MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Department of Physics

8.02   Spring 2005

Experiment 5: Magnetic Fields of a Bar Magnet and of the Earth

OBJECTIVES

1. To examine the magnetic field associated with a bar magnet and construct the magnetic field lines.
2. To measure the magnitude and approximate orientation of the Earth's magnetic field in classroom.
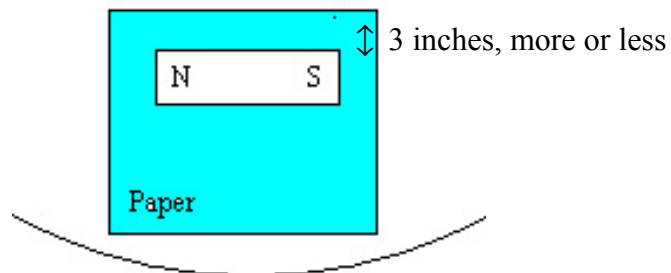
INTRODUCTION

In these exercises, you will study the magnetic field of bar magnets and the earth. You will draw field lines and analyze their meaning.   You will measure the Earth's magnetic field in classroom.
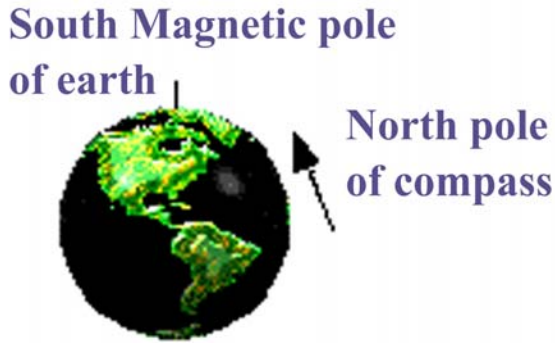
PROCEDURE

Part 1: Constructing Magnetic Field Lines of a Bar Magnet

Tape a piece of brown paper (provided) onto your table. Stay far away from any iron objects. Place a bar magnet about 3 inches from the far side of the paper, as shown in Figure 1. Trace the outline of the magnet on the paper.
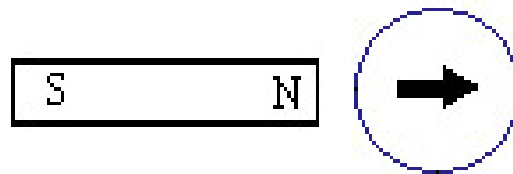

Figure 1 Setup for constructing magnetic field lines of a bar magnet

Determine which ends of your magnet are north or south magnetic poles. Take one of your small compasses. The arrow on the compass is magnetic and will experience a torque so that the North pole of the compass will point in the direction of the Earth's magnetic field if no other magnetic fields are present. As depicted in Figure 2, the North pole of the compass points towards the South magnetic pole of the Earth which is very close to the Earth's geographic North Pole.

Figure 2 Earth's magnetic pole and compass heading.

It also means that, if you place the compass near the bar magnet, the North pole of your compass will point *toward* the South pole of the bar magnet or *away* from the North pole when placed as shown in Figure 3.
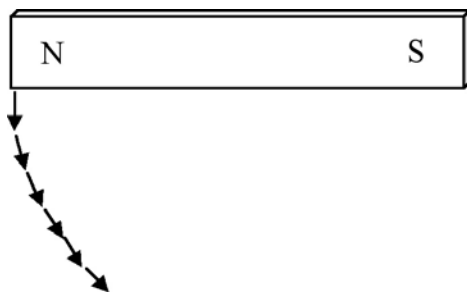

Figure 3 Direction of the compass when placed near a bar magnet

Mark the North and South magnetic poles of your magnet on the paper. Make sure you stay away from any other magnets, electrical circuits or iron materials as you do this.

WARNING: Don't rely on the painted arrows on the pointers in the compass to tell which pole is North and which is South; they don't all use the same convention. Make sure the pointers can rotate freely.

A. Construct Field Line #1: 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 in Figure 4:

Figure 4 Constructing magnetic field lines

B. Construct Field Line #2: Repeat the process described above, but this time, start with the compass touching the magnet approximately 1 cm (1/2 inch) in from the same end of the magnet that you used above.
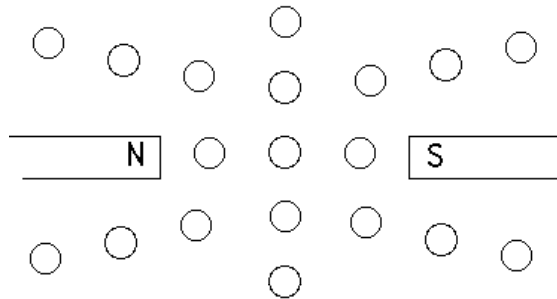
C. Construct Field Line # 3: Repeat once more, but start about 4 cm (1.5 inches) from the same end.

