Investigation of Magnetic Fields due to Current Loops (approx. 2.25 h) (4/11/2018)

Every electrical current has a magnetic field associated with it. Even the small electric currents in the human brain can be detected by the magnetic fields they generate. In this lab we will detect and measure magnetic fields due to bar magnets and to current loops.

Equipment

- Power Supply (2 amp output)
- 2 bar magnets
- 2 vertical rods with bench clamps
- Helmholtz coil
- meter stick
- compass
- banana plug leads
- magnetic field sensor
- small coil
- level (no mag.)
- masking tape
- Capstone Software
- alligator clips

Part I. Magnetic Fields around a bar magnet.

Equipment needed: two bar magnets, compass.

Investigation of Bar magnets: How do bar magnets compare to electric dipoles?

You should have two bar magnets, each with ends marked North and South. Have all members of your group study the behavior of the two magnets. Use a compass to investigate the shape of the field around the magnets (the compass needle will point in the direction of the field.

Part II. Magnetic field due to coils of wire (experiment)

You will use the magnetic field probe and the interface to measure the "z" dependence of the magnetic field along the (z) axis of a 200-turn coil. The magnetic field probe uses the "Hall Effect", which is described in your book.

You will use the equation for the magnetic field produced along the axis of a coil:

$$B(z) = N\frac{\mu_0}{2}\frac{IR^2}{\left(R^2 + z^2\right)^{3/2}}$$

(Equation 1)

where N is the number of turns in the coil, I is the current, R is the radius and z is the distance along the axis of the coil, and $\mu_o = 4\pi \times 10^{-7}$ Tm/A. The derivation of this formula is sketched out in the Appendix.

Set up the meter stick along the axis of the 200-turn coil, supported on each side of the coil by clamps attached to vertical rods as shown in the following photo

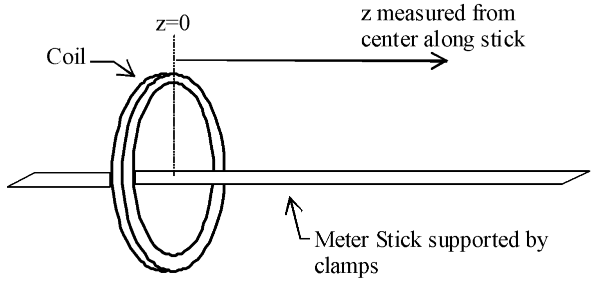
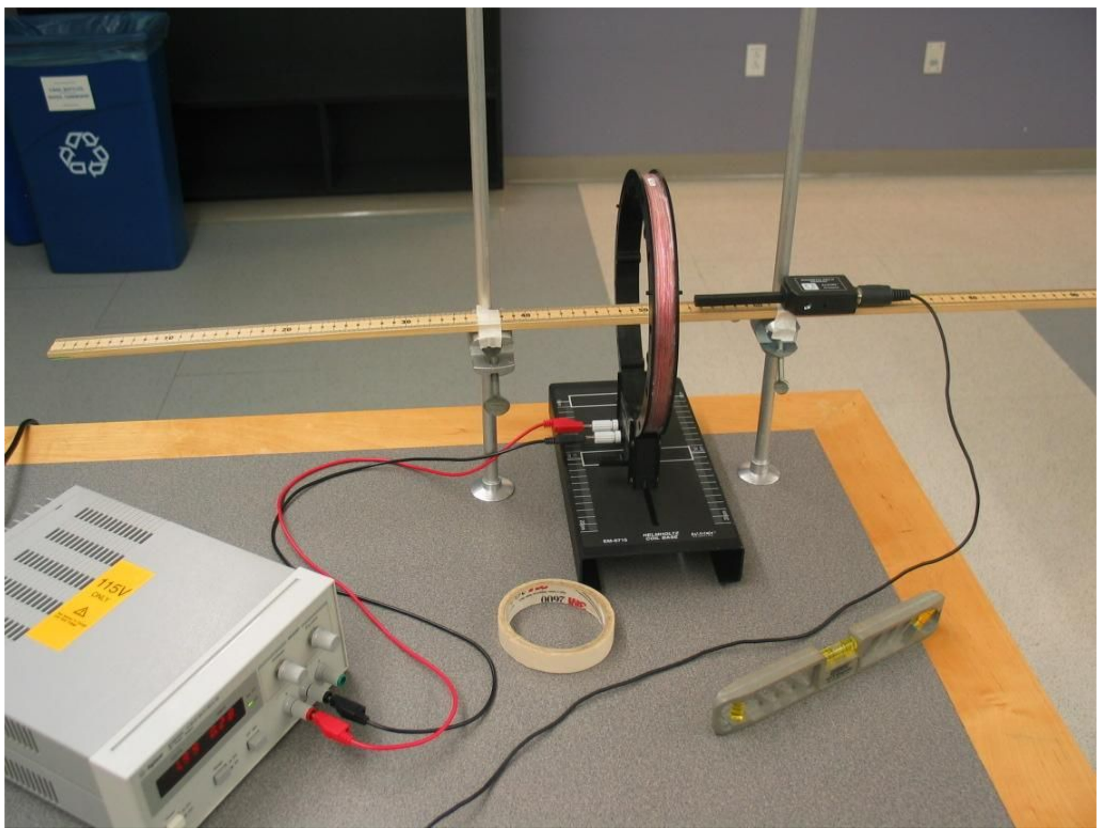


