

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
Department of Physics

### Experiment 3: Magnetic Fields of a Bar Magnet and Helmholtz Coil

#### OBJECTIVES

1. To learn how to visualize magnetic field lines using compasses and a gauss meter
2. To examine the field lines from bar magnets and see how they add
3. To examine the field lines from a Helmholtz coil and understand the difference between using it in Helmholtz and anti-Helmholtz configurations.

#### PRE-LAB READING

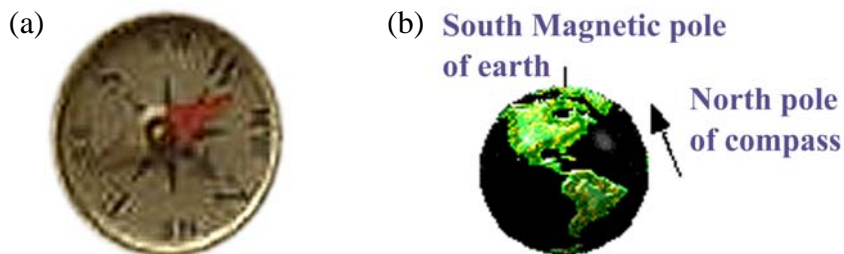
#### INTRODUCTION

In this lab we will measure magnetic field lines using two methods. First, we will use small compasses that show the direction, but not magnitude, of the local magnetic field. Next we will use a gauss meter, which measures the magnitude of the magnetic field along a single, specific axis and thus does not allow as easy a visualization of the magnetic field direction. We will measure fields both from bar magnets and from a Helmholtz coil.

#### APPARATUS

##### 1. Mini-Compass

You will receive a bag of mini-compasses (Fig. 1a) that indicate the magnetic field direction by aligning with it, with the painted end of the compass needle pointing away from magnetic north (i.e. pointing in the direction of the magnetic field). Conveniently, the magnetic south pole of the Earth is very close to its geographic north pole, so compasses tend to point North (Fig. 1b). Note that these compasses are cheap (though not necessary inexpensive) and sometimes either point in the direction opposite the way they should, or get completely stuck. Check them out before using them.



**Figure 1** (a) A mini-compass like the ones we will be using in this lab. (b) The painted end of the compass points north because it points towards magnetic south.

## 2. Science Workshop 750 Interface

As always, we will use the Science Workshop 750 interface, this time for recording the magnetic field magnitude as measured by the magnetic field sensor (gauss meter).

## 3. Magnetic Field Sensor

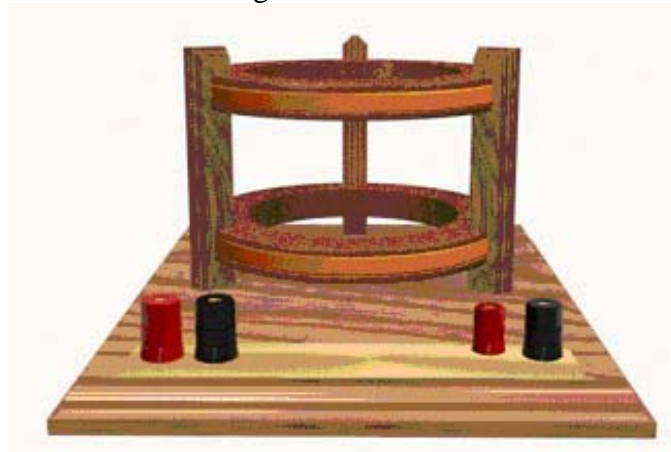
The magnetic field sensor measures the strength of the magnetic field pointing into one of two white dots painted at its measurement end (far left in Fig. 2). Selecting “radial” mode records the strength of the field pointing into the dot on the side of the device, while “axial” records the strength of the field pointing into the dot on the end. There is also a tare button which sets the current field strength to zero (i.e. measures relative to it).



