Performance: Report: Total:

Physics 212-4

MAGNETISM

NAME: ______________________________ ☐

STUDENT ID: ______________________________ ☐

LAB PARTNER(S): ______________________________ ☐

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Check the box next to the name of the person to whose report your group's data will be attached.

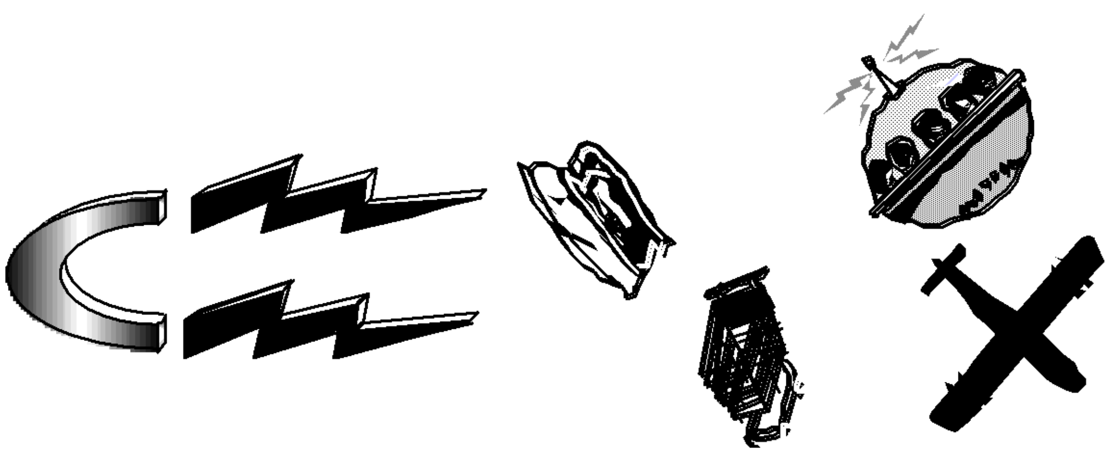
LAB SECTION: ________________________

INSTRUCTOR: ________________________

DATE: ________________________

TABLE: ________________________

(YOU WILL BE TAKEN 3 POINTS IF TABLE IS VACANT.)



Written by Beda, Dick, Errede, Hearn, Hertzog, Kwiat, Makins & Weissman, modified by Xia Huanxin for ZJUI

Physics Lab 212-4

Equipment List
Compasses (3)
Magnetic field sensor
Bar magnets (3)
ruler
Cylinders: aluminum (1), and black-painted μ-metal (1)
Magnet strip

Up front setup consisting of:
Magnetic Demonstration System

Computer File List
Capstone file "212-04 Hefty Magnet"

Physics Lab 212-4

Magnetism

Investigation 1: Magnets and the magnetic field

To find out
- What a magnetic field is, and to characterize its shape around a magnet or set of magnets
- How magnets interact with other materials

Preview
- Use a magnetic compass needle to identify and explore the magnetic field around a bar magnet
- Use a magnetic field probe and *Capstone* software to measure the magnetic field strength around a bar magnet

WARNING: This Investigation Utilizes Some Relatively Strong Magnetic Fields That Can Be Hazardous to Your Possessions. Be Sure To Keep Computer Monitors, Watches, Credit Cards, And Student IDs Away From The Magnets.

Activity 1 Magnetic Fields Created by Bar Magnets

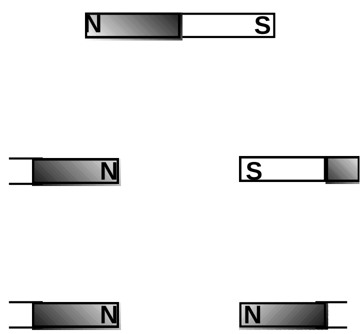
In this activity we will visualize the field line patterns created by a magnet and combination of magnets. The method consists of the use of a tiny compass. As learned in the pre-lab, the compass needle lines up along the line of the earth's magnetic field and will point north.

1. First verify your compass.
   - Each group member should obtain a tiny compass and test it to make sure it points the right way (don't laugh, these things often get magnetized incorrectly and *N* becomes *S* and so forth -- very confusing).
   - **WARNING: Do not put compasses in direct physical contact with any of strong permanent magnets; the field strength can flip the polarity of the compasses!**
   - Clear your area of bar magnets. Do all three compasses point the same way? Is it what you believe to be north?

