### LABORATORY 7 MAGNETISM I: MAGNETIC FIELDS

### Objectives

- to be able to represent a magnetic field by appropriately drawn magnetic field lines
- to observe that a current gives rise to a magnetic field
- to be able to determine the direction of the magnetic field due to a currentcarrying wire
- to be able to recognize and discuss the superposition of magnetic fields
- to be able to determine quantitatively and discuss qualitatively the dependence of the magnitude of the magnetic field with distance from a current-carrying wire
- to be able to measure the strength of a magnetic field as a function of distance from a current-carrying wire
- to be able to discuss qualitatively and determine quantitatively the magnetic field near the center of a solenoid

**Overview:** In this laboratory, we will observe that a current gives rise to a magnetic field and determine the direction and magnitude of the magnetic field by observation and measurement.

### **Equipment:**

permanent magnet
small compasses
10-12 square stack magnets

### **Exploration 1 Magnetic fields of magnets**

### Exploration 1.1 The direction of the magnetic field of a magnet

**a.** Consider a bar magnet. Draw the magnetic field lines for a bar magnet in the diagram below.



**b.** Consider a small magnet, like one of the stack magnets at your table. Where are the poles of the stack magnet? Test for the poles with other magnets or compasses. Label the poles of the magnet and then draw the field lines for one of the small magnets at your table.



Check your labeling of the poles with your TA.

**c.** Now consider a stack of magnets, as in the diagram below. Label the north and south poles and draw the field lines. Explain why you drew the field lines the way you did.

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**d.** Remove the left half of the stack as in the diagram below.

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Draw the direction of the magnetic field at the point to the left of the magnet in the diagram.

e. Replace the left half and remove the right half as in the diagram below.

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Draw the direction of the magnetic field at the point to the right of the magnet in the diagram.

**f.** By superposition, when both halves are in place, the magnetic field points in the direction of the sum of all magnetic fields at that point. Which direction does the magnetic field point inside a magnet? Explain.

# **Exploration 1.2**

**a.** Draw the magnetic field of a horseshoe magnet in the diagram below.



Discuss your drawing with a TA.

# **Equipment:**

1 wire stand
6-9 small compasses
1 power supply
1 3-dimensional compass

# Exploration 2: The magnetic field of a current-carrying wire

# **Exploration 2.1 The Earth's magnetic field**

Consider the set up at your table that consists of a wire, a stand and a power supply, as in the diagram below. The wire passes through a hole in the wood that is supported by the stand. The power supply is connected to the wire and a current can be sent through the circuit, when the power supply is turned on. DO NOT turn on the power supply until instructed to do so. With the power supply turned off, place about 6 compasses on the wood in a small circle around the wire.



- **a.** With the power supply turned off, which direction do the compasses point? Do they all point in the same direction?
- **b.** A compass is a small magnet. It will align itself with a magnetic field. What produces the net magnetic field with which it is aligned? Do you think there is more than one magnetic field in the region of the compasses? Do you think there is a dominant magnetic field in the region of the compasses? Explain.

**c.** If the compasses were not constrained to rotate only in the plane, but could rotate in three dimensions, do you think they would point in the same direction as they do now? Predict the direction a three-dimensional compass would point.

**d.** Use the three-dimensional compass at your table to test your prediction.

#### Exploration 2.2 Direction of the magnetic field of a current-carrying wire

**a.** This is a prediction. Do not carry it out yet. Do not turn on the power supply. Predict what would happen to the compasses, if the power supply were turned on and there was a current in the wire.

- **b.** Turn on the power supply and turn the current up to about 0.75A. DO NOT turn the current up over 1.0 A. (There is very little resistance in the wire and you will burn it up, if you turn the current on too high or leave it on for a long period of time.) Observe what happens to the compasses. Do not the leave the current on for a long period of time, just long enough to observe the compasses, then turn the current off. Record what happened below. Is there a pattern to the direction of the compasses?
- **c.** Connect the power supply so that the current travels the other direction through the wire. Turn the current on again. Observe what happens, then turn the current off. How is the pattern of the compasses the same or different as in part **b**?

- **d.** Based on your knowledge of compasses as small magnets, is there a magnetic field near the wire
  - (i) when current is not flowing through the wire?
  - (ii) when current is flowing through the wire?

Explain your reasoning.

- e. Is there more than one magnetic field in the region of the compasses when the current is flowing through the wire? Explain.
- **f.** If there is more than one field near the current-carrying wire, discuss the strength of the fields, based on your observations.
- **g.** Discuss the approximate direction of the magnetic field of a current-carrying wire, if the current is moving up the wire in the region near the compasses.
- **h.** Discuss the approximate direction of the magnetic field of a current-carrying wire, if the current is moving down the wire in the region near the compasses.

### Exploration 2.3 Magnitude of the magnetic field

**a.** Place the compasses on the wood in a line away from the wire, each at a different distance from the wire.

**b.** Does this give you any information on the magnitude of the magnetic field? Where is it weak and where is it strong? Explain.

