(version 6/26/06)

Magnetic Fields

Goals

1) To visualize the magnetic fields produced by several different configurations of simple bar magnets using iron filings.

2) To use small magnetic compasses to trace out the magnetic field lines of a single bar magnet on a large sheet of paper.

3) To calculate the "pole strength" of the two magnetic poles of the bar magnet by determining the location(s) of null points where the net magnetic of Earth and the bar magnet sum to zero.

Introduction

A magnetic field exerts forces on a compass needle such that the needle tends to align itself with the direction of the field. If the magnetic field is strong enough and additional non-magnetic forces (gravity, etc.) are negligible, then the compass needle points for all practical purposes in the direction of the field. In this lab the magnetic fields surrounding bar magnets are mapped out using a compass and iron filings.

The end of your compass needle that points toward the magnetic pole of the Earth in the northern hemisphere (when it is far away from any magnet or other magnetic material) is by definition an N pole. Then we must conclude that the earth's magnetic pole in northern Canada is actually an S pole, since the N pole of the compass points to it and unlike poles attract. The N pole of the compass needle points toward the S pole of your magnet. The magnetic poles of all magnets can thus be labeled by means of a compass and the definition of an N pole as just stated.

Exercise 1: Observing Magnetic Fields with Iron Filings

In the presence of a magnetic field iron filings act like many small compass needles. By spreading them out on the paper above the magnet a "picture" of the magnetic field is produced. At your lab station you have a piece of particle board with some grooves in it of just the right size to hold the bar magnets.

Warning - Please do not pick up iron filings with the magnet. The filings are very difficult to remove from the magnet. See instructions for getting the filings back in the jar under 2(d) below.

1. Draw a full scale outline of the bar magnet on fresh piece of paper and label the N and S poles. Place the bar magnet in the middle groove of the particle board and cover it with a second piece of white paper. Sprinkle iron filings around on the surface of this second sheet of paper. Now on the first sheet of paper with the outline of the bar magnet already drawn make a careful free hand sketch of the magnetic field lines as shown by the iron filings. **On your sketch include the direction of the field lines by means of arrows. By convention the field lines go from the N pole to the S pole outside the magnet itself.** [Note: Each person in your lab group is expected to draw her/his own sketch here.]

2. Now repeat this process for the following configurations of bar magnets. In each case sketch the magnetic field lines and indicate the direction of the field lines everywhere on your sketch.

   a. Place two bar magnets end to end in the same groove along the middle of the particle board with their N poles several centimeters apart.

   b. Place two bar magnets side by side in parallel grooves with either like poles near or unlike poles near each other.

   c. Pick another configuration of your choice.

   d. To pick up the iron filings, **DO NOT USE THE MAGNET**! Place the jar on a clean piece of paper and open the lid. (Filings often will spill out from under the lid.) Gently lift the paper with filings off of the magnet. Let the paper sag to make a funnel of sorts, and then pour the filings into the jar. Replace the jar cover.

3. Data analysis/Conclusions.

   a. Describe the general characteristics of the field that you observe.

   b. On your sketches label by some means the regions where the magnetic field is strongest and weakest for each configuration. Are there any points where the field is essentially zero? Identify these locations clearly as well. Be sure to include the reasoning behind your answers.

   c. Can you find any places where the magnetic field lines ever cross? If there was a spatial point where two field lines crossed, what would the direction of the field be at that point? If there are fields from two sources present at some point in space, for instance the magnetic fields of Earth and the bar magnet, will some iron filings feel forces from one field and other filings feel forces from the other field, or will all filings feel forces from both fields simultaneously? Discuss/explain.

Exercise 2: Mapping the Magnetic Field of a Bar Magnet with a Magnetic Compass

1. The set-up

   a. Tape a large sheet of paper to the hardboard sheet (approx. 1 m^2) located at your lab station. Place a bar magnet at the center of the sheet oriented as directed by your TA.

b. Carefully outline the bar magnet and mark the orientation of its magnetic poles on the sheet of paper.

2. Making the map

a. You can start your map anywhere in principle, but let's start with a point about 10 cm from the center of the magnet. Place the compass on your paper. Use a non-magnetic pencil (**Check this carefully!**) to put dots on the paper at the tip and tail of the arrow of the compass.

b. Now move the compass (approximately one diameter) so that the tail of the arrow is at the point where the tip was previously. Put a dot at the location of the tip of the arrow. Repeat this procedure until you move off the edge of the paper or run into the magnet itself.

c. To complete the field line in the other direction go back to the initial position, but this time move the compass so that the tip of the arrow is where the tail was previously. This time put a dot at the location of the tail of the arrow and repeat.

d. Connect all the dots with a smooth curve. This now constitutes one magnetic field line. Before proceeding put arrows on the line to indicate which way the magnetic field is pointing.

e. Choose a new starting point and repeat the procedure until you have filled your paper with field lines. Check with your TA to make sure that you have sufficiently mapped the field.