Figure 1: B(z) is measured along the axis of the coil



If you set the magnetic field probe on the meter stick as shown in the photo, you will need to position the meter stick somewhat below the axis of the coil to account for the fact that the tip of the probe will be higher than the surface of the meter stick. (The inside radius of the coil frame shown is 9.8 cm.) Adjust the heights of the clamps until the meter stick is properly positioned and level. Make sure the plane of the coil is perpendicular to the meter stick. Use masking tape to hold the meter stick in the correct position during measurements. You will move the probe along the axis of the coil, measuring the magnetic field as a function of z along this axis, taking data every 2 cm.

Safety Note: If your coil or any part of your apparatus becomes hot or has a burning smell, turn of the current immediately and contact your instructor.

Computer/Interface/Probe Instructions

550 PASCO Capstone 2-Axis Magnetometer Download (Click or type)
https://tinyurl.com/ybpycqqz
850 PASCO Capstone 2-Axis Magnetometer Download (Click or type)
https://tinyurl.com/y8pmhoda

Make sure the PASCO interface is on and connected to the computer, then open Capstone on the desktop and select Create Experiment. Then, under Sensors, click on Magnetic Field Sensor. Align and connect your magnetic field sensor to the blue PASPort. Set your magnetic field sensor Radial/Axial setting to Axial and the units for measurement to Gauss. You can change the Radial/Axial Settings or the units of measure by clicking on the variables on any Capstone display.

Procedure for measuring the magnetic field, B.

Place the tip of your magnetic field sensor at the center of the coil (i.e. z=0). Remove any possible sources of magnetic fields, such as magnets or current-carrying wires, well away from the sensor. Turn your power supply OFF. When you are reasonably certain your sensor is not exposed to any significant magnetic field, push the Tare button on your sensor. This will zero your sensor, establishing a baseline for your measurements. Turn the power source on and set the current to 2 amps. Turn it back off. Click on Start to begin taking baseline (i.e. nominally zero) data. Turn your power supply back on and continue taking data for a few seconds. Turn the power supply back off to record more baseline data on your graph. Click on Stop when finished.

If the pre- and post measurement baseline data are not negligible, average them and subtract it from your average B measurement. Determine the value of B for using this procedure for each measurement location (i.e. 2 cm intervals along the axis), until B is less than 10% of its maximum value.

Data collection and analysis

Make a table and record the true value for B(z) for each value of z (distance from the center). ***Be sure to obtain a good value for B(0) at z=0 in the center of the coil.***
For each data point calculate the ratio B(z) to B(0), where B(0) is the value at the center of the ring.

Magnetic Field as a function of z

Make a sketch of your experimental setup, showing how z is defined. Your sketch should show how "z" is defined. Submit your data table and a plot of B(z)/B(0) versus z. From the formula given (Equation 1) show that $\frac{B(z)}{B(0)} = \frac{1}{\left(1+\left(\frac{z}{R}\right)^2\right)^{3/2}}$. Plot this function and compare to your experimental results.