Q1 The north and south conventions associated with compasses can be confusing. Recall the last question from the pre-lab: What type of magnetic pole is really present at the earth's geographic "North Pole?"

Explore the direction of magnetic field lines around actual bar magnets.

Prediction Draw a few magnetic field lines for the three configurations of magnets shown below.

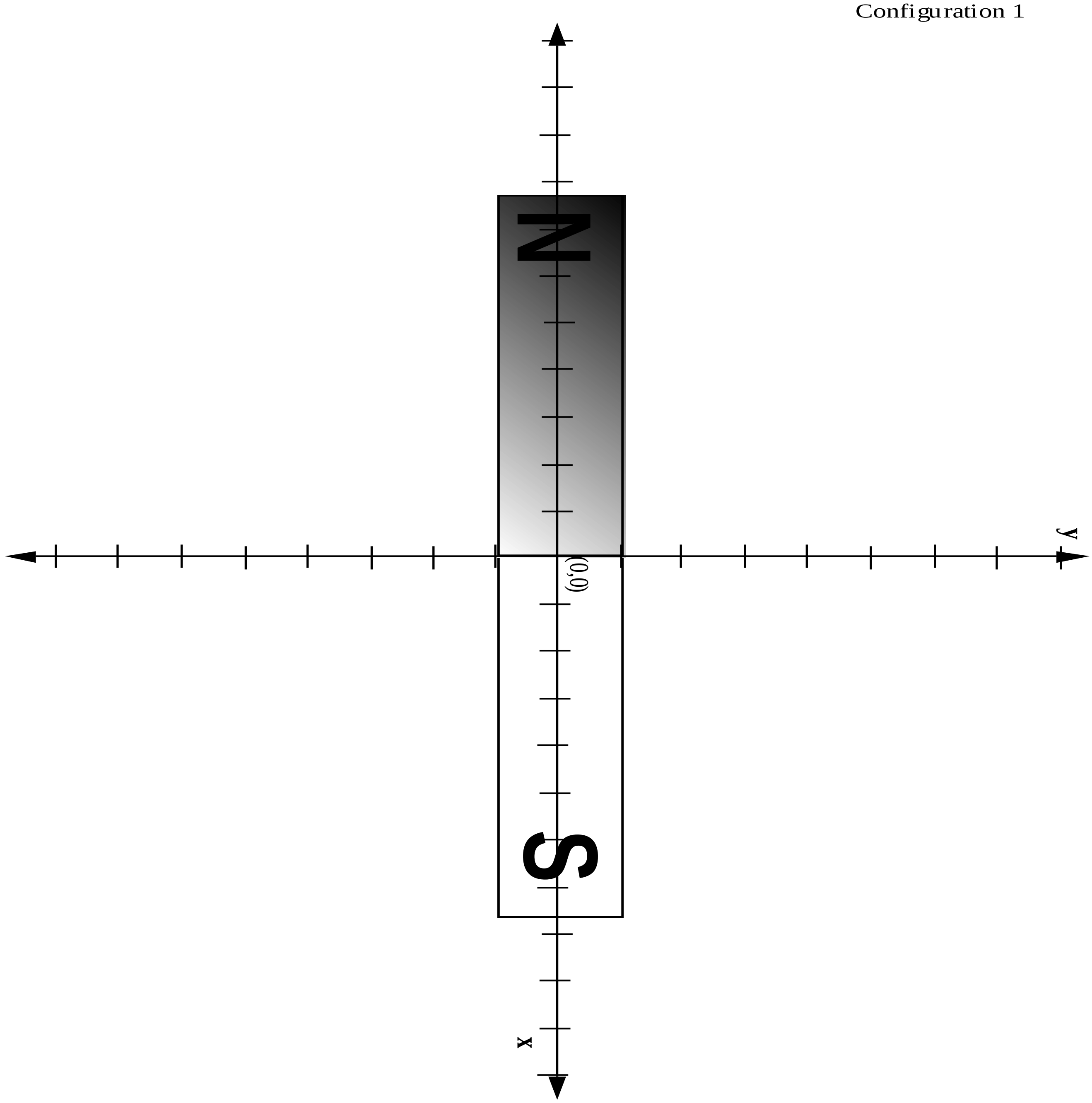


Q2 In drawing these lines, list a few rules you used for coming up with your patterns.