Question 1 (*answer on your tear-sheet at the end*):
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? What's going on?

Part 2: Constructing a Magnetic Field Diagram

Using a clean portion of the paper (or turn the paper over, or get a new piece of paper), arrange compasses and two magnets as shown in Figure 5 below. Allow enough room between the magnet poles to place three compasses roughly as shown below. ***Please do NOT force a north pole to touch a north pole or a south pole to touch a south pole, as this will demagnetize the magnets.***
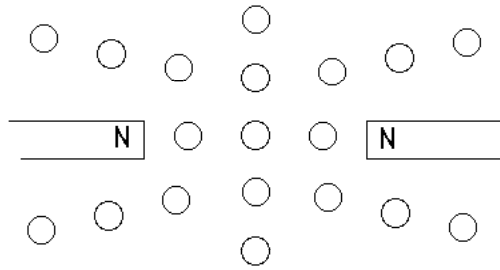
Figure 5 Two magnets with opposite poles facing each other.

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

Question 2 (*answer on your tear-sheet at the end*):
Transfer the field lines you have drawn on the brown paper to the figure on your tear-sheet at the end.

Next reverse one magnet so that the two north poles are facing each other, as shown in Figure 6:

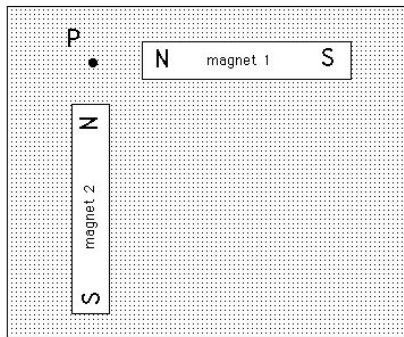**Figure 6** Two magnets with like poles facing each other.

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

Question 3 (*answer on the tear-sheet at the end*):
Transfer the field lines you have drawn on the brown paper to the figure on your tear-sheet at the end. Is there any place in this diagram where the magnitude of the magnetic field is equal to zero? Where?

Part 3: Superposition of Vector Fields

Place two bar magnets on the paper at right angles to one another as illustrated below in Figure 7. Let *P* be the point that lies along the centerlines of both magnets. Arrange the two bar magnets so that their ends are equidistant from *P*. Trace the outlines of the two magnets and label their poles.

Figure 7 Two magnets at right angles to each other.

Place a compass at point *P*. Mark the needle position with two dots, and draw an arrow indicating the needle's direction.

Now remove bar magnet 1 and indicate the compass needle's direction in the same manner as above. Then replace bar magnet 1 to its original position and remove bar magnet 2. Again, indicate the compass needle's direction by drawing an arrow. Are bar magnet 1 and bar magnet 2 of equal strength?

Next with both magnets back in the position shown above, move magnet 1 a few centimeters to the right and describe the change in direction of the needle. Move it a few more centimeters to the right, and again observe the result.

Question 4 (*answer on your tear-sheet at the end*):

Imagine that two bar magnets are placed at right angles to one another, arranged as shown in Figure 7. The magnets are equidistant from point *P*, the point that lies along the centerlines of both magnets. A compass is placed at the point *P*. In what direction does the needle point?

Prediction: _____

Observed Orientation: _____

Part 4: Measuring the Earth's Magnetic Field

You may wish to refer to Sections 9.5.1 of the 8.02 *Course Notes* for a discussion on the Earth's magnetic field at MIT.

APPARATUS

A. Connecting the Magnetic Field Sensor to the 750 Interface

To connect the magnetic field sensor to the 750 Interface, take the cable attached to the sensor (shown in Figure 8 below) and plug it into ANALOG CHANNEL A on the front of the 750 Interface, as shown in Figure 9 below

Figure 8 Top view of the 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.
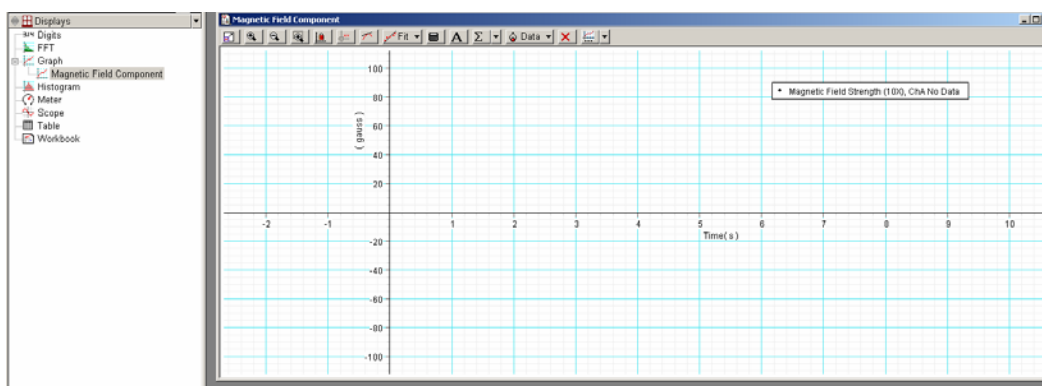

Figure 9 Frontal view of the 750 Interface, with the magnetic field sensor plugged into the "A" analog channel port.

