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Magnetism II ~~Lab Title~~

Name: Bill Bair

PES 215 Report

Lab Station:

Objective

The purpose of this lab was to determine what a magnetic field in a wire looks like, and to understand how the shape of the magnetic field is determined by the current that creates that magnetic field. We were to also determine the value of μ_0, the permeability of free-space, and to determine the relationship between the magnetic field and the current in solenoid.

Data and Calculations

Part A – Magnetic Field Mapping:

For this part of the lab, we set up the following circuit:

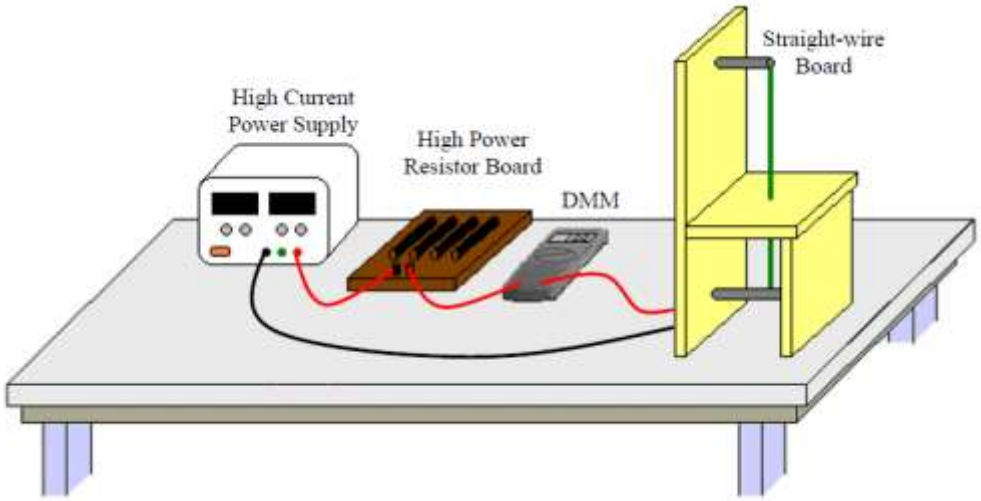

Figure 1: Setup for Part A of Magnetism II Lab

We used the provided graph paper and put it on the straight-wire board so we could effectively map out the magnetic field generated by the current through the wire. Using a compass and the graph paper, we plotted the direction of the magnetic field at every intersection of the solid black lines on the graph paper around the vertical wire.

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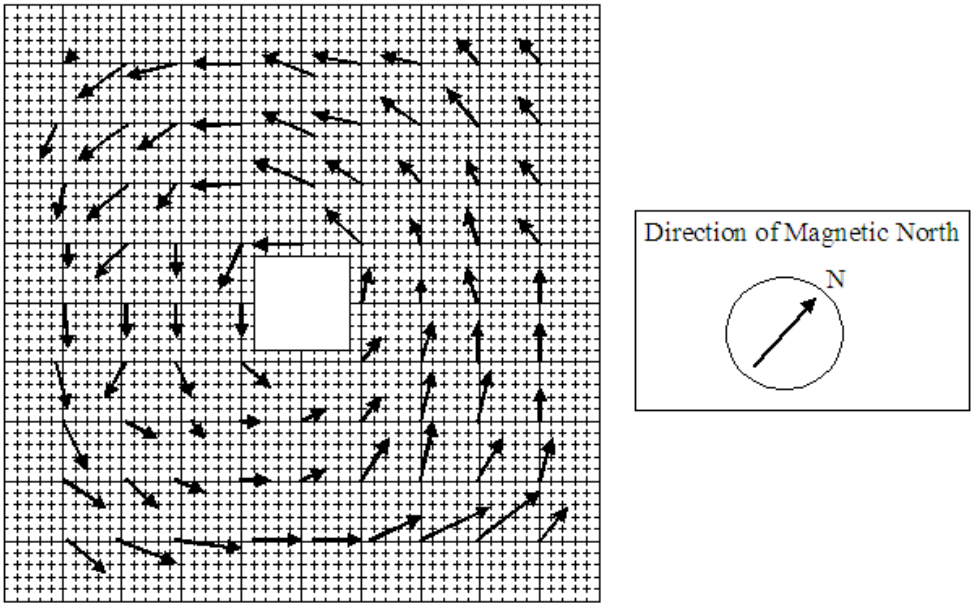

Figure 2: Magnetic Field Map using a Current of 5.0 A

1. Discuss the shape of your field map. How does the field of the long straight wire relate to the current that caused it? Does the long straight wire have a north and south pole like a bar magnet does?