2. Divide and conquer.
   - On the following pages you will find sheets of paper with templates for the placement of bar magnets. Your setup includes several magnets and compasses so that each of the members of your group can experiment independently and at the same time. *Each* team member should explore the directions of the magnetic field for *at least* one of the configurations. Overall, your team should do all configurations. (If you have time, and want to do any of the others, feel free.)
   - Fill your diagram with many small (~1 cm) arrows indicating the direction of the magnetic field. Using the small compass find the magnetic field directions in the space surrounding the bar magnet or magnets. Denote the directions with arrows about one third or one fourth the length of the compass needle. Write directly on one of the sheets. (Are there any symmetries that can help you perform this task more efficiently?)
   - Draw enough arrows so that you can tell where the magnetic field lines go; there should be an arrow every few centimeters.

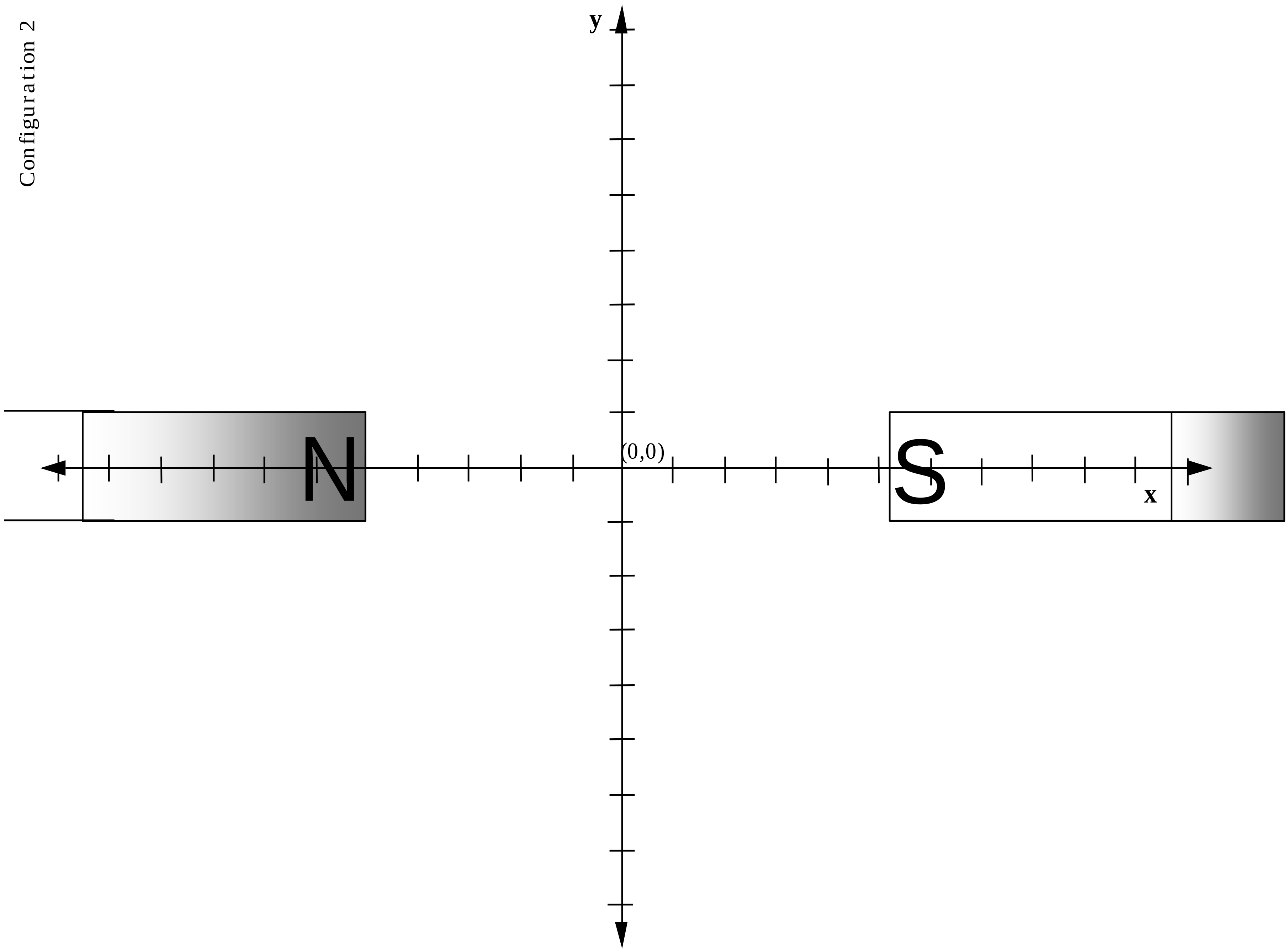
Configuration 1

Draw your field directions on this sheet



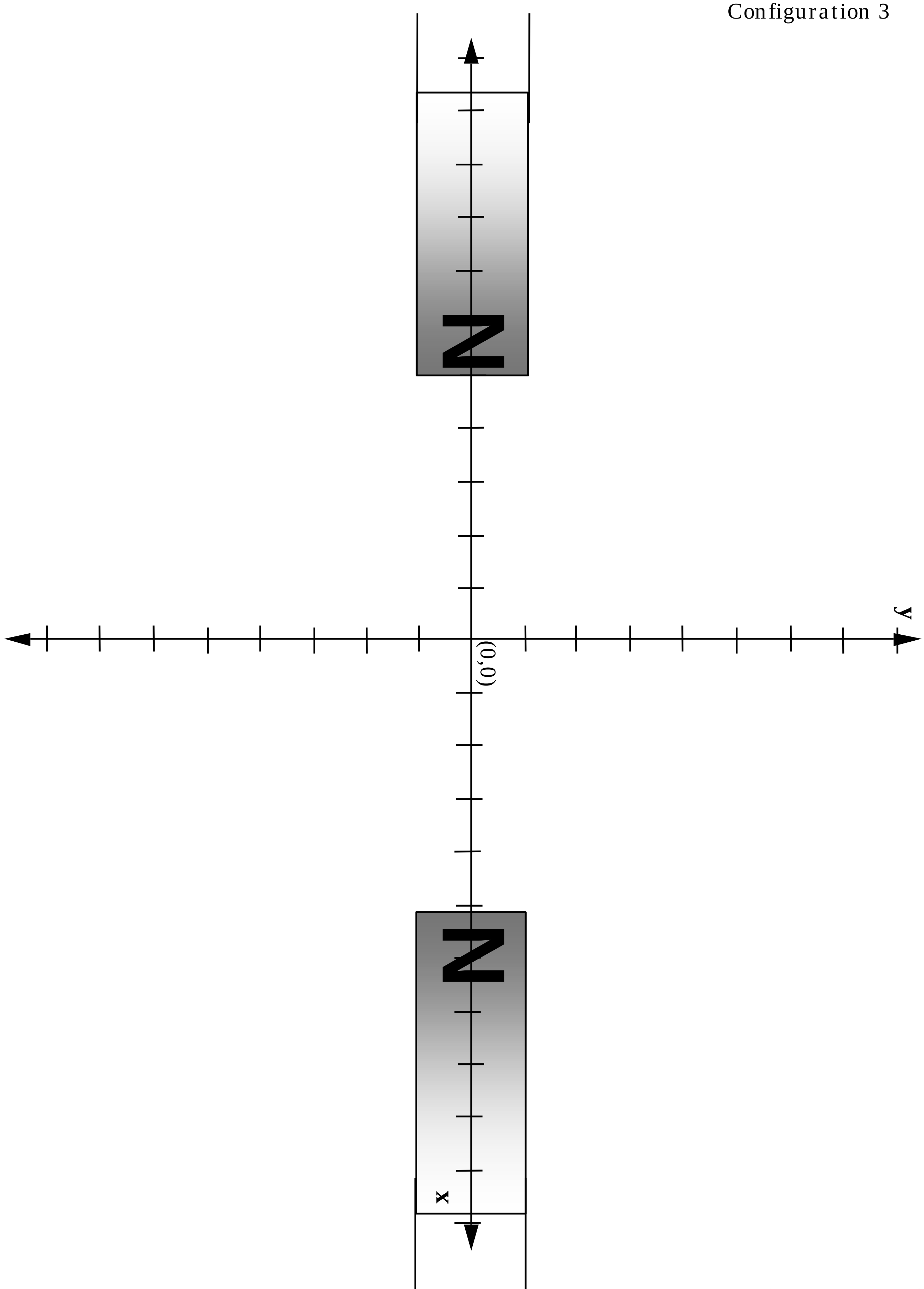
Draw your field directions on this sheet

Configuration 2



Configuration 3

Draw your field directions on this sheet



3. Draw complete field lines with arrows indicating the field direction on each line.
   - Using your rules for magnetic field lines, each group member should sketch continuous field lines on his or her map using the grid of “direction points” as a guide. Use a different color pen or pencil to draw the lines.
   - Make quick sketches of the field lines that you did not map from your partners' data.
   - Discuss in your group what is going on with these field lines. Are the fields limited to the two-dimensional surface of the page? Do the lines represent constant force lines? Do they represent some kind of "equipotential?" Answer the following formal questions.

