EXPERIMENT 2
MAGNETIC FIELD PLOTTING

I. THEORY

Compass needles and bar magnets which are free to rotate are observed to orient themselves along magnetic field lines. For the common use of a compass, these field lines are the magnetic field lines of the Earth. Opposite ends of a magnet or compass needle are labeled "North" and "South". North and South poles exhibit similar properties as positive and negative electric charges. Like poles repel each other and opposite poles attract each other. Thus, the North pole of a compass needle is attracted to the South Magnetic pole of the Earth and the South pole of a compass needle is attracted to the North Magnetic pole of the Earth. The South Magnetic pole of the Earth is not at a fixed location on the Earth; its location in 2003 was 78°18' North, 104° West, near Ellef Ringness Island, one of the Queen Elizabeth Islands, in Canada according to NationMaster.com (http://www.nationmaster.com/encyclopedia/North-Pole).

If poles of two different magnets are brought near each other, it is found that like poles repel each other and unlike poles attract. The force is found to increase as the distance between the poles decreases.

It is found experimentally that the two poles of a magnet are always equal in strength; that is, they exert forces of equal magnitude on a third pole located equally distant from the two given poles. It is not possible to isolate the two poles of a magnet; if the magnet is sawed into two shorter pieces, each will have a North and a South pole.

A magnetic field is said to exist at a point in space if the needle of a test compass placed at the point always returns to the same orientation after being disturbed. In the absence of a magnetic field, the needle will remain in any orientation in which it is placed.

The magnetic field (also called magnetic induction) $\vec{\mathbf{B}}$ at a point is a vector whose direction is the same as the direction in which a test compass points if placed at the point. This is also the direction of the force which would act on a test north pole if placed at the point of interest. By analogy with the electric field, the magnitude of the magnetic field may be defined as the force acting on a test pole, divided by the pole strength of the test pole, although modern textbooks define both the magnitude and the direction of the magnetic field in terms of the force acting on a moving charge, as we will see later in this course. The magnetic field vector near a North pole points away from the pole; the field near a South pole points toward the pole.

Since the force between two poles falls off with increasing distance between the poles, it is reasonable to assume that the magnetic field due to a single pole falls off with distance in a similar way. Assume that the field varies inversely as some power n of the distance r from the pole:

$$B = \frac{C}{r^n} \qquad (1)$$

The constant C used here cannot be a universal constant, since it clearly depends on the strength of the pole producing the field.

In the vicinity of a bar magnet the resultant field is the vector sum of the fields due to the two poles separately. That is,

$$\vec{\mathbf{B}} = \vec{\mathbf{B}}_{\mathbf{N}} + \vec{\mathbf{B}}_{\mathbf{S}} \tag{2}$$

Since each component field of equation (2) is given by equation (1), and since the two poles of any bar magnet are of equal strength, it follows that the ratio of B_N to B_S should depend only on the quantity n and on the distances to each pole, as follows:

$$B_N / B_S = (r_S / r_N)^n \tag{3}$$

The unknown constant C of equation (1) has cancelled out. Equation (3) may be solved for n when r_S and r_N are not equal,

$$n = \log(B_N / B_S) / \log(r_S / r_N) \tag{4}$$

Note that the subscripts occur in opposite order in the numerator and denominator of this equation.

One purpose of this experiment is to make a rough approximation to n, using equation (4).

Another purpose of this experiment is to trace out magnetic field lines in the vicinity of sets of poles, so as to obtain a graphical representation of the forces which would act on any test pole placed there. Magnetic field lines are curved lines drawn in space in such a way that a tangent line at any point is parallel to the magnetic field vector at that point. Magnetic field lines may be traced out, stepwise, with the help of a small test compass, which indicates the direction of the field at any point.

II. LABORATORY PROCEDURE

CAUTION: If you have a mechanical watch, keep it at some distance from the magnets. Also, avoid dropping the magnets, or striking them together, as jolts tend to demagnetize a magnet.

1. Place a sheet of paper on a level surface at some distance from other students and their magnets. Use laboratory tables, since desk tops are not level. Place a single bar magnet near the middle of the sheet, parallel to a long side of the sheet. The other magnet of the pair should be placed some distance away. Trace around the magnet with your pencil. (If the poles of the magnet attract the pencil, it is ferromagnetic and should not be used in the remainder of the experiment, as it will affect the compass needle.) The use of mechanical pencils should be avoided.

2. The poles of the bar magnet are located near, not at, the ends of the magnet, on the central line of the magnet. Locate the approximate position of each pole by sliding the test compass alongside the magnet. When the compass needle points perpendicular to the length of the magnet, the center of the compass is opposite the pole. Remove the magnet and mark a dot on the center line of the outline of the magnet, even with the center of the compass. Do this at each pole. Label each pole with the letter N or S. Replace the magnet.

3. Choose a point at random at some distance in any direction from the magnet. Place the compass at this point. The compass needle will be pointing in a direction tangent to the magnetic field at that point. Mark a dot just outside the case of the compass, next to one end of the compass needle. Move the compass so that the other end of the compass needle is near the dot and mark another dot in the same way. Repeat this process until you reach the magnet or the edge of the paper. Return to the starting point and trace the line in the opposite direction until you reach the magnet or the edge of the paper. Draw a smooth curve through the points. Add an arrowhead to the curve to indicate the sense of the magnetic field line, which must run away from the N pole of the magnet and toward the S pole of the magnet. This counts as one line, whether it extends from one pole of the magnet to the other or goes off the paper.