From examining the field map of the magnetic field, we can see that the field is circling around the wire in a counter-clockwise direction. This follows the right hand rule (as seen below):

Figure 3: Right Hand Rule for the Generated Field

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There is no distinct "North" or "South" poles in this field (as it is curling around the wire).

2. For the long straight wire, which way was the current flowing? How do you know from looking at your graph paper? Does your plot for the long straight wire demonstrate the shape of the field predicted in Prelab 1?

It's obvious from the right hand rule that the current was flowing up through the apparatus. Again, this is obvious from the right hand rule. This is exactly what was predicted in the pre-lab.

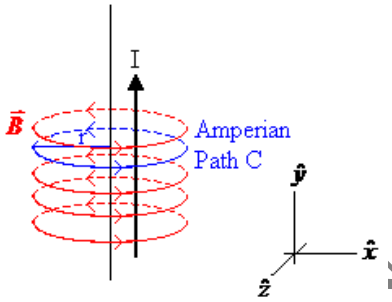

Figure 4: Predicted Field from Pre-Lab Question 1

Likewise, we calculated the magnetic field should be:

$$\vec{B} = \frac{\mu_o I}{2\pi r}\hat{\theta}$$

Just from this equation alone, we see the direction of the predicted magnetic field should be in the counter-clockwise position (as we saw).

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Part B – Magnetic Field of a Solenoid, Qualitative:

For this part of the lab, we set up the following circuit:

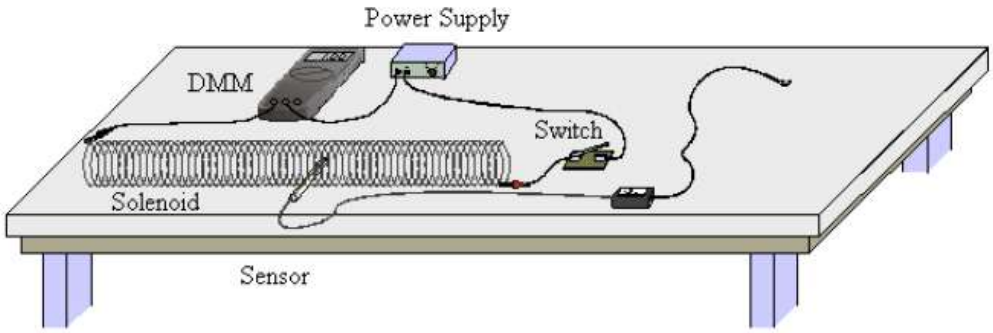

Figure 5: Setup for Part B of Magnetism II Lab

First, we inserted the magnetic field sensor near the center of the solenoid. We rotated the sensor until we got the largest positive number reading on the sensor. This gave us the direction and the magnitude of the field created by the solenoid. We then rotated the sensor until we got the largest negative number reading on the sensor. We noted that this was in the opposite direction of the generated field. Finally, we rotated the sensor to be perpendicular to the field (both up and down) and noted the magnitude of the field in this configuration, as well. The following table summarizes the results we found:

Direction the sensor was pointing	**Magnitude of the field**
To the Right ($+\hat{x}$)	0.2050 *mT*
To the Left ($-\hat{x}$)	-0.2050 *mT*
Toward the Ceiling ($+\hat{y}$)	0 *mT*
Toward the Floor ($-\hat{y}$)	0 *mT*

Next, we measured the magnetic field strength at various intervals down the solenoid. This was done with always orienting the sensor to the right (i.e., in the $+\hat{x}$ direction). The following table summarizes the results we found:

Distance (m)	**Magnetic Field (mT)**
0.00	0.1423

0.10	0.2190
0.20	0.230
0.30	0.2231
0.40	0.2224
0.50	0.2144
0.60	0.2280
0.70	0.2284
0.80	0.2232
0.90	0.2098
0.96	0.1245

Finally, we measured the magnetic field strength outside the solenoid and across the cross-sectional inside the solenoid. Again, the sensor was rotated to find the maximum field strength, and the direction was noted. The following table summarizes the results we found:

Direction the sensor was pointing	**Magnitude of the field**
Outside the Solenoid to the Left ($-\hat{x}$)	0.1000 *mT*
Across the cross-section of the Solenoid ($+\hat{z}$)	0.007 *mT*

From examining the sensor readings of the magnetic field, we can see that the field is running down the solenoid in the right direction. This follows the right hand rule (as seen below):

Figure 6: Right Hand Rule for the Generated Field

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1. Discuss the observations you made concerning the solenoid? How does the magnetic field behave both inside and outside the solenoid? Does this match what you discovered in Prelab 2?

