B5a: Magnetic Force & Fields

Introduction:

It is impossible to picture our modern life without a number of household appliances: microwaves, refrigerators, air conditioners, etc. You might be surprised to find out that in the heart of operation of most of them lies physics phenomena associated with the magnetic fields and the magnetic forces. Magnetic fields and magnetic forces play an important role in the operation of electro generators and transformers, without which production of electricity and a large-scale power grid would not be possible, eliminating many modern conveniences. They are also at the basis operation for MRI machines - instruments that drastically changed medical diagnostics.

Magnetic phenomena are numerous and complex, but all of them have the same fundamental nature: interaction between moving charged particles. In this experiment, you will explore one of the basic interactions: magnetic force acting on a current carrying wire due to the magnetic field of a permanent magnet. The focus will be on the magnetic force experienced by the current carrying wire. Then this information will be used to determine the magnetic field of the external magnet.

A single wire loop is positioned in the gap between two plates that are a part of an external permanent magnet. As current is applied to the wire the net force on the wire will move it from its original zero position. As the current through the wire is changed the wire's displacement correspondingly changes. The data that is collected will be analyzed to determine the magnetic force for each current measurement. Subsequently this data is graphed and statistically analyzed to determine the magnitude of the external magnet's field.

Finally, to obtain additional information about the external magnet, a magnetic field sensor will be used to determine both magnitude and direction of the field. Additionally, the sensor's measurement between the magnet's plates can be compared to the field calculated from the graph.

Apparatus:

- variable gap magnet
- power supply (10 amp)
- magnetic field sensor (with computer)
- digital multimeter (contained within power supply)
- wire loop with non-conducting mount
- support stands
- hook-up wire

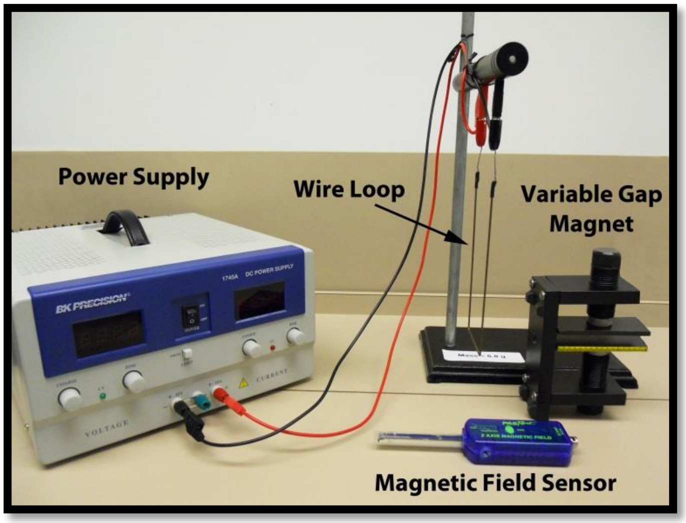

Figure 1

Discussion:

A magnetic field is a vector field which can be produced by charged particles in motion, electric current, and an alignment of "elementary currents" (domains) in some materials. If a charged particle q is moving with a velocity $\vec{\boldsymbol{v}}$ in a magnetic field $\vec{\boldsymbol{B}}$, there is a magnetic force $\overrightarrow{\boldsymbol{F_B}}$ acting on this particle:

$$\overrightarrow{F_B} = q\left[\vec{v} \times \vec{B}\right] \qquad (1)$$

An electric current is an oriented motion of charged particles. Therefore, if a current carrying wire is placed in a magnetic field, there will be a magnetic force acting on each charged particle and therefore there will be a magnetic force acting on segments of the current carrying wire. For a straight segment of wire length $\vec{l}$ placed in a uniform magnetic field $\vec{B}$ this force will be given by:

$$\overrightarrow{F_B} = i\left[\vec{l} \times \vec{B}\right] \qquad (2)$$

Where i is the current in the wire and vector $\vec{l}$ has a magnitude l and direction that is the same as the current. While magnetic forces acting on individual electrons in a wire are very small, the magnetic force acting on a current carrying wire is significantly larger and can be easy observed and measured in the lab.

