**PHY 112L Activity 5**

**Magnetic Fields**

Name: ______________________________ ID #: ______________________________

Section: ______________________________ Date: ______________________________

Lab Partners: ______________________________ TA initials: ________

**Objectives**

1. Introduce magnetic fields and the “right-hand rule”
2. Experimentally determine the relationship between distance and magnetic field strength
3. Investigate and experimentally verify the magnetic field inside of a solenoid (lab report)

**Materials & Resources**

1. Computer with DataStudio, multimeter, and magnetic field sensor
2. Bar magnet and solenoid

**Introduction**

Magnetic fields are, in most respects, very similar to the electric fields seen in previous labs. They have potentials associated with them and attract and repel each other in almost the same way as electric fields, which can easily be verified with a simple bar magnet. The principle difference between electric and magnetic fields is the way they are created.

Electric fields are created with positive and negative charges, as discussed in previous labs, and magnetic fields are created between N- and S-poles. However, unlike electric charges, which can stand alone as a positive or negative charge and become “neutral” when brought close enough together, the N and S magnetic poles always exist as a pair (no magnetic monopoles!). As such it is impossible to find a positive or negative magnetic “charge.” This relies on the fact that fundamentally magnetic fields are created by the motion of electric charges or current as in the figures to the right.

The SI unit of magnetic field is tesla (T). Another common unit is called gauss (G), where 1 T = 10,000 G. As mentioned above, magnetic fields are created by electric currents. The properties of the magnetic field depend on the properties of the electric current that created it. These properties include things like strength, direction, and spatial configuration (or shapes and distances).

The direction of the magnetic field created by a current depends on the direction of the current flow that creates it; they are related by an easy to remember rule known as the “right-hand rule.” This rule states that if you hold your right hand thumb in the direction of the current, then the direction your fingers curl is the same direction as the magnetic field, as illustrated in Figure 1 and Figure 2 to the right. Ask your TA to explain this if it is unclear.

For example, if you apply a current to a solenoid, which is a long cylindrical coil that is tightly wrapped with a current carrying wire, the magnetic field created inside the solenoid will be:

$$B = \mu_0 n I$$

where $\mu_0 = 4\pi \times 10^{-7}$ Tm/A, $n$ is the number of turns per unit length $N/L$, and $I$ is the current flowing through the solenoid, as shown in Figure 3.
1. Distance and Magnetic Field Strength

Procedure:

1) Set up the experiment as shown in Figure 4. Place the bar magnet so that the north end is precisely even with the 50 cm mark on the meter stick, and parallel with it.

2) Start DataStudio, select a magnetic field sensor for the appropriate analog input port, and verify that it is set to the “1X” setting in DataStudio. Then verify that the sensor’s scale switch is set to 1X, and that it is set to Axial mode.

3) Open a graph of magnetic field strength (1X) vs. time from the Displays menu, and then position the tip of the sensor exactly 10 cm from the north end of the bar magnet.

4) Click “Start” in DataStudio, and then press the “Tare” button on the sensor. Verify that your reading on the graph goes to zero. Hold the sensor still for about 5 seconds parallel to the meter stick, and then move the sensor exactly 1 cm closer to the bar magnet.

5) Repeat this process, holding the sensor still and parallel to the meter stick, until you are only 1 cm from the end of the magnet. Click “Stop” in DataStudio; your graph should look “like steps” now. Adjust the completed graph so that it is clearly visible and fills the entire window.

6) In the “Σ” menu on the graph, uncheck “mean,” and then recheck it again. This should bring up a box with values for “max,” “min,” and “mean” on the graph. Now, highlight the physically meaningful data for each “step” on the graph and record the “mean” value next to the corresponding distance in the table below. Hint: the slope of the line that appears when you are highlighting the “step” data should be zero, or the line should be flat, for good data. Print this graph with one of the “steps” highlighted and the data box showing the values for that sample of data.