Q3 For the single bar magnet, which way does the magnetic field point *outside* the magnet — from N to S or from S to N?

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Q4 Is the strength of the magnetic field constant along a field line?

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Q5 Does the field mapped in Configuration 1 remind you of any of the fields mapped in Lab 2 where you measured equipotential lines for various charge configurations and deduced the electric field lines? What is the electrostatic equivalent of a bar magnet?

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Q6 Consider Configuration 3, with like poles pointing at one another. Is there a place on the page where the magnetic field is zero? Explain.

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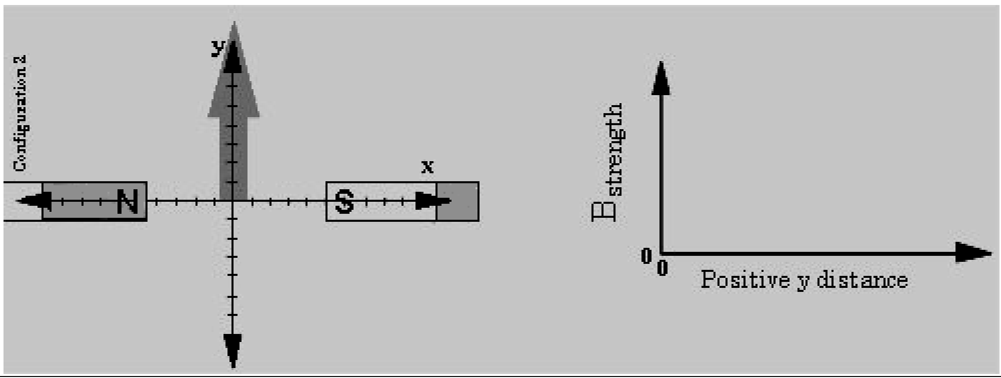
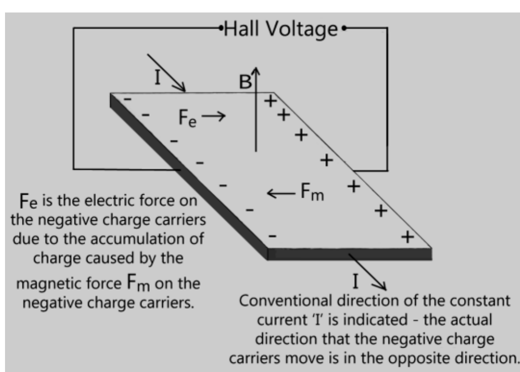
Activity 2 Measuring Field Strength

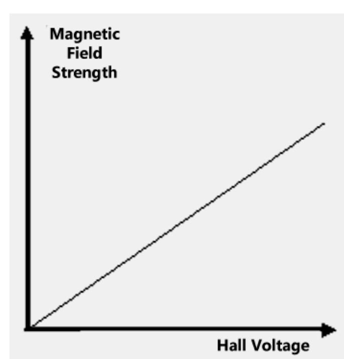
Prediction	We are interested in how the magnetic field strength is represented on diagrams of magnetic field lines. Consider the second configuration, where the opposite poles are aimed at one another. What do you think is happening to the *strength* of the magnetic field as you move along the **y**-axis away from the **x**-axis, as indicated by the gray arrow below? Make an estimate of field strength versus distance on the graph shown below.



You will now use a Hall element magnetic field probe (as shown in Figure 1a and 1b) to measure the strength of a magnetic field. See the *technical aside* below for a brief explanation of how the sensor works.

Technical Aside	A Hall element is a thin rectangular conductive material through which a constant current is established from one edge to its opposite edge. The element also has output connections perpendicular to the flow of this current. When a magnetic field is applied with a non-zero component perpendicular to the flat surface of the Hall element, charge accumulation creates an electric field perpendicular to the path of the current. A measurable output voltage (the Hall Voltage) is generated which has a magnitude that is directly proportional to the strength of the perpendicular component of the magnetic field. This phenomenon is called the *Hall Effect*. The Hall element for illustration shown below is made of a metal conductor in which electrons are the charge carriers. In this lab, a Hall element and its associated electronics comprise a magnetic field probe which can be used with the computer interface box and computer software to translate the *Hall Effect* voltage into a calibrated measurement of the magnetic field in Gauss.