During this experiment a segment of current carrying wire will be placed between two plates of a permanent magnet that have a gap. The direction of the current is going to be perpendicular to the direction of the magnetic field. The magnetic field of the permanent magnet $\overrightarrow{B_{ext}}$ between the plates is uniform. Therefore, as long as the wire is between the plates of the magnet, the magnetic force acting on it depends only on the current in the wire and has a magnitude of:

$$F_B = ilB_{ext} \qquad (3)$$

According to (2), the direction of the magnetic force acting on the wire is given by the right-hand rule and is perpendicular to directions of the magnetic field (up or down in your experiment) and the direction of the current. The force $\overrightarrow{F_B}$ will be directed horizontally and will pull the wire from its equilibrium position by a small distance d. The wire, in fact, will be caused to rotate around its axis (the connection between the wire and the wire holder), inscribing the arc of a circle. As the current increases, the magnetic force acting on a segment of current will also increase, inscribing a larger arc of displacement.

For more of a complete discussion of the topics in this experiment see the textbook:
Young & Freedman. (2008). Sears & Zemansky's University Physics. Ch 27, 28
The section 27-6, "Magnetic Force on a Current Carrying Wire" directly applies.

The following equation is used to calculate the magnetic force experienced by the current carrying wire. Its derivation is obtained by applying Newton's 1st Law (∑Forces=0 , ∑τorques=0) to the hanging wire loop. Assume current is flowing through the wire and it is hanging between the plates of the external magnet.

$$F_B = \frac{mgd}{R} \qquad (4)$$

Procedures:

1. Adjust the magnetic plates for a one-centimeter gap.
2. Measure the length (*l*) of the wire that will be in the magnetic field of the magnet.
3. Measure the radius (*R*) of the hanging wire loop starting at the pivot point, the bottom of the plastic holder where the wire is visible.
4. Determine the effective mass (*m*) of the wire, provided on the apparatus. **DO NOT REMOVE THE WIRE FROM ITS NON-CONDUCTING MOUNT.** ***Please see a lab instructor if there are any issues with finding the mass.***
5. Position the wire loop, centered, in between the magnetic plates, aligned with one of the millimeter marks on the attached scale (designated as your zero position).
6. Check that the power supply current and voltage dials are all zeroed, then turn on the power supply. ***Use caution with this power supply due to the high current.***
7. Slowly adjust the power supply until the wire loop has a displacement of (2.5 mm) from its zero position & record the current.
8. Collect measurements each time recording the current for displacements of an additional (2.5 mm) through the last displacement of (25.0 mm).
9. Zero the power supply current and then carefully reverse the positive and negative connections at the power supply.
10. Repeat the same sequence of measurements each time recording the current for negative displacements using (-2.5 mm) increments.
11. After collecting all measurements, zero the current and turn off the power supply.
12. Calculate the magnetic force for each data point collected.
13. Construct a linear graph, using excel, of the magnetic force as a function of the current. Use the slope of the line to calculate the magnetic field of the external magnet.
14. In order to have a comparison to the magnetic field obtained from the graph, a magnetic field sensor can be used. This sensor provides both field strength and field direction when placed near a magnetic source. Measure the magnetic field between the plates using the computer magnetic field sensor. *Please see the lab instructor for details about the computer magnetic field sensor if needed.*

Part II. Ampere's Law

1. Ask the lab instructor to show you the equipment. It includes a board with a coil in it, a Wireless 3-Axes Magnetic Field Sensor, a Wireless Rotary Motion sensor, a Pasco Interface, and a computer.

2. Turn on the wireless sensors. In PASCO Capstone, connect wirelessly to the Wireless Rotary Motion sensor and the Wireless 3-Axis Magnetic Field sensor. Keep the default sample rate of 20 Hz.

3. In PASCO Capstone, Create a graph of the x-axis of the Magnetic Field vs. Position and a graph of the x-axis of the Magnetic Field vs. Time.

4. Connect Output 1 of the 850 Universal Interface to the coil.

5. In PASCO Capstone, in the Hardware Setup, click on Output 1 and select the Voltage/Current sensor.

6. Open the Signal Generator and set it to DC with an amplitude of 15 V. Set it on Auto.

A . Path Encloses Current.