**Figure 2 Magnetic field sensor**, showing (from right to left) the range select switch, the tare button, and the radial/axial switch, which is set to radial.

## 4. Helmholtz Coil

Consider the Helmholtz Coil Apparatus shown in Fig. 3. It consists of two coaxial coils separated by a distance equal to their common radii. The coil can be operated in 3 modes. In the first, connections are made only to one set of banana plugs, pushing current through only one of the coils. In the second, a connection is made between the black plug from one coil to the red plug from the other. This sends current the same direction through both coils and is called “Helmholtz Mode.” In the final configuration “Anti-Helmholtz Mode” a connection is made between the two black plugs, sending current in the opposite direction through the two coils.



**Figure 3 Helmholtz Coil Apparatus**

## 4. Power Supply

Because the Helmholtz coils require a fairly large current in order to create a measurable field, we are unable to use the output of the 750 to drive them. For this reason, we will use an EZ dc power supply (Fig. 4). This supply limits both the voltage and the current, putting out the largest voltage possible consistent with both settings. That is, if the output is open (no leads connected, so no current) then the voltage output is completely determined by the voltage setting. On the other hand, if the output is shorted (a wire is placed between the two output plugs) then the voltage is completely determined by the current setting ( $V = IR_{short}$ ).



**Figure 4 Power Supply for Helmholtz Coil**

The power supply allows independent control of current (left knob) and voltage (right knob) with whichever limits the output the most in control. The green light next to the “CV” in this picture means that we are in “constant voltage” mode – the voltage setting is limiting the output (which makes sense since the output at the bottom right is not hooked up so there is currently no current flow).

### GENERALIZED PROCEDURE

This lab consists of three main parts. In each you will measure the magnetic field generated either by bar magnets or by current carrying coils.

#### **Part 1: Mapping Magnetic Field Lines Using Mini-Compasses**

Using a compass you will follow a series of field lines originating near the north pole of a bar magnet.

#### **Part 2: Constructing a Magnetic Field Diagram**

A pair of bar magnets are placed so that either their opposite poles or same poles are facing each other and you will map out the field lines from these configurations.

#### **Part 3: Helmholtz Coil**

In this part you will use the magnetic field sensor to measure the amplitude of the magnetic field generated from three different geometries of current carrying wire loops.

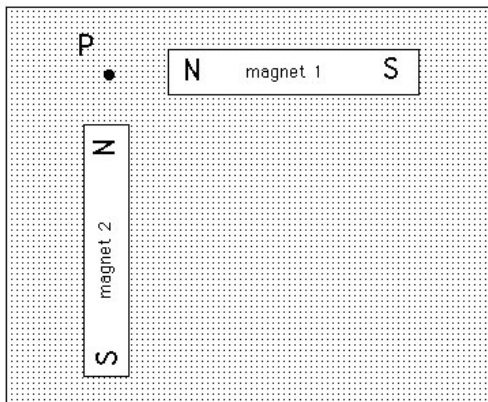
**END OF PRE-LAB READING**



## Experiment 3: Magnetic Fields Pre-Lab Questions

Answer these questions on a separate sheet of paper and turn them in before the lab

### 1. Superposition



Consider two bar magnets placed at right angles to each other, as pictured at left.

(a) If a small compass is placed at point P, what direction does the painted end of the compass needle point?

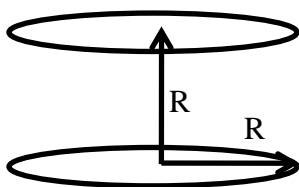
(b) If the compass needle instead pointed 15 degrees clockwise of where you predicted in (a), what could you *qualitatively* conclude about the relative strengths of the two magnets?

### 2. Helmholtz Coil

In class you calculated the magnetic field along the axis of a coil to be given by:

$$B_{axial} = \frac{N \mu_0 I R^2}{2} \frac{1}{(z^2 + R^2)^{3/2}}$$

where  $z$  is measured from the center of the coil.



