

# PH102 Lab: Magnetic field Mapping and Ampere's Law

## **Introduction**

In this experiment, we will verify Ampere's Law using a coil and a Giant MagnetoResistive or GMR sensor.<sup>1</sup> A GMR sensor probe is a device whose resistance varies with magnetic field, and thus it can be used to measure magnetic field strength. When supplied with a source voltage, the sensor has an output voltage which is proportional to magnetic field (as well as the input voltage).

Ampere's law relates the current flowing through a closed surface to the magnetic field tangential to the curve bounding the surface. Take any arbitrary closed path surrounding a current, and break it up into infinitesimal segments  $\Delta l$ . Now find the component of the magnetic field parallel to the segment,  $B_{||}$ , and compute the product  $B_{||}\Delta l$ . The sum of all such products around the closed path gives the current passing through the surface bounded by the path:

$$\sum_{\text{loop}} B_{||} \cdot \Delta l = \mu_0 I_{\text{encl}}$$

In this laboratory, we will verify Ampere's law by measuring the magnetic field due to a current-carrying coil of wire on a path enclosing a portion of the coil.

## **Setup**

**Magnetic field sensor:** We will use the BamaLab box to supply voltage to the field sensor (from the +/-  $V_{\text{out}}$  terminals). Open the "Multimeter" panel from the "dc Circuits" menu, and select voltage sourcing.

- Plug the red and black sensor plugs into the +/-  $V_{\text{out}}$  connections.
- Set the voltage output to 5.0V.

The 5.0V source voltage is used to power the sensor. The sensor output is taken from the blue (+) and white (-) plugs. The voltage between these two plugs is proportional to magnetic field strength for a given supply voltage. We will use the +/-  $V_{\text{in}}$  connections on the BamaLab box to measure the sensor voltage.

- Plug the blue and white sensor plugs into the +/-  $V_{\text{in}}$  connections

Once this is done, select "voltage measurement" in the multimeter panel.

- Go into the settings menu, and change " $V_{\text{in}}$  gain" to 0.1 instead of 1.

This will magnify your voltage readings by 10 times on the screen to give you more resolution, but you have to remember to factor this into your analysis.

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<sup>1</sup> The discoverers of the GMR effect won the 2007 Nobel prize in physics.

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With 5.00 V powering the sensor, it has a calibration constant of 150 Volts per Tesla (or 150 mV/mT). That is, to calculate the magnetic field in mT from the sensor voltage, divide the sensor voltage in mV by 150.

**Magnetic field coil:** The coils used in this experiment have 1500 turns of copper magnet wire. The coils will be powered by the Pasco power supplies, *using the dc source plugs on the left-hand side of the supply*. Do not connect the coil to the ac source, and do not connect your sensor to the Pasco supply.

- With the power supply off, and all knobs turned maximally counter-clockwise (*i.e.*, off), connect your coil to the left-hand +/- plugs on the supply.
- Before powering up your coil (below), measure the inner and outer diameters of the coil.

### **Procedure**

Now place your sensor in the center of the coil. The source voltage for the sensor should be set to 5V in software, and its voltage reading displayed (though multiplied by 10). On the Pasco supply, turn the current knob up about 1 turn. This is not supplying current yet, but setting a limiting value.

Following the table below, increase the voltage on the Pasco supply (the coil voltage) and record the current values *from the supply*. From these values, you can determine the coil resistance. At each voltage/current value, record the sensor voltage at the center of the coil, and the resulting magnetic field. Do not forget to divide your on-screen readings for the sensor voltage by 10!

- Plot coil voltage (y axis) versus coil current to determine the coil resistance.
- Plot your measured magnetic field (y axis) versus coil current and determine the slope.

There is no need to print any graphs out. Once you have plotted your data in Excel to determine the slope (using a trendline, as before), have an instructor initial that your plot is satisfactory.

Coil Voltage (V)	Coil Current (mA)	Sensor (mV) (on screen)	Sensor (mV) (actual = screen/10)	Magnetic Field (mT) (sensor mV / 150)
0				
2.5				
5				
10				
15				
20				

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1. Resistance of coil  $R =$  \_\_\_\_\_ (slope or average of coil  $V/I$ )

2. Inner diameter of coil \_\_\_\_\_ m

3. Outer diameter of coil \_\_\_\_\_ m

4. Average diameter of coil  $2a =$  \_\_\_\_\_ m

5.  $N = 1500$

6. Expected slope of  $B$  vs.  $I = \frac{\mu_0 N}{2\pi a} =$  \_\_\_\_\_ mT/mA

7. Measured slope of  $B$  vs.  $I =$  \_\_\_\_\_ mT/mA

Plot OK: \_\_\_\_\_ (instructor initials)

8. % Difference in slope = \_\_\_\_\_ mT/mA

Now set the **coil voltage** to 20.0 V using the Pasco supply, and measure the magnetic field at each of the alignment marks on the coil support. Start with the sensor at the center of the coil (call this mark 1, for example), and 'walk' the sensor around the groove without changing its orientation along the path.

The sensor measures the component of the magnetic field along the length of the support, so this is equivalent to taking the dot product of the vectors of  $B$  and  $L$  at every marked point. The sum of these measurements, multiplied by the increment of the displacement, is the sum of  $B_{\parallel}\Delta l$  around the enclosed current,  $NI$ . Note that you will need to measure the increment of displacement (the distance between the grooves). Use the table on the next page.

9.  $\Delta L \cdot \sum B_i =$  \_\_\_\_\_ as measured

10.  $\mu_0 NI = \mu_0 N \left( \frac{V}{R} \right) =$  \_\_\_\_\_ (20V and measured R for coil)

11. % Difference = \_\_\_\_\_

### **When finished:**

Go back to the settings menu of the "Circuits Tutorial" software, and change "V<sub>in</sub> gain" to 1. Clean up your area.