B. The *DataStudio* Software

Download the Data Studio file **exp05.ds** from the web page and save it on your desktop. Open the activity by double clicking on the icon on the desktop. This Data Studio file is set to take data continuously when you hit START until you hit STOP (the START button changes to STOP once you start, and vice versa). You will be measuring one component of the magnetic field at the sensor (see description below). When the plot if the data taken reaches the right end of the graph the oldest data will drop off the screen.

You will probably find it convenient to start and stop often, and to erase previous data runs if they get in the way. To erase previous data runs, go to the Experiment menu item and select Delete ALL Data Runs.

Figure 10 The bottom of the screen after opening the **exp05.ds** file

C. Data Collection

Look at the top of your magnetic field sensor, as shown in Figure 8 above. The software is assuming that you have set the gain on the magnetic field sensor to 10X; look at on the magnetic field sensor and make sure the RANGE SELECT button is set on 10X. Now hit the TARE button on the top of the sensor. This action zeroes the sensor at the value of the field it is reading when you hit TARE. That is, *your measurement of the field is not an absolute measurement, but a relative measurement (relative to the value of the field when you hit the TARE button).*
The magnetic field sensor can measure the component of the magnetic field in two different directions:
1. along the axis of the probe (axial),
2. perpendicular to the axis of the probe (radial).

You choose which component the sensor will measure by using the switch marked RADIAL/AXIAL on the top of the sensor (see Figure 8).

If you choose axial, the sensor will measure the component of the magnetic field along the axis of the probe, giving **a positive value when the magnetic field is pointing *into* the white dot on the end of the probe.**

If you choose radial, the sensor will measure the component of the magnetic field perpendicular to the axis of the probe at the white dot on the side of the probe **giving a positive value when the magnetic field is pointing *into* this white dot.**

MEASUREMENTS

To get a sense of how the Magnetic Field Sensor operates, we'll start by using the sensor to find components of the magnetic field of the bar magnet used in Parts 1-3.

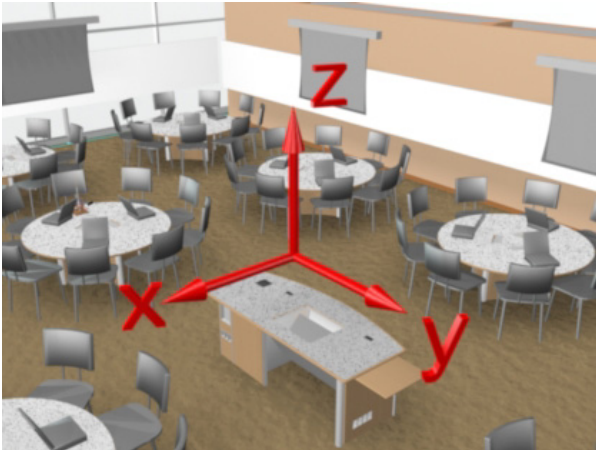### I: The axial component of the bar magnetic field

Use your magnetic compass to determine the North and South poles of your bar magnet. Put the sensor's range switch on 1X (the bar magnet field is much stronger than the earth's field), select AXIAL, and push the TARE button while the sensor is far away from the bar magnetic. Start taking data, and move the sensor towards one end of the bar magnet, with the probe on and parallel to the magnet axis. (Some find it easier to hold the sensor fixed and move the magnet.) On your graph, notice the sign of the magnetic field when the sensor points towards the North pole and when the sensor points towards the South pole.

II: The radial component of the bar magnetic field

Now select RADIAL and push the TARE button. Repeat the above step, keeping the same orientation of the sensor and magnet. Move the sensor from side to side.

III. Measuring the magnetic field of the Earth

In Figure 11 a Cartesian coordinate system is shown for the TEAL classroom.

Figure 11 Coordinate system for the TEAL classroom.