As pictured at left, a Helmholtz coil is created by placing two such coils (each of radius  $R$  and  $N$  turns) a distance  $R$  apart.

(a) If the current in the two coils is parallel (Helmholtz configuration), what is the axial field strength at the center of the apparatus (midway between the two coils)? How does this compare to the field strength at the center of the single coil configuration (e.g. what is the ratio)?

(b) In the anti-Helmholtz configuration the current in the two coils is anti-parallel. What is field strength at the center of the apparatus in this situation?

(c) Our coils have a radius  $R = 7$  cm and  $N = 168$  turns, and we will run with  $I = 0.6$  A in single coil and 0.3 A in Helmholtz and anti-Helmholtz mode. What, approximately, are the largest on-axis fields we should expect in these three configurations? Where (approximately) are the fields the strongest? **Write the answer to this question in your notes. You will need it for the lab.**

## IN-LAB ACTIVITIES

### EXPERIMENTAL SETUP

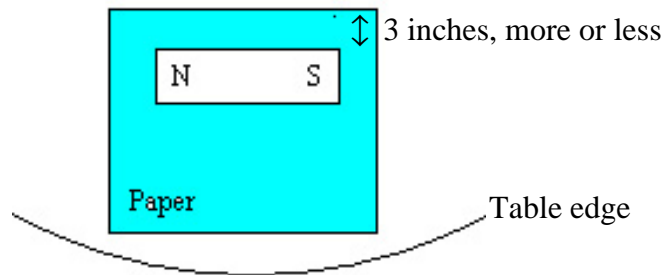
1. Download the LabView file and start up the program.
2. Connect the Magnetic Field Sensor to Analog Channel A on the 750 Interface
3. Without leads connected to the power supply, turn it on and set the voltage output to 2 V. Turn it off.

**NOTE:** When working with bar magnets, please do NOT force a north pole to touch a north pole (or force south poles to touch), as this will demagnetize the magnets.

### MEASUREMENTS

#### Part 1: Mapping Magnetic Field Lines Using Mini-Compasses

1. Tape a piece of brown paper (provided) onto your table.
2. Place a bar magnet about 3 inches from the far side of the paper, as shown below. Trace the outline of the magnet on the paper.



3. Place a compass near one end of the magnet. Make two dots on the paper, one at the end of the compass needle next to the magnet and the second at the other end of the compass needle. Now move the compass so that the end of the needle that was next to the magnet is directly over the second dot, and make a new dot at the other end of the needle. Continue this process until the compass comes back to the magnet or leaves the edge of the paper. Draw a line through the dots and indicate with an arrowhead the direction in which the North end of the needle pointed, as shown below



- Repeat the process described above several more times (~4 field lines), starting at different locations on the magnet. Work fairly quickly – it is more important to get a feeling for the shape of the field lines than to map them precisely.

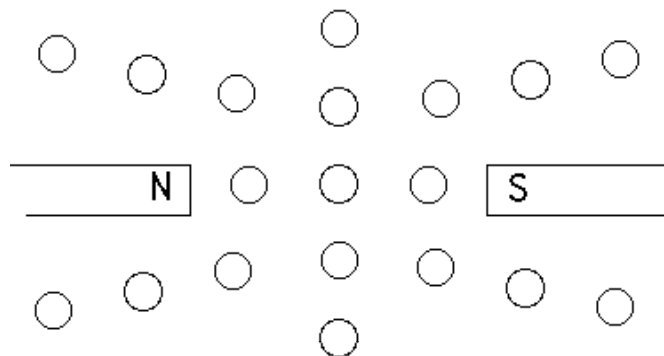
**Question 1:**

Mostly your field lines come back to the bar magnet, but some of them wander off and never come back to the bar magnet. Which part of your bar magnet do the ones that wander off never to return come from? Where are they going?

