MAGNETIC FIELD MAPPING

Objectives: • To learn how to find magnetic field
• To gain fluency in sketching magnetic field lines.

Prelab:
In class you are learning that the magnetic field from the end of a solenoid varies with the *z* position according to

$$B_z \propto f(z) = \frac{-z}{\sqrt{R^2 + z^2}} + \frac{L + z}{\sqrt{R^2 + (L + z)^2}}$$

In the next step, you will need to type this expression into excel. You may either use a series of cells to calculate pieces of the expression and then combine them, or try to type the whole expression in one cell.

1. If L = 18 cm, z = 6 cm, R = 5 cm, then use your excel formula to calculate the value of the function $f(z)$.
2. Use the excel function =FORMULATEXT() to display the formula for $f(z)$ in another cell. Make sure the cell is wide enough so that the whole thing will print out. If you used multiple cells to calculate pieces of the expression, do formulatext for all of the formulas.
3. Print it to submit as a prelab and keep a copy of the excel file handy for the lab.
4. Read the lab!

Aparatus: DC power supply, Keithley multimeter, Silva magnetic compass, 1800-turn solenoid wound on PVC tubing, connecting leads, wood, wooden platform and rail, magnifying glass.

Introduction

It was known more than 2000 years ago that certain naturally occurring stones (containing the mineral magnetite) attract small pieces of iron. About 1000 years ago navigators had begun to use the magnetic compass as a guidance tool. However, the connection between electricity and magnetism was not discovered until about 1820, when Hans Oersted first noticed that a compass needle was affected by an electric current.

In each of the cases above, one object exerts a force on another object without any obvious physical contact. To explain this magnetic ‘action at a distance’ physicists use the concept of a *magnetic field*. In this lab you will examine properties of the magnetic field around a *solenoid,* a long wire wrapped many times around a cylindrical core.

Just like the electric field, the magnetic field is a vector; it has a magnitude and a direction. The *direction* of the magnetic field at a point is conveniently determined by placing a compass at the point. The compass needle points in the direction of the magnetic field. The *magnitude* of the magnetic field can be defined in terms of the torque the field exerts on a “test compass”, although this definition is not of much practical use. In this lab we will determine the magnitude of the magnetic field of a solenoid relative to the magnetic field of the earth.

Procedure:

Build a series circuit containing the Filtered D.C. Power Supply, the solenoid, and the Keithley multimeter.

Caution: The power in this circuit is quite large. With a current of **>1A** the solenoid may eventually get so hot that it will melt the PVC tube or the enamel insulation on the copper wire. **Never run the solenoid for a long period of time, and throughout each experiment check the solenoid frequently to make sure it is not too hot.**

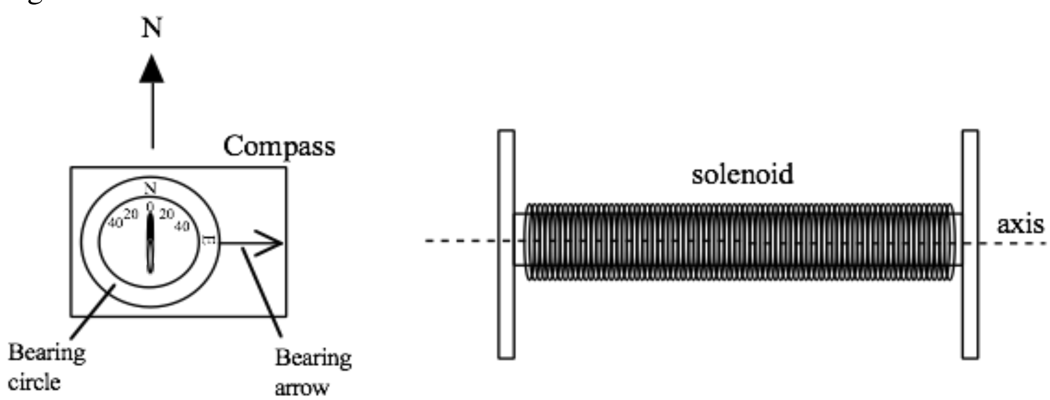
1. Investigating the direction of the magnetic field produced by a solenoid

a) Set the current through the solenoid at about 400 mA, using the multimeter to measure the current. Move the compass around on the platform and observe how the direction of the magnetic field varies with position. Note especially the direction of the magnetic field along the axis of the solenoid. Collect enough data so you will be able to sketch the field around the solenoid.

b) Reverse the direction of the current through the solenoid. How does this affect the direction of the magnetic field? Take note of this technique!

2. The effect of current on the strength of the magnetic field

a) Place the large compass in the wooden rail, 20 cm from the center of the solenoid. With **no current** in the circuit, verify that the axis of the solenoid is perpendicular to the horizontal component of earth's magnetic field as shown in the diagram below. To check this alignment, turn the bearing circle of the compass until W is lined up with the bearing arrow and then rotate the entire apparatus until the compass needle is pointing at 0^{o} on the small red scale that runs inside the bearing circle. Use the magnifying glass to help you see the needle position. Clamp the apparatus to the table once you're satisfied with the alignment.



b) Devise an experiment to determine the relationship between the solenoid's ***B***-field and the current through the coil. Write the procedure in your notebook. Be sure to record and use uncertainties. Also take advantage of reversing the current to further reduce alignment error. Between measurements turn off the power supply and check that the apparatus is aligned properly and that the solenoid is not too hot.

Here are some questions to help you on your way: What is the ratio of the solenoid's ***B***-field relative to the earth's ***B***-field? And what is the relation between the deflection of the compass needle and the solenoid's ***B***-field?

Find the mathematical relationship between magnetic field strength and current. Celebrate your result with a box.

3. Variation of field strength with axial distance from the solenoid: Devise an experiment to determine the variation of the ***B***-field with distance from the solenoid. Keep the current set at a constant setting (no greater than 1.0 A). As before write up your procedure carefully. You may wish to have a second methods section, to keep your notes in chronological order.

4. We derived the axial magnetic field of a solenoid in class (http://academics.hamilton.edu/physics/smajor/courses/195Guides/solenoid_b.pdf). Graphically compare the theoretical result with your data. To do this is to create a new calculated column using the functional form of the magnetic field strength as a function of distance along the axis. Create a fitting parameter that will scale your results, and modify that constant as needed to make your theoretical and experimental data match. Ask your instructor to help you if you are uncertain how to do this. Make sure that it is clear which data points are theoretical and which data points are experimental. In your summary comment on the quality of the match between the theoretical result and the data. Be sure to include error bars on your experimental data points. Print out a graph for your notebook and to turn in for the postlab.

5. Magnetic field summary: Make a *careful* sketch of the magnetic field lines in the region around the solenoid and write a brief description. Be sure to indicate where you have quantitative information about the field and where you only have qualitative information. Use the compass to help with the sketch.