4. Repeat the preceding step until you have traced out 10 lines, well distributed over the data sheet. A line which reaches to the edge of the sheet counts as one line, not half a line.

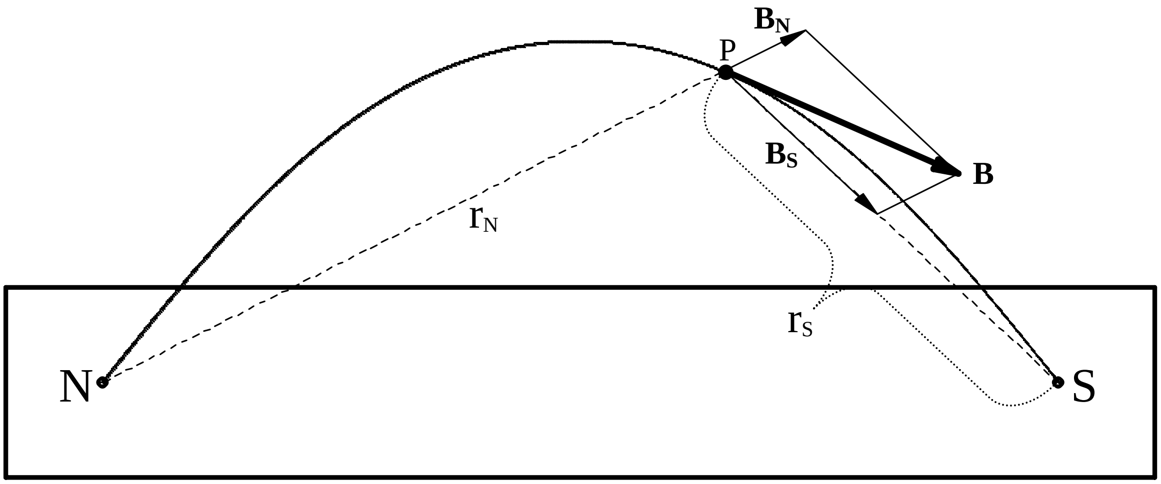
5. Take a new data sheet and place both bar magnets on it. The magnets should be about 7 to 10 cm apart, parallel to each other and to the long side of the paper. Both N poles should point in the same direction. Trace around the magnets. Locate each pole, and mark it with a dot and the letter N or S. As before, trace out 10 magnetic field lines around and between the magnets. Begin one of the field lines on a line halfway between the magnets and several centimeters from the midpoint of the system. Begin another of the field lines on the line halfway between the magnets, but several cm beyond the ends of the magnets. These last two lines are necessary because we must know the directions of the magnetic field vectors at the two starting points in order to complete the analysis for this experiment.

6. Repeat the previous step with the N poles of the magnets pointing in opposite directions from each other.

7. Return the magnets to their boxes with N poles pointing in opposite directions. If ferromagnetic "keepers" are available, place one on top of each end, in contact with the unlike poles.

III. CALCULATIONS AND ANALYSIS

1. On the data sheet for the single magnet, select a point P on a smooth segment of one of the magnetic field lines. P should be some distance from each pole, but not near the perpendicular bisector of the magnet. Draw a line from P to each of the poles. Draw a tangent line at least 2 cm long through P, representing the magnetic field vector at P. Draw a parallelogram about this vector as diagonal, with sides parallel to the lines from P to the poles. Add arrowheads to the diagram, so that it represents equation (2) geometrically. Measure the necessary distances and solve for n, using equation (4). The expected value is 2, but this experiment gives only a very rough estimate of n. Experiment 3 provides a more precise value.



2. On a separate sheet of paper (not the data sheet) make a large diagram of the magnets of II-5. Mark the poles with dots and label each with the letter N or S. Add the subscripts 1 to 4 to the letters N and S to identify each pole uniquely. Draw a line midway between the magnets, extending beyond the ends. Choose a point P on this line, about 1/4 bar magnet length from the center of the line. Draw four magnetic field vectors B_1 to B_4 at P, each representing the field at P due to one pole. Draw the vectors with their tails at P and their heads pointing in the appropriate directions. Although all four poles are assumed to be of equal strength, fields due to distant poles must be shown as weaker than fields due to near poles. Using a pen or pencil of a different color, draw a single vector representing the resultant magnetic field at P. The vector addition is only qualitative, since both absolute and relative magnitudes are unknown. It is easiest to sum the fields due to the two nearer poles, then the fields due to the two further poles, and then sum the sums. It is not necessary to show the partial sums on the diagram. Is the direction of the resultant field at P consistent with the pattern of lines on your data sheet for II-5?

3. Make another diagram of the magnets and their poles, as in step 2. Choose a point Q on the central line of the diagram, but located about 1/4 bar magnet length beyond the ends of the magnets. Make the same kind of vector diagram as in step 2. Is the direction of the resultant field at Q consistent with the pattern of lines on your data sheet for II-5?

4. Repeat the previous two steps for the data of II-6.