# **Exploration 2.4 The field of a wire loop**

**a.** Suppose a single current-carrying wire was bent into a loop as in the diagram below. Draw the magnetic field lines for the area around the loop (inside and outside the loop) in the diagram below.



wire with current I flowing clockwise

**b.** Consider a sideview of the same loop. Draw the magnetic field lines. In the picture below.



side view of the top loop

**c.** Compare the field lines for a closed loop to that of the magnets above. Are there any similarities with the field lines of any of the magnets?

### Exploration 2.5 The magnetic field of a solenoid

**a.** Draw the field lines for a solenoid, a series of closed loops, in the diagram below.



**b.** Compare the field lines of a solenoid to that of the magnets above. Is there a similarity to any of the magnets? Which ones?

#### **Equipment:**

wire mounted vertically on a stand
power supply
magnetic field sensor
computer interface
computer software

### Investigation 1 The magnetic field of a current carrying wire

Theoretically, the value of the magnetic field of a current carrying wire is

Where I is the current, r is the distance from the wire and  $\mu_0$  is a constant.  $\mu_0 = 4\pi \times 10^{-7} \text{ nm}^2/\text{C}^2$ . We are going to measure the magnitude of the field of a current-carrying wire at different distances from the wire using a magnetic field sensor.

### Investigation 1.1 The magnitude of the magnetic field of a current carrying wire

**a.** If you were to plot the magnitude of the magnetic field vs. the distance from the wire, what kind of graph you would expect? Sketch the shape of the graph in the space below.

**b.** Would the plot in **a.** be the best way to verify how the magnetic field depends on the distance from the wire? Is there any other way you could plot the data? Explain.

The magnetic field sensor is mounted on a rotary motion sensor, so you can easily move it a small distance at a time. It should be connected to the computer interface and the computer interface connected to the computer. Bring up Data Studio. Click on Create and Experiment. Click on one of the digital input channels on the left. Select Rotary Motion Sensor. Click on the second "Measurement" tab. Choose Position. Click on Analog Channel A. Choose Magnetic field Sensor. Select Magnetic Field Strength 100x. Select units Tesla.

Align the Sensor. The Sensor should be radial along ruler on stand, offset 7mm from the wire when sensor casing is touching wire. See picture on board.

**c.** Before turning the power supply on (no current through the wire), would yu record a magnetic field, if you took data? Why or why not? Explain.

Test your answer, by hitting the Start to take data.

If there is a field, what is the magnitude of the magnetic field in mT? Does the magnitude make sense? Explain.

If you would like to record only the field of the current-carrying wire, you can zero the sensor when there is no current through the wire by pressing the "Tare" button on the sensor. Press the "Tare" button now.

- **d.** Now turn on the current through the wire to about 0.75A. Take data by hitting "Start" and moving the sensor very slowly away from the wire.
- e. View the data on a graph and bring up a table of the data by sliding the graph and table icons to the right of the screen.

Copy the data from the table to an Excel file.

Delete any early data with position zero. Delete any data taken after the motion has stopped.

Shift the position data by 0.007m (to account for the initial offset of the probe).

The magnetic field should not have any negative values, since you zeroed the sensor. However, if you do have negative values, you will have to add a constant to all of the data, so that none of the values are negative.

Plot B vs. r and fit the data to a power law.

- **f.** Plot B vs. (1/r) and fit the data to a straight line.
- g. Find  $\mu_0 I/2\pi$  from each of your plots. You should use 25 times the current value you read on the power supply because the wire really consists of 25 wires. Show your calculations below.
- **h.** Determine the value of  $\mu_0/2\pi$  from each graph. Show your work below.

# **Equipment:**

solenoid
power supply
magnetic field sensor
computer interface
computer software

### Investigation 2 The magnetic field of a solenoid

In this section, we will measure the magnetic field of a solenoid and use it to determine the number of turns of the solenoid.

# Investigation 2.1 The magnetic field of a solenoid

a. Discuss the strength of the magnetic field inside a solenoid. Is it constant?

- **b.** If you were to measure the magnetic field inside a solenoid, would it be uniform everywhere?
- c. Is the field inside the solenoid approximately uniform in some region?

**d.** Test your predictions with the magnetic field sensor.

### Investigation 2.2 Measuring the magnetic field of a solenoid

Theoretically, the magnetic field near the center of a solenoid is

where I is the current and n is the number of turns per unit length.

We are going to determine the number of turns per unit length of the solenoid by measuring the magnetic field in the center of the solenoid.

**a.** Use the magnetic field sensor to measure the field inside the solenoid at your table for 5-6 values of the current through the solenoid. Keep the current below 1.0A as much as possible. Record your data in the table below.

Current (A)	Magnetic field (T)

**a.** In Excel, plot your data and determine the *n*, the number of turns per unit length, of the solenoid. Describe your method for determining *n* and show your work clearly in the space below.

**Summary.** Summarize how you determined the magnitude and direction of the magnetic field due to a current-carrying wire in a few sentences in the space below.

# Laboratory 7 Homework Magnetic Fields

1) Two long wires lie parallel in the plane of the paper, with current in the direction indicated.



- a) Calculate the magnitude and direction of the net magnetic field at Point P. Show your work and explain your calculations.
- b) Calculate the magnitude and direction of the net magnetic field halfway between the two wires. Show your work and explain your calculations.