Lab 5. Magnetic Fields

Goals

- To visualize the magnetic fields produced by several different configurations of simple bar magnets using iron filings.
- To use small magnetic compasses to trace out the magnetic field lines of a single bar magnet on a large sheet of paper.
- To calculate the magnetic flux passing through the bar magnet by determining the locations of the points where the magnetic fields of the Earth and the bar magnet sum to zero.

Introduction

A magnetic field exerts forces on a compass needle (a small magnet) 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 other magnets and magnetic materials) is by definition a N (north-seeking) pole. Therefore 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.

Keep cell phones, credit cards, mechanical watches, etc. away from the big magnet on the TA table. Keep compasses at least 20 cm away from big magnet. The big magnet is used to "remagnetize" the bar magnets used in this laboratory. This can become necessary if the bar magnets are dropped or get too close to other magnets. If the poles are reversed on your bar magnet, or it is unusually weak, ask your teaching assistant to remagnetize it.

Mapping 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 to hold the bar magnets.

Do not pick up iron filings with the magnet. The filings are difficult to remove from 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. Then replace the jar cover.

Sketch field lines for isolated bar magnet

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. Gently tapping the board will often make the pattern of field lines more clear. 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 shown by the iron filings. **On your sketch include the direction of the field lines by means of arrows. By convention the field lines outside the magnet itself go from the N pole to the S pole.** Each member of your lab group is expected to draw their own sketch.

Sketch field lines for more complex configurations

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.

1. Place two bar magnets end-to-end in the same groove along the middle of the particle board with their N poles 2-3 centimeters apart.
2. Place two bar magnets side by side in parallel grooves with either like poles near or unlike poles near each other.
3. Pick another configuration of your choice. Ensure at least a 2-3 cm gap between any magnets in a common groove.

Analyze your drawings

1. Describe the general characteristics of the fields that you observe.
2. On your sketches label the regions where the magnetic field is especially strong and where it is especially weak for each configuration. Are there any points where the field is essentially zero? Identify these locations clearly as well. Include the reasoning you use to identify these regions of strong and weak fields.
3. Can you find any places where the magnetic field lines cross? If there were a point in space where two field lines crossed, what would the direction of the field be at that point? If magnetic fields from two difference sources are 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.

Mapping a magnetic field with a compass

Equipment set up

1. Tape a large sheet of paper to the hardboard sheet (area about 1 m^2) located at your lab station. Orient a bar magnet at the center of the sheet as directed by your TA.
2. Carefully outline the bar magnet and mark the orientation of its magnetic poles on the sheet of paper.

Map the field

1. 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.
2. 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.
3. 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.
4. 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.
5. 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.

Analyze your map

1. 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?
2. Look at the magnetic field maps drawn by the other lab groups in your lab section. Each map has been made with the bar magnet in a different orientation. Sketch simple halfpage diagrams of these other map configurations to include with your lab notes. Do these other maps have any features in common with your map? How do they differ from your map? Explain.

Calculating the magnetic flux of the 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. As you move away from the bar magnet and its field gets weaker, Earth's field, which is essentially constant everywhere on your map, begins to dominate. Use your knowledge of the magnetic field due to 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 the Earth cancel at this point, summing to zero net field. Look at the other map configurations to determine whether this seems to be a general result.

Magnetic field lines exit the N pole of the magnet, circle around, enter the S pole of the magnet, and return through the magnet to the N pole. Since magnetic charges have never been observed, we can safely assume that every field line observed outside the magnet passes through the magnet itself. A useful measure of the strength of a magnet is the magnitude of the magnetic flux, Φ_{BAR}, passing through the magnet. This flux equals the product of the average magnetic field inside the magnet and its cross sectional area.

The pattern of magnetic field lines *outside* a magnet looks much like the pattern of electric fields lines from an electric dipole. That is, the vector sum of a radially outward field from a N pole and a radially inward field into a S pole will circle around from the N pole to the S pole outside the magnet, as observed. The critical difference between magnetic and electric dipoles is that the magnetic field lines complete the circuit through the magnet, running from the S pole to the N pole. In addition, the N and S poles are not right at the ends of the physical magnet. A sketch of the relation between a "fat" physical magnet and the ideal, thin magnet used to model it is shown in Figure 5.1.[1] Although the magnetic field is only approximated by the dipole field, the approximation is quite good at positions far from the magnet.

