The Magnetic Field of a Permanent Magnet

Introduction

A bar magnet is called a *dipole* since it has two poles, commonly labeled North and South. Breaking a magnet in two does not produce two isolated poles; each fragment still has two poles. Similarly, two magnets together still exhibit only two poles. Since to our knowledge there are no magnetic monopoles, the dipole is the simplest possible magnetic field source. The dipole field is not limited to bar magnets, for an electrical current flowing in a loop also creates this common magnetic field pattern.

The magnetic field \(B_{\text{axis}}\) measured in teslas (T) of an ideal dipole measured along its axis is

\[
B_{\text{axis}} = \frac{\mu_0}{4\pi} \frac{2\mu}{d^3}
\]

where \(\mu_0\) is the permeability constant \((4\pi \times 10^{-7} \text{ T m/A})\), \(d\) is the distance from the center of the dipole in meters and \(\mu\) is the magnetic moment. The magnetic moment \(\mu\) measures the strength of a magnet, much like electrical charge measures the strength of an electric field source. Note that the distance dependence of this function is an inverse-cube function, which is different from the inverse-square relationship you may have studied for other situations.

In this lab, you will examine how the magnetic field of a small, powerful magnet varies with distance, measured along the axis of the magnet. A Magnetic Field Sensor will be used to measure the magnitude of the field.

Simple laboratory magnets are approximately dipoles, although magnets of complex shapes will exhibit more complex fields. By comparing your field data to the field of an ideal dipole you can see if your magnet is very nearly a dipole in its behavior. If it is nearly a dipole, you can also measure its magnetic moment.

Objectives

In this experiment, you will
- Use a computer to measure magnetic field strength.
- Graph and analyze data.
- Make conclusions about the relationship between magnetic field strength and distance.
- Measure and graph magnetic field strength at points along a bar magnet.
- Make conclusions about the magnetic field at various points on a bar magnet.

Materials

*Do not drop magnets or place them next to computer screen.*

- Powerful enough to disrupt hard drive.
- Computer
- Tape
- Vernier computer interface
- Bar magnet
• Logger Pro
• Meter stick
• Magnetic Field Sensor

Figure 1

Preliminary Question

Place one magnet on a table and hold the other in your hand, well above the first. From directly above, slowly lower the upper magnet toward the first. Watch for the moment when the lower magnet jumps up to meet the upper. Separate the magnets and try again. From the sudden jump of the lower magnet, what can you conclude about the way the magnetic force between the magnets varies with distance?

Procedure

Part A: Magnetic Field Strength and Distance
1. Tape a meter stick to the table top at its 50 cm and 95 cm lines. Tape a Magnetic Field Sensor perpendicular to the table top as shown in Figure 1. The edge of the Magnetic Field Sensor should be at the zero line of the meter stick. The small white spot should be facing the meter stick. The sensor should be set to 6.4 mT (low amplification). Do not put a magnet near the sensor yet.
2. Connect the Magnetic Field Sensor to the computer interface. Prepare the computer for data collection by opening the file “27a Magnetic Field” from the Physical Science w/ Vernier folder. (zero the sensor away from any magnets)
3. Click Collect to begin data collection.
4. Collect data at the 4 cm distance.
   a. Place the N pole of the bar magnet at the 4 cm line of the meter stick. If the poles are not marked, orient the magnet so that you get positive magnetic field readings. Keep the magnet in this orientation throughout Part A. When the reading has stabilized, click Keep
   b. Type 4 in the edit box (for 4 cm from the end of the magnet).
   c. Press ENTER. The magnetic field strength value for 4 cm is now saved.
5. Move the magnet and repeat the Step 4 procedure at each 2 cm interval up to 14 cm.
6. Click to end data collection. Record the magnetic field strength values displayed in the table in your data table.
7. Print copies of the graph.

**Part B: Mapping a Bar Magnet’s Magnetic Field**

8. Using tape, tape a ruler to your desk top. Place a bar magnet beside the ruler. Position the S-pole end of the magnet at the 3 cm mark as shown in Figure 2. Tape the magnet to the table top.

9. Prepare the computer for data collection by opening the file “27b Magnetic Field” from the Physical Science w Vernier folder.
10. Click Collect to begin data collection.
11. Collect data at the 0 cm distance.
   a. Place the Magnetic Field Sensor perpendicular to the bar magnet as shown in Figure 2. Center the white spot at the 0 cm mark of the ruler. Rotate the Magnetic Field Sensor so the white spot faces up and is parallel to the table top. Keep the white spot parallel to the table top throughout Part B. When the reading has stabilized, click **Keep**.
   b. Type 0 in the edit box (for 0 cm).
   c. Click **OK**. The magnetic field strength value for 0 cm is now saved.

12. Move the sensor, and repeat the Step 11 procedure at 1 cm intervals until you have reached a point 3 cm beyond the N-pole end of the bar magnet.
13. Click **Stop** to end data collection. Record the magnetic field strength values displayed in the table in your data table.
14. Print copies of the graph as directed by your teacher.

**Part A**

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### Analysis

**Part A: Magnetic Field Strength and Distance**
1. What happens to magnetic field strength as distance increases?
2. What would the magnetic field strength be at 7 cm? What would it be at 16 cm?
3. What is the dipole moment of the magnet?

**Part B: Mapping a Bar Magnet’s Magnetic Field**
3. Where on the bar magnet was the largest positive magnetic field strength reading observed?
4. Where on the bar magnet was the most negative magnetic field strength reading observed?
5. At what centimeter distance does your graph have a zero value magnetic field strength value? At what point is this on the bar magnet?
6. Why does the graph have both positive and negative magnetic field strength values?
7. Use what you learned in Part A to explain the shapes of the end portions of your Part B graph.

### Extensions

1. Stack similar magnets, one at a time, and measure the combined field strength. Graph your data and describe the relationship you find.
2. Place two magnets 5 cm apart and facing each other. Use a Magnetic Field Sensor to explore the field strength between the magnets. Try N-N, N-S, and S-S pole combinations. What differences do you find?
Concluding Questions

1. How would you change the magnetic moment of a permanent magnet?
2. The magnets used in this lab are cow magnets. Explain the practical use of these magnets and why such a design and material might be chosen.