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It's obvious from the right hand rule that the current was flowing out and then in through the solenoid apparatus; and the generated field ran down through the center of the solenoid. This is exactly what was predicted in the pre-lab.

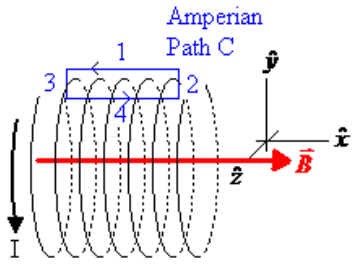

Figure 7: Predicted Field from Pre-Lab Question 2

Likewise, if we compare the various calculated results of the pre-lab with what we observed, we can see that we were basically measuring the field and direction along the amperian path we defined in the pre-lab. While we were doing that problem, we noticed that we needed to consider each of the 4 integrals separately:

$$\oint_C \vec{B} \bullet d\vec{\ell}_1 = B\ell_1 \cos(\theta)(\hat{x} \bullet -\hat{x}) = 0\,\ell_1 \cos(180^o)(-1) = 0$$

Hence, this is why we measured 0 *mT* when the sensor was outside of the solenoid.

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$$\oint_C \vec{B} \bullet d\vec{\ell}_2 = B\ell_2 \cos(\theta)(\hat{x} \bullet \hat{y}) = B\ell_2 \cos(90^o)(0) = B\ell_2(0)(0) = 0$$

Hence, this is why we measured 0 *mT* when the sensor was pointing toward the ceiling in the solenoid.

$$\oint_C \vec{B} \bullet d\vec{\ell}_3 = B\ell_3 \cos(\theta)(\hat{x} \bullet -\hat{y}) = B\ell_3 \cos(270^o)(0) = B\ell_3(0)(0) = 0$$

Hence, this is why we measured 0 *mT* when the sensor was pointing toward the floor in the solenoid.

$$\oint_C \vec{B} \bullet d\vec{\ell}_4 = B\ell_4 \cos(\theta)(\hat{x} \bullet \hat{x}) = B\ell_4 \cos(0^o)(1) = B\ell_4(1)(1) = B\ell_4$$

We also need the integral for the cross-section:

$$\oint_C \vec{B} \bullet d\hat{z} = B\cos(\theta)(\hat{z} \bullet \hat{x}) = B\cos(90^o)(0) = 0$$

Hence, this is why we measured 0 *mT* when the sensor was pointing across the cross-section of the solenoid.

Likewise, from the pre-lab, we calculated the magnetic field should be:

$$\vec{B} = \mu_o nI\ \hat{x}$$

Just from this equation alone, we see the direction of the predicted magnetic field should be in the right direction (as we saw).

Part C – Magnetic Field of a Solenoid, Quantitative:

For this part of the lab, we used the same setup that was used for part B. However, instead of measuring the magnetic field at various distances with the same current – we instead measured the magnetic field at the same location with alternating currents. The following table summarizes the results measured:

Current Through the Solenoid (A)	Magnetic Field Strength (mT)
0.50	0.0626
1.00	0.1381
1.50	0.1736
2.00	0.2339

In order to perform the analysis of theoretical and experimental values for the equation

$$\vec{B} = \mu_o n I \ \hat{x}$$

we also need the following information:

Length of the Solenoid (L) [m]	0.97
Number of Turns (N) [AU]	86
Number of Turns per Meter ($n=N/L$) [1/m]	88.66

1. Plot a graph of magnetic field B vs, the current I through the solenoid. You can do this by hand or with computer software like Excel.