1. Notice two small stickers on the platform indicating suggested starting position of the rotary motion sensor. Since Ampere’s Law has a closed integral, you must start and end the loop on the same point.

2. To zero the Magnetic Field sensor, insert the probe into the Zero Gauss Chamber. You must make sure that the Magnetic Field sensor is selected in the sample rate window. Looking at the X-Magnetic Field vs. Time graph, start recording, and click on the zero button that is in Capstone on the bottom bar next to the sample rate. Make sure that the sensor reads zero. If not, click the zero button again. Then stop recording and delete the last run.

3. Attach the Magnetic Field sensor to the sensor bracket and place the wheel of the Rotary Motion sensor on your starting position. Note which direction you are pointing the Magnetic Field Sensor so you can return it to the same orientation when you return to this spot as you close the loop.

4. Start recording. The power to the coil will automatically turn on when you start recording. Slowly move the sensors around the path you choose through the coil, returning to the starting point, with the sensor pointing in the same direction as when you started. Then stop recording.

5. On the graph, find the area under the curve. Show your graph and determined area to the lab instructor. After instructor’s approval, Record it in Table 2. Also record in the table current in the coil.

6. Set the voltage on the signal generator to 14 V. Repeat steps 4 and 5.

7. Repeat steps 4 and 5 for three more different voltages: 13V, 12 V, and 11 V.

8. Using Excel, construct a graph of $\oint \vec{B} \cdot \vec{dl}$ as a function of current, I. Fit it with a linear curve and determine the slope of the graph. Record the slope. Then calculate the number of loops in the coil.

B. Path does not enclose current.

1. Place the wheel of the Rotary Motion sensor on your starting position. Set voltage to 15 V

2. Start recording. Slowly move the sensors around a closed path you choose that does not go through the coil, returning to the starting point. Then stop recording.

3. On the graph, find the area under the curve. Record it in Table 3. Also record current in the table.

4. Repeat for voltages set at 13 V and 11V.

Experiment B5a: Magnetic Force & Fields

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: B5a: Magnetic Force & Fields

NAME: ____________________ DATE: __________________

length =________________ *Radius* =_______________ *mass* =_________________

d displacement (mm)	*i* current (A)	F_B Magnetic Force (N)	*d* displacement (mm)	*i* current (A)	F_B Magnetic Force (N)
2.5			-2.5		
5.0			-5.0		
7.5			-7.5		
10.0			-10.0		
12.5			-12.5		
15.0			-15.0		
17.5			-17.5		
20.0			-20.0		
22.5			-22.5		
25.0			-25.0		

Slope of Graph________________________ Std. Deviation________________________

Magnetic Field (T) from graph_________________

Magnetic Field (T) from sensor_________________

Data Sheets: B5a: Ampere's Law

NAME: ____________________ DATE: __________________

Table 2. Path encloses current

Voltage of Signal Generator, V, (V)	Current through the coil, I, (A)	$\oint \vec{B} \cdot \vec{dl}$ (Area under the curve in Capstone Graph)
15.0		
14.0		
13.0		
12.0		
11.0		

Slope of the graph of $\oint \vec{B} \cdot \vec{dl}$ as a function of current, I_____________________

Calculation of the number of loops in the coil: (note that, according to Ampere's Law, the slope of the graph must be equal $\mu_0 N$, where $\mu_0 = 4\pi \times 10^{-7} \frac{T \cdot m}{A}$and N is the number of loops in the coil. Because $\oint \vec{B} \cdot \vec{dl}$ was measured in Gauss, not Teslas, you need to divide your answer by 10000)

Table 3. Path does not enclose current

Voltage of Signal Generator, V, (V)	Current through the coil, I, (A)	$\oint \vec{B} \cdot \vec{dl}$ (Area under the curve in Capstone Graph)
15.0		
14.0		
13.0		
12.0		
11.0		

Compare values for $\oint \vec{B} \cdot \vec{dl}$ you obtained for paths enclosing current with those that did not enclose current. What can you conclude?