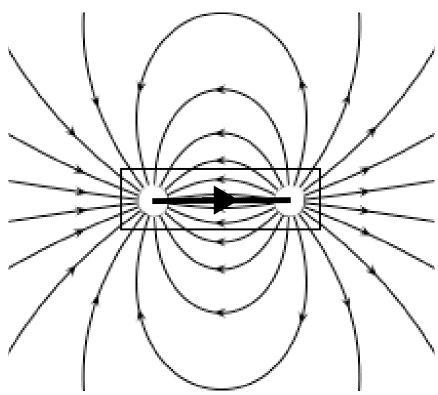

Figure 5.1. Sketch of the magnetic field due to an ideal, infinitely thin permanent magnet. The thick dark line represents the ideal magnet, while the dotted line outlines the corresponding physical magnet.

We will use this approximation to determine the magnetic flux of the bar magnet. That is, we will treat the magnetic field *outside* the magnet, $\mathbf{B_{BAR}}$, as the sum of a vector directed away from the N pole, $\mathbf{B_N}$, and another vector directed into the S pole, $\mathbf{B_S}$.

$$\mathbf{B_{BAR}} = \mathbf{B_N} + \mathbf{B_S} \quad , \tag{5.1}$$

[1] The image of the field lines, without the magnets, was supplied by the Wikimedia Commons.

where $\mathbf{B_N}$ and $\mathbf{B_S}$ vary with distance like electric fields (Coulomb's law). In the case of magnets, however, the source of these fields are the magnetic fluxes leaving the N pole and entering the S pole. At distances far from the poles, the equation for the magnetic field due to one pole can be obtained from Coulomb's law by replacing q/ε_0 with Φ_{BAR}. (The total electric flux from a positive point charge is q/ε_0 by Gauss's Law.)

$$\begin{aligned} \mathbf{B_N} &= \frac{\Phi_{BAR}}{4\pi r_N^2} \qquad \{\text{Pointing radially away from the north pole}\}, \text{ and} \\ \mathbf{B_S} &= \frac{\Phi_{BAR}}{4\pi r_S^2} \qquad \{\text{Pointing radially away from the south pole}\}. \end{aligned} \tag{5.2}$$

Figure 5.2 shows a typical null point and the vectors $\mathbf{B_N}$ and $\mathbf{B_S}$ showing the contribution of the magnet's N and S poles to the magnetic field at the null point. In the equations and the diagram, r_N is the distance from the N pole of the magnet to the null point and r_S is the distance from the S pole of the magnet to the null point. Since the magnetic field is a vector quantity we must be careful to add the fields associated with the N and S poles as vectors.