**Part 2: Constructing a Magnetic Field Diagram**

**2A: Parallel Magnets**

- Arrange two bar magnets and a series of compasses as pictured here:



- Sketch the compass needles' directions in the diagram. Based on these compass directions, sketch in some field lines.

**Question 2:**

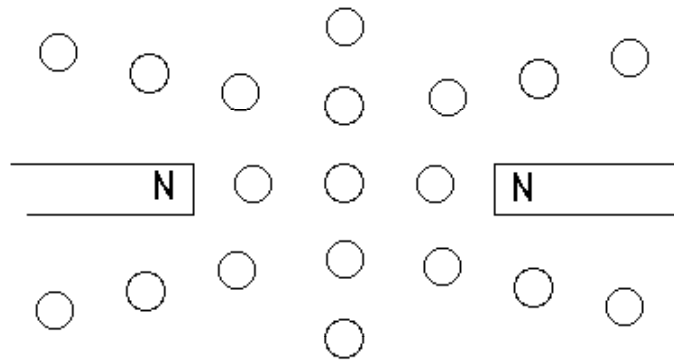
Is there any place in this region where the magnetic field is zero? If so, where? How can you tell?

**Question 3:**

Where is the magnetic field the strongest in this situation? How can you determine this from the field lines?

**2B: Anti-Parallel Magnets**

1. Arrange two bar magnets and a series of compasses as pictured here:



2. Sketch the compass needles' directions in the diagram. Based on these compass directions, sketch in some field lines.

**Question 4:**

Is there any place in this region where the magnetic field is zero? If so, where? How can you tell?

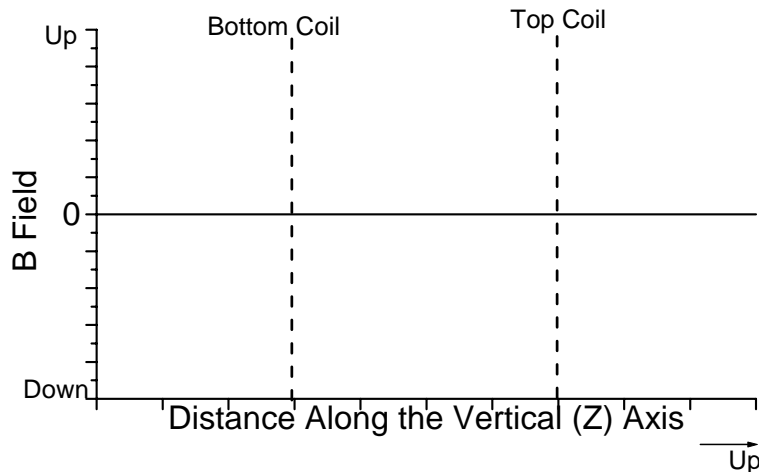


### **Part 3: Helmholtz Coil**

In this part we are going to measure the z-component of the field along the z-axis (central axis of the coils)

#### **3A: Using a Single Coil**

1. With the power supply off, connect the red lead from the power supply to the red plug of the top coil, and the black lead to the black plug of the top coil. Turn the current knob fully counter-clockwise (i.e. turn off the current) then turn on the power supply and slowly turn the current up to  $\sim 0.6$  A.
2. Put the magnetic field sensor in axial mode, set its gain to 10x and place it along the central axis of the Helmholtz coil, pushing into the indentation at the center of the holder. Tare it to set the reading to zero.
3. Start recording magnetic field (press Go) and raise the magnetic field sensor smoothly along the z-axis until you are above the top coil. Try raising at different rates to convince yourself that this only changes the time axis, and not the measured magnitude of the field.
4. Sketch the results for field strength vs. position

