab station. Make sure you put all wires away.**

Homework

The horizontal component of the Earth's magnetic field, B_h, the magnetic inclination, θ, and the vertical component of the Earth's magnetic field, B_v, is shown in the diagram below. B_e, is the local magnetic field.



1. Both B_h and θ were measured during lab. Use these values to determine B_v.
2. Determine the magnitude of the local magnetic field, B_e.