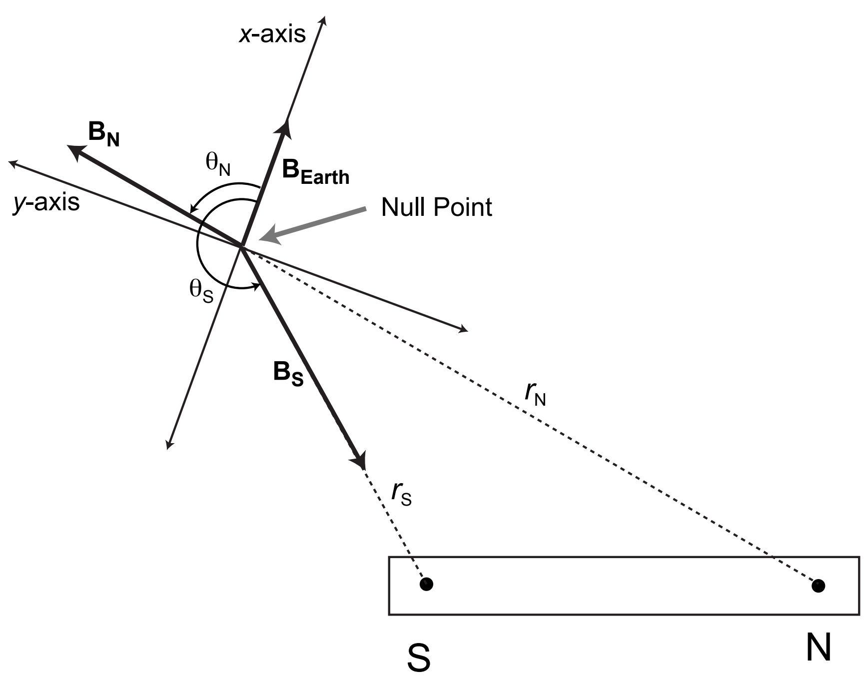

Figure 5.2. Diagram of a coordinate system with its origin at a null point and with its $+x$-axis pointing in the direction of the Earth's magnetic field vector, $\mathbf{B_{Earth}}$. Also shown are $\mathbf{B_N}$ and $\mathbf{B_S}$, vectors that mathematically represent the contribution of the N and S poles of the magnet to the magnetic field at the null point. The distances from null point to the N and S poles of the magnet are labeled r_N and r_S, respectively.

On the magnetic field map you made with a compass, choose one of the special "null" points where the magnetic fields of Earth and the bar magnet cancel one another. Earth's magnetic field actually points downward at an angle of about 70° relative to the surface of Earth at the latitude of Pullman, but the magnetic field map you have drawn lies only in a horizontal plane. Further, our compasses are constrained to rotate only about a vertical axis, so they respond only to the horizontal (parallel to Earth's surface) component of Earth's magnetic field. In other words the magnetic field of the bar magnet cancels only the horizontal component of Earth's field at a null point. That is,

$$\mathbf{B_N} + \mathbf{B_S} + \mathbf{B_{Earth}} = \mathbf{0} \qquad \{\text{horizontal component only}\} \tag{5.3}$$

at a null point. The magnitude of the horizontal component of Earth's field is 1.9×10^{-5} T here at Pullman. Show the direction of Earth's field on your map at your null point. Now you know the horizontal component of $\mathbf{B_{Earth}}$ (both direction and magnitude) at the null point. Define a coordinate system with its origin at the null point and with the positive x-axis in the direction of Earth's magnetic field at the null point, as shown in Figure 5.2. Draw this coordinate system directly on your field map. This choice of coordinate system simplifies the equations so that we only need to look at the x-components of $\mathbf{B_N}$ and $\mathbf{B_S}$. Then you can draw radial lines from the N and S poles of the bar magnet to the null point. The lengths of these lines give you r_N and r_S. After measuring the angles θ_N and θ_S (shown in Figure 5.2), you can calculate the x-components of the magnetic fields associated with $\mathbf{B_N}$ and $\mathbf{B_S}$ in terms of Φ_{BAR}. Since Φ_{BAR} is the only remaining unknown, you can complete the solution.

	No Effort	Progressing	Expectation	Scientific
SL.A.a Is able to analyze the experiment and recommend improvements Labs: 1-3, 5, 7, 9, 11, 12	No deliberately identified reflection on the efficacy of the experiment can be found in the report	Description of experimental procedure leaves it unclear what could be improved upon.	Some aspects of the experiment may not have been considered in terms of shortcomings or improvements, but some are identified and discussed.	All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made. Justification is provided for certainty of no shortcomings in the rare case there are none.
SL.A.b Is able to identify the hypothesis for the experiment proposed Labs: 4-6	No deliberately identified hypothesis is present in the first half page or so of notes	An attempt is made to state a hypothesis, but no clearly defined dependent and independent variable, or lacking a statement of relationship between the two variables	A statement is made as a hypothesis, it contains a dependent and independent variable along with a statement of relationship between the two variables. This statement appears to be testable, but there are some minor omissions or vague details.	The hypothesis is clearly stated and the direct link to the experiment at hand is apparent to any reasonably informed reader.