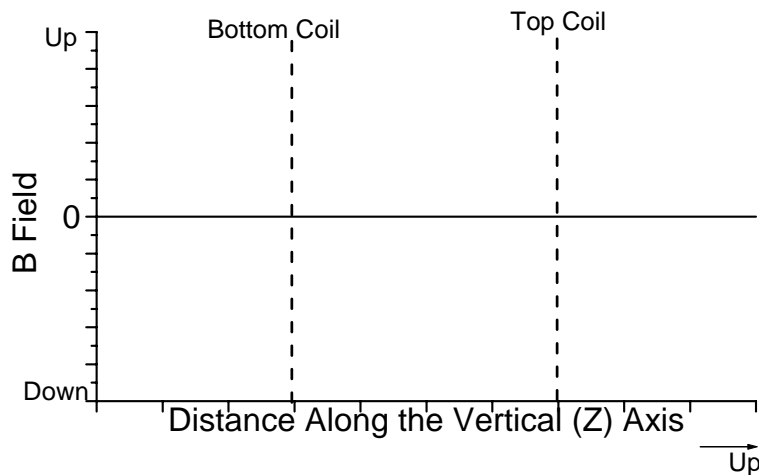


#### **Question 5:**

Where along the axis is the field from the single coil the strongest? What is its magnitude at this location? How does this compare to your pre-lab prediction?

### 3B: Helmholtz Configuration

1. Move the black lead to the black terminal of the lower coil, and connect a lead from the black terminal of the upper to the red terminal of the lower, sending current in the same direction through both coils. Set the current to  $\sim 0.3$  A
2. Follow the procedure in 3A to again measure field strength along the z-axis, plotting on the below figure.

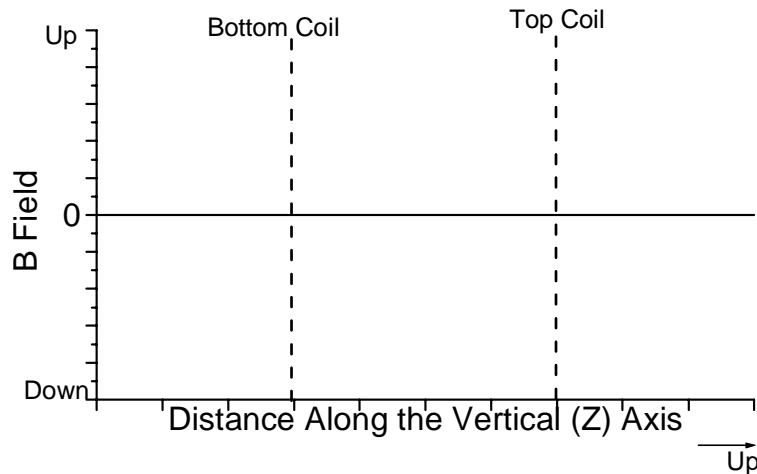


#### Question 6:

Where along the axis is the field from the strongest? What is its magnitude at this location? How does this compare to your pre-lab prediction. Aside from the location and strength of the maximum, is there a qualitative difference between the single coil and the Helmholtz coil field profile? If so, what is the difference?

### 3C: Anti-Helmholtz Configuration

1. Swap the leads to the lower coil, keeping the current at  $\sim 0.3$  A, although now running in opposite directions in the top and bottom coil.
2. Follow the procedure in 3A to again measure field strength along the z-axis.



**Question 7:**

What are two main differences between the field profile in Anti-Helmholtz configuration and in Helmholtz configuration? Does the maximum field strength match your prediction from the pre-lab?

**Further Questions (for experiment, thought, future exam questions...)**

- What does the field profile look like if we place two bar magnets next to each other rather than collinear with each other (either parallel or anti-parallel to each other).
- What does the radial field profile (e.g. the x component of the field) look like along the z-axis of the Helmholtz coil?
- What do the radial and axial field profiles look like moving across the top of the Helmholtz coil rather than down its central axis?
- It looks as though there is a local maximum of magnetic field strength at some point on the axis for both the single coil and Helmholtz coil configurations (at least looking at them along the z-axis only). If we consider them three dimensionally are they still local maxima? That is, if we move off axis does the magnitude of the field also decrease as we move away from these maxima points?