The horizontal component of the Earth's magnetic field

Put the sensor's range switch on 10X, select RADIAL and push the TARE button. Then watch how the measured component of the magnetic field changes as you move the probe

to different orientations.   Do this by holding the sensor by the connecting cable (to the right, just out of the range of Figure 8 above) so that the probe points vertically down, and let the sensor rotate.   This ensures that the component measured is horizontal. Identify the direction in the *x-y* plane in which the horizontal component of the magnetic field is largest. (Unless you're clever about how you "Tare" the sensor, your measured field component will probably **NOT** be symmetric about zero).   Mark this direction as best you can, with a ruler or pencil on the tabletop or floor.
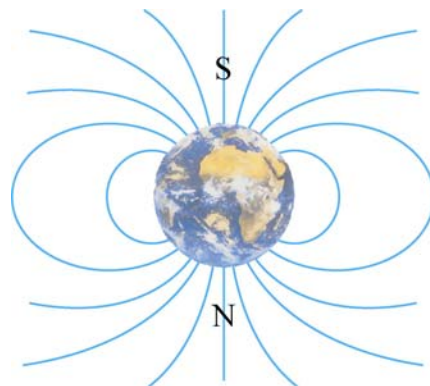
The direction of the Earth's magnetic field

Keep the sensor's range switch on 10X, select AXIAL and push the TARE button. Move the magnetic field sensor in a circle in a plane perpendicular to the floor that intersects the *x-y* plane along the line in which the horizontal component of the magnetic field is largest. Identify the direction in which the Earth's magnetic field points. Do this by specifying the direction found in the part above, and by estimating the angle that the field direction makes with the vertical.

Using the coordinate system in Figure 11, your group should then decide upon answers to the following questions**:**

Question 5 (*answer on your tear-sheet at the end*): Based on your measurements, what angle does the horizontal component of the magnetic field make with the *x*-axis shown in Figure 11? Give your answer in degrees; an approximate value is ok.

Question 6 (*answer on your tear-sheet at the end*): Based on your measurements, what is the ratio of the *vertical* to the *horizontal* component of the Earth's magnetic field in classroom? An approximate value is ok.

Question 7 (*answer on your tear-sheet at the end*):
The plot on the right shows the magnetic field of the Earth. Boston's latitude is about 45°
(it's closer to 42°, but we're not that precise today).
Does your answer agree with what you expect on the basis of looking at this plot?

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Tear off this page and turn it in at the end of class.

Note:
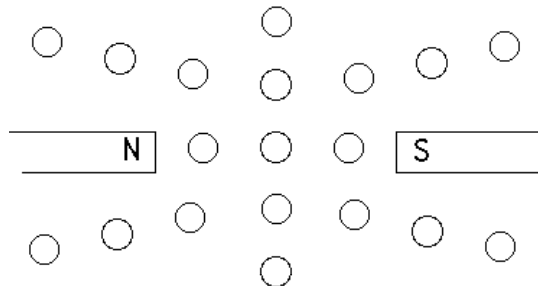**Writing in the name of a student who is not present is a Committee on Discipline offense.**

Experiment Summary 5: Bar Magnet and Earth's Magnetic Field
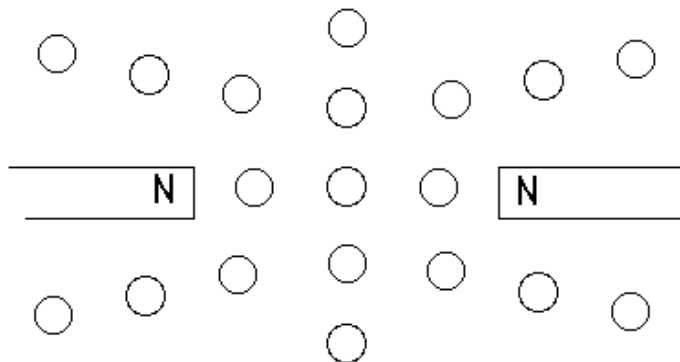
Group and Section _____ **(e.g. 10A, L02: Please Fill Out)**

Names _____

_____

_____

Question 1: Some of your field lines wander off and never come back to the bar magnet. Which part of your bar magnet do the ones that never return come from? What's going on?

Question 2: Transfer the field lines you have drawn on the brown paper to the figure below.

Question 3: Transfer the field lines you have drawn on the brown paper to the figure on the next page. Is there any place in this diagram where the magnitude of the magnetic field is equal to zero? Where?

Question 4: Two bar magnets are placed at right angles to one another. A compass is placed at the point *P* in Figure 7. In what direction does the needle point?

   Prediction: _____

   Observed Orientation: _____

Question 5: Based on your measurements, what angle does the horizontal component of the magnetic field make with the *x*-axis in Figure 11? An approximate value is ok.

Answer: _____ degrees

Question 6: Based on your measurements, what is the ratio of the *vertical* to the *horizontal* component of the Earth's magnetic field in classroom? An approximate value is ok.

Answer: _____

Question 7: The plot on page E05-8 shows the magnetic field of the Earth. Boston's latitude is about 45°. Does your answer agree with Question 6 with what you expect on the basis of looking at this plot?

Answer: _____