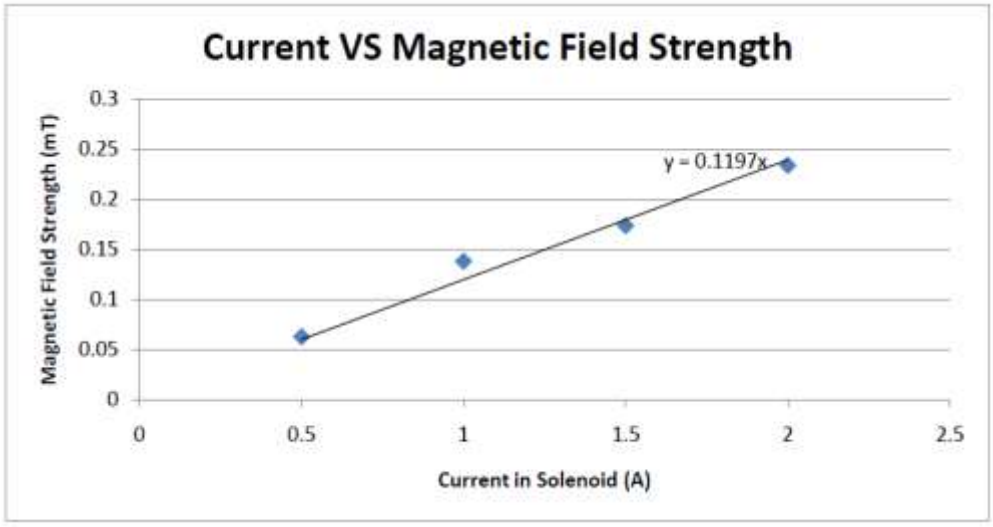

Figure 8: Current versus Magnetic Field Strength

2. How is magnetic field related to the current through the solenoid?

It is obvious that as the current is increased, the magnetic field strength also increases. This would indicate that they are directly related. This is also re-enforced by looking at the equation we derived in the pre-lab:

$$\vec{B} = \mu_o nI\ \hat{x}$$

We can see that this also supports the fact that current and magnetic field strength are directly related since everything else is constant.

3. Find the best-fit line, including the y-intercept. If you are using Excel -> 'Add Trendline' feature will determine the equation of the best-fit line. Note the constants and their units. When you are in the 'Add Trendline' dialog box in Excel, click the 'Options' tab. Then, be sure to select the 'Set Intercept = 0' box. This will allow Excel to calculate a slope more appropriate to this experiment.

We found the best fit line of the graph to be:

$$y = 0.1197x + 0$$

4. From Ampere's law, it was shown in Prelab 2 that the magnetic field B inside a long solenoid is:

$$\vec{B} = \mu_o nI\ \hat{x}$$

~~$nIB\mu =$~~

where μ_0 is the permeability constant. Do your results agree with this equation? Explain.

Our results agree very well with the equation we derived from the pre-lab. We see that the derived equation showed the magnetic field should be pointing to the right, which we observed; and it should be directly proportional to the current through the solenoid.

5. From the slope of your graph, find your experimentally determined value of μ_0. Look up the value of μ_0, the permeability constant. Compare it to your experimental value.

Solving the equation from the prelab for the permeability constant, we get:

$$\mu_o = \frac{B}{nI}$$

The slope of the best fit line above is simply the magnetic field strength divided by the current. So, if we use the number of turns per meter that we recorded in the table above, we can divide the slope by that value to determine the permeability of free space.

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$$\mu_o = \frac{0.1197\,x10^{-3}\,\frac{T}{A}}{88.66\,\frac{1}{m}} = 1.3501\,x10^{-6}\,\frac{T\,m}{A}$$

6. Was your solenoid positioned along an east-west, north-south, or on some other axis? Will this have any effect on your readings?

The solenoid was positioned along an east-west axis. This was just due to the table setup in the lab. After some hindsight, it is realized that this was fortunate, since we then had the magnetic field due to the Earth and the changing field due to the rotation from night-to-day minimized (since they were cross-sectionally aligned).

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Conclusion

You write the details. ← Include your answer here. Use complete sentences!!!!

** NOTE: There are several components of error which could significantly modify the results of this experiment. Some of these are listed below:

- Heat
- Age
- Humidity
- Short circuit
- Fuse
- Bad power supply (recall we used the DMM to attempt to alleviate this problem.)
- Bad connections (in protoboard)
- Insulation
- Length of wire and Gauge accuracy of wire (copper)
- Bad power supply (recall we used the DMM to attempt to alleviate this problem.)
- Buckling, bending, etc… of wire
- Elemental components/material makeup of the wire
- Earth's magnetic field
- The rotation of the Earth and the "squishing" of the magnetic field due to the Sun
- ??

It is recommended that you take these and explain the "***why"*** part of each for your results and conclusions sections – and possibly what could have been done (if anything) to minimize the effects of these errors.

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