NOTE: Average Radius of Large Coil is: R = 10.5 cm.

Data Table

	Data	Experimental	Theoretical
z (cm)	B(z)	B(z)/B(0)	B(z)/B(0)
0		1.00	1.00

Part III: Small coils

Set up a simple circuit to supply current to the small coil of wire. (You may need banana plug-to-alligator clip leads for this.) (Note: If you choose to insert the probe via the access port between the coils you will need to change the probe setting from Axial to Radial.)

<u>Small Coil</u>

Measure and record the field at the center of the small coil for a current of 2 Amps. Sketch the circuit and the coils, record their dimensions, separation and radii. Use Equation 1 and the dimensions you've measured to make a calculation for the field at the center of the coil. Compare to your measurement.

<u>Field as a function of current</u>

Measure the magnetic field at currents ranging from 0 A to 3 A in increments of 0.5 A. Plot B field versus current and determine the slope of the plot. Compare to the expected value for the slope.

Appendix: Magnetic Field of a Coil

Figure 2: Magnetic field due to a small piece of a circular current loop.

The magnetic field produced at a given point in space by a small piece of current of length ds is given by

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{s} \times \vec{r}}{r^3}$$

where I is the current, the vector points in the direction of the current, is the vector pointing from the piece of current to the point in space, and μ_o is a constant given by $\mu_o = 4\pi \text{ X } 10^{-7}$ T□m/A.

Note that because of the cross-product the direction of the vector is perpendicular to both the direction of the current and the vector . In this section you will derive the magnetic field produced by a circular loop of current at a point along the axis running through the center of the loop.

Figure 2 shows the magnetic field due to one piece of the circular current loop at a distance z along the axis through the center of the loop. We consider the piece of current going directly into the paper.

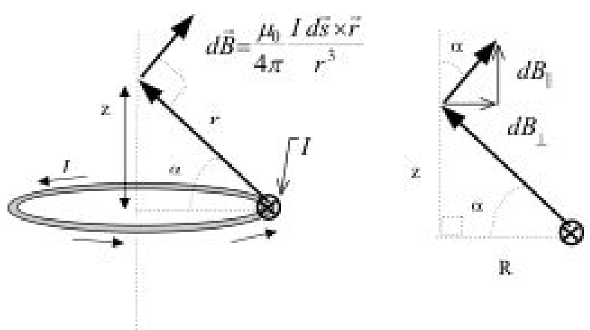


Figure 2: Magnetic field due to a small piece of a circular current loop.

If the radius of the loop is R, find the distance r in terms of R and z.

Find the cosine and sine of the angle, α, in terms of R and z.

Consider the cross product *ds x r* . For the piece indicated the current points into the paper and so does the direction of *ds*. Since *ds* and *r* are perpendicular to each other, show that the magnitude of the magnetic field can be written as

$$|dB| = \frac{\mu_0}{4\pi}\frac{Ids}{r^2}$$

Now let be broken into two components, $dB_{parallel}$ and $dB_{perpendicular}$, as shown. Show that because is perpendicular to these components are given by

$$dB_{parallel} = dB\cos\alpha \text{ and } dB_{perpendicular} = dB\sin\alpha$$

(*Hint: consider which angles add to 90 degrees or to 180 degrees.)*

Now consider what happens when we add up the magnetic field due to all the pieces of current around the whole loop. Imagine taking the piece shown in the figure and letting it rotate around 360 degrees to account for all the current in the loop. Which component of the magnetic field ($dB_{parallel}$ or $dB_{perpendicular}$) will add? Which component will cancel?

Since one component cancels we only have to integrate one of the two components to find the total magnetic field due to the loop. Use your results (cosα or sinα and r in terms of z and R) to show that the magnetic field can be written as

$$B = \int dB_{\parallel \text{ or } \perp} = \frac{\mu_0}{4\pi}\frac{IR}{\left(R^2+z^2\right)^{3/2}}\int ds = \frac{\mu_0}{4\pi}\frac{IR}{\left(R^2+z^2\right)^{3/2}}\cdot 2\pi R = \frac{\mu_0}{2}\frac{IR^2}{\left(R^2+z^2\right)^{3/2}}$$

where the integral over all the pieces d*s* gives the total circumference of the loop.