<table>
<thead>
<tr>
<th>Distance from Bar Magnet (cm)</th>
<th>Magnetic Field Strength (gauss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 cm</td>
<td></td>
</tr>
<tr>
<td>9 cm</td>
<td></td>
</tr>
<tr>
<td>8 cm</td>
<td></td>
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<tr>
<td>7 cm</td>
<td></td>
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<tr>
<td>6 cm</td>
<td></td>
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<tr>
<td>5 cm</td>
<td></td>
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<tr>
<td>4 cm</td>
<td></td>
</tr>
<tr>
<td>3 cm</td>
<td></td>
</tr>
<tr>
<td>2 cm</td>
<td></td>
</tr>
<tr>
<td>1 cm</td>
<td></td>
</tr>
</tbody>
</table>

7) Select a “New Activity” from the “File” menu; do not save the old activity when asked. Choose “Enter Data” and then enter your values for distance $d$ in the “X” column, and your measured values for magnetic field strength $B$ in the “Y” column. Adjust the graph so that the data is clearly visible and fills the graph window, highlight all of the data points that appear and select “Inverse Fit” from the “Fit” menu. Print this graph with the “Inverse Fit” included.

Questions:

1) How closely does your “Fit” curve resemble your measured data for magnetic field vs. distance?

2) What can be said about the mathematical relationship between the field strength $B$ and distance $d$ based on this fit?
2. Solenoids and the Right Hand Rule (Lab Report)

Procedure:

1) Connect the solenoid, multimeter, and Pasco interface as shown in Figure 5. Set the multimeter to measure a DC current that is less than 300 mA.

2) In DataStudio, click on the output channel, select “DC Voltage,” set the voltage to 5V, and click “Auto.”

3) Place the tip of the magnetic field sensor as close to the center of the solenoid as possible, click “Start,” push the “tare” button on the sensor and verify that the reading goes to zero, then click “On” to initiate the flow of current, and so the magnetic field, inside the solenoid.

4) Note the sign of the magnetic field measurement. A positive value indicates that the magnetic field is pointing into the tip of the sensor; a negative value indicates the field is pointing away from tip. Using the right hand rule, determine the direction of the current through the coil.

5) Also note the sign of the current reading on the multimeter, which indicates the direction of current. Conventionally, current is said to flow from the positive terminal to the negative terminal. Is this consistent with your measurement?

6) Click “Off,” reverse the voltage leads coming out of the Pasco interface, then click “On” again. This change reverses the direction of the current through the solenoid so that it is now opposite the measurement from Step 4. Use the right hand rule with the new direction for current to find the direction of the magnetic field. Is this consistent with the sign of your magnetic field measurement?

8) Record your values for $B_E$ (gauss) and $I$ (mA) in the table below while the voltage is set to 5V, and then change the voltage to 4V by clicking the “–” button. Repeat this for each voltage listed in the table, then click “Off” and “Stop.”

9) Convert your measured values for $B_E$ and $I$ into SI units and enter your results into the table below.

10) Select a “New Activity” from the “File” menu; do not save the old activity when asked. Choose “Enter Data,” enter your converted values for current $I$ in the “X” column, and then your converted values for magnetic field strength $B$ in the “Y” column.

11) Adjust the graph so that the data is clearly visible and fills the graph window, highlight all of the data points that appear on the graph and select “Linear Fit” from the “Fit” menu. Print this graph with the “Linear Fit” included and record the slope $m$ below.

\[
Slope \ (m) = \frac{B}{I} = \mu_0 n = \text{______________} \quad (\quad) \\
L = \text{______________} \pm \text{______________} \quad (\quad)
\]

12) Measure the length of the solenoid $L$ with the meter stick and record your result in the space above, then calculate the total number of turns $N_E$ in your solenoid. Show all of your work below.

\[
N_E = \text{______________} \quad (\quad)
\]

Questions:

1) Calculate the % error for the total number of turns if $N_A = 1340$ turns. % error: ____________ %

2) Did you calculate more or less (circle one) turns than the accepted value?

3) List all sources of error in this experiment that are physically consistent with your actual results below.