3. Data analysis/Conclusions.

a. Are there any regions on the map that the field lines seem to avoid? What is the magnetic field at these points? Explain your reasoning. How many such points are there on your map?

b. Look at the magnetic field maps done by the other lab groups in your lab section. Each map has been made with a different orientation of the bar magnet. Sketch simple half-page diagrams of these other map configurations to include with your report. Do these other maps have any features in common with your map? How do they differ from your map? Explain.

Exercise 3: Finding the Magnetic Pole Strength of the Bar Magnet

When a magnet is immersed in the Earth's magnetic field, the resulting field is the vector sum of the magnet's field and Earth's field. In regions where the magnet's field is larger than Earth's field, a compass aligns itself more with the magnet's field. In regions where Earth's field dominates, a compass aligns more with Earth's field.

You should be able to see this effect on your magnetic field map from Exercise 2. As you move away from the bar magnet and its field gets weaker, Earth's field, which is pointing in a known direction and is essentially constant everywhere on your map, begins to dominate. Use your knowledge of the magnetic field of a bar magnet alone to predict the direction of the field due to only the bar magnet at the "special" point(s) that field lines have avoided. Note the direction of Earth's magnetic field at this same "special" point. This result suggests that the sum of the fields from the bar magnet and Earth cancel at this point, thus summing to zero net field. Look at the other map configurations to determine whether this seems to be a general result.

Since the magnetic force between two magnetic poles experimentally behaves similarly to the electric force between two electric charges, a useful method for characterizing a magnetic pole is the so-called "pole strength" in analogy to the amount of electric charge. Magnetic poles differ from electric charges in one important way. Magnetic poles always occur in pairs, one N pole (analogous to a positive electric charge) and one S pole (analogous to a negative electric charge) of the same pole strength. We have yet to observe in nature an N pole (or S pole) existing all by itself, even though such an entity (called a "magnetic monopole") holds significant theoretical interest and has been the object of numerous experimental searches. On the other hand electric charge can occur as isolated positive or negative charge. For the bar magnet let us define the symbol, q_m, as the magnitude of the pole strength. We can then write an expression for the magnetic field of the bar magnet at any point outside the magnet in vector format as follows:

1) $\boldsymbol{B}_{bar} = (\mu_o q_m/4\pi)[(1/r_N^2)$ *{pointing radially away from the N pole}* $+ (1/r_S^2)$ *{pointing radially toward the S pole}*$]$

where r_N is the distance from the N pole of the magnet to the point where we wish to find the value of the field and r_S is the distance from the S pole of the magnet to this same point. Since the magnetic field is a vector quantity we must be careful to add the fields from the N and S poles, respectively, as vectors.

On your magnetic field map from Exercise 2 choose a special "null" point where the magnetic fields of Earth and the bar magnet exactly cancel one another. Earth's magnetic field actually points downward at an angle of about 70^0 relative to the surface of Earth at the latitude of Pullman, but the magnetic field map done previously was only in a horizontal plane, and the compasses are constrained to rotate only about a vertical axis so they only respond to the horizontal (parallel to Earth's surface) component of Earth's magnetic field. In other words the magnetic fields of the bar magnet and only the horizontal component of Earth's field are canceling at a "null" point. Mathematically this means that

2) $\boldsymbol{B}_{bar} + \boldsymbol{B}_{Earth}$ *(horizontal component only)* $= \boldsymbol{0}$

The magnitude of the horizontal component of Earth's field is 1.9×10^{-5} T here at Pullman. Knowing this value it is now possible to use Eqs. 1 and 2 to solve for q_m. A suggestion is to choose a coordinate system having its positive x-axis in the direction of Earth's magnetic field at the "null" point, and draw it directly on your field map. This simplifies Eq. 2 so that we only need to look at x-components of $\boldsymbol{B}_{bar}$. Then you can draw radial lines from the N and S poles of the bar magnet (note that these poles do not seem to be right at the ends of the magnet) through the "null" point, and measure the angles that these radial lines make with the x-axis previously drawn in order the calculate the x-components. After measuring r_N and r_S you can now put all the numbers into Eqs. 1 and 2 with q_m as the only unknown and complete the solution.

By dimensional analysis figure out the SI units for magnetic pole strengths to include with your numerical value. (Note that μ_o is a constant with "units.")

Summary and Conclusions:

Summarize your results and make any final conclusions.