	No Effort	Progressing	Expectation	Scientific
SL.A.c Is able to determine hypothesis validity Labs: 4-6	No deliberately identified attempt to use experimental results to validate hypothesis is present in the sections following data collection.	A statement about the hypothesis validity is made, but it is not consistent with the data analysis completed in the experiment	A statement about the hypothesis validity is made which is consistent with the data analysis completed in the experiment. Assumptions which informed the hypothesis and assumptions not validated during experimentation are not taken into account.	A statement about the hypothesis validity is made which is consistent with the data analysis and all assumptions are taken into account.
SL.B.b Is able to explain patterns in data with physics principles Labs: 1-3, 5, 7, 9-11	No attempt is made to explain the patterns in data	An explanation for a pattern is vague, OR the explanation cannot be verified through testing, OR the explanation contradicts the actual pattern in the data.	An explanation is made which aligns with the pattern observed in the data, but the link to physics principles is flawed through reasoning or failure to understand the physics principles.	A reasonable explanation is made for the pattern in the data. The explanation is testable, and accounts for any significant deviations or poor fit.
CT.A.b Is able to identify assumptions used to make predictions Labs: 4-6	No attempt is made to identify any assumptions necessary for making predictions	An attempt is made to identify assumptions, but the assumptions stated are irrelevant to the specific predicted values or apply to the broader hypothesis instead of the specific prediction	Relevant assumptions are identified regarding the specific predictions, but are not properly evaluated for significance in making the prediction.	Sufficient assumptions are correctly identified, and are noted to indicate significance to the prediction that is made.
CT.A.c Is able to make predictions for each trial during experiment Labs: 4-6	Multiple experimental trials lack predictions specific to those individual trial runs.	Predictions made are too general and could be taken to apply to more than one trial run. OR Predictions are made without connection to the hypothesis identified for the experiment. OR Predictions are made in a manner inconsistent with the hypothesis being tested. OR Prediction is unrelated to the context of the experiment.	Predictions follow from hypothesis, but are flawed because relevant experimental assumptions are not considered and/or prediction is incomplete or somewhat inconsistent with hypothesis or experiment.	A prediction is made for each trial set in the experiment which follows from the hypothesis but is hyper-specific to the individual trial runs. The prediction accurately describes the expected outcome of the experiment and incorporates relevant assumptions.
CT.B.a Is able to describe physics concepts underlying experiment Labs: 1-3, 5, 7, 9-12	No explicitly identified attempt to describe the physics concepts involved in the experiment using student's own words.	The description of the physics concepts underlying the experiment is confusing, or the physics concepts described are not pertinent to the experiment for this week.	The description of the physics concepts in play for the week is vague or incomplete, but can be understood in the broader context of the lab.	The physics concepts underlying the experiment are clearly stated.

	No Effort	Progressing	Expectation	Scientific
QR.B Is able to identify a pattern in the data graphically and mathematically Labs: 1-3, 5, 7, 9-11	No attempt is made to search for a pattern, graphs may be present but lack fit lines	The pattern described is irrelevant or inconsistent with the data. Graphs are present, but fit lines are inappropriate for the data presented.	The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity - is the proportionality linear, quadratic, etc. Graphs shown have appropriate fit lines, but no equations or analysis of fit quality	The patterns represent the relevant trend in the data. When possible, the trend is described in words. Graphs have appropriate fit lines with equations and discussion of any data significantly off fit.
IL.A Is able to record data and observations from the experiment Labs: 1-12	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.
WC.A Is able to create a sketch of important experimental setups Labs: 1, 2, 4-8	No sketch is constructed.	Sketch is drawn, but it is incomplete with no physical quantities labeled, OR important information is missing, OR it contains wrong information, OR coordinate axes are missing.	Sketch has no incorrect information but has either a few missing labels of given quantities, or subscripts are missing/inconsistent. Majority of key items are drawn with indication of important measurements/locations.	Sketch contains all key items with correct labeling of all physical quantities and has consistent subscripts. Axes are drawn and labeled correctly. Further drawings are made where needed to indicate precise details not possible in the scale of initial sketch.

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 5 Magnetic Fields:

Name: ____________________ Lab Partner: ____________________

EXIT TICKET:

- ☐ Return the bar magnet(s) to the TA Table.
- ☐ Put your rulers, compasses, and iron filings in the basket at your workstation.
- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Required Level of Effort.
  - ☐ Complete the pre-lab assignment ☐ Arrive on time
  - ☐ Work well with your partner ☐ Complete the lab or run out of time

SL.A.a	
SL.A.b	
SL.A.c	

SL.B.b	
CT.A.b	
CT.A.c	
CT.B.a	

QR.B	
IL.A	
WC.A	

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SL.A.b	
SL.A.c	

SL.B.b	
CT.A.b	
CT.A.c	
CT.B.a	

QR.B	
IL.A	
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