The proper orientation of the magnetic field probe to record a maximum positive reading of a magnetic field is shown in Figure 1a (**sensor measures field strength along the axis of its probe**); note that the square chip at the tip of the probe is facing in the direction that the field lines are going for this case. **Compare carefully the situation in Figure 1a with that of Figure 1b.** Note that the magnitude of the readings of the probe will be largest when the flat surface of the Hall element is perpendicular to the magnetic field.

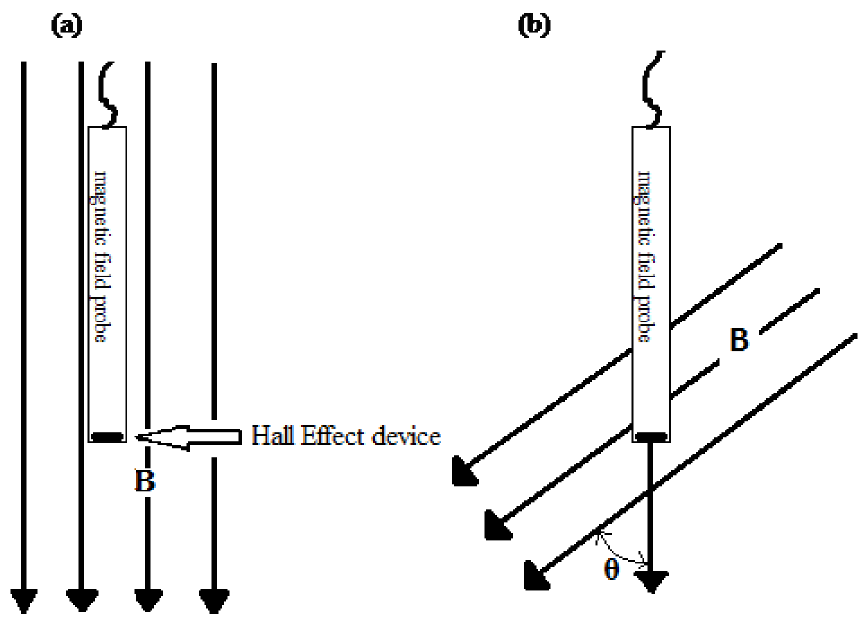


Figure 1a. The field lines are perpendicular to the flat face of the Hall Effect element. This orientation gives a maximum reading which corresponds to the true magnitude B of the magnetic field $\boldsymbol{B}$.

Figure 1b. The sensor is oriented at angle θ with respect to the field lines. The reading is reduced to $B\cos(\theta)$ because the probe measures the projection of the field *perpendicular* to the face of the Hall Effect element.

Note We use the PASCO CI-6520A magnetic field sensor. It has three ranges, 1X(±1000gauss), 10X(±100gauss), and 100X(±10gauss). Below are the sensor specifications:

Range*	Gain	Resolution	Accuracy[1]	Calibration Factor
±1000 gauss	1X	0.5 gauss	10% of reading	100 gauss/volt
±100 gauss	10X	0.05 gauss	10% of reading	10 gauss/volt
±10 gauss	100X	0.05 gauss	10% of reading	1 gauss/volt

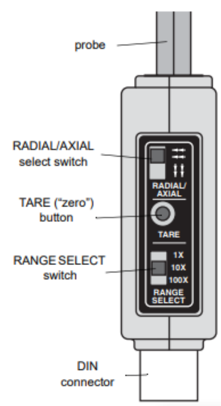
The sensor uses Hall Effect devices as sensing elements. There are two of these devices oriented perpendicularly to one another located at the end of the probe. The RADIAL/AXIAL switch on the top of the sensor selects the sensor orientation. NOTE: It is not possible to measure magnetic fields in both directions simultaneously.

Note: this magnetic field sensor is very sensitive, and its range is not large, don’t put it near any rare-earth magnet!

Example: **even you put it near an iron object, its reading will be changed due to the iron object magnetized by the earth magnetic field!**

1. Set up the software.
    - Start the *Capstone* program by double-clicking on the file named “Hefty Magnet” in the “212 lab files” folder on the desktop.
    - Connect the DIN plug cable to the analog adapter (the blue box), take care of the position! Collimate these two cables and connect them.


- Choose Radial or Axial and zero the sensor.
In our case, we can choose the Axial.
When you zero the sensor, hold the sensor away from any magnetic source (other than the earth’s field) and press the TARE button on the top of the sensor. To zero the sensor more completely, especially when using the 100X (±10 gauss) range to record very small magnetic fields, place the probe of the sensor into a Zero Gauss Chamber (such as the EM-8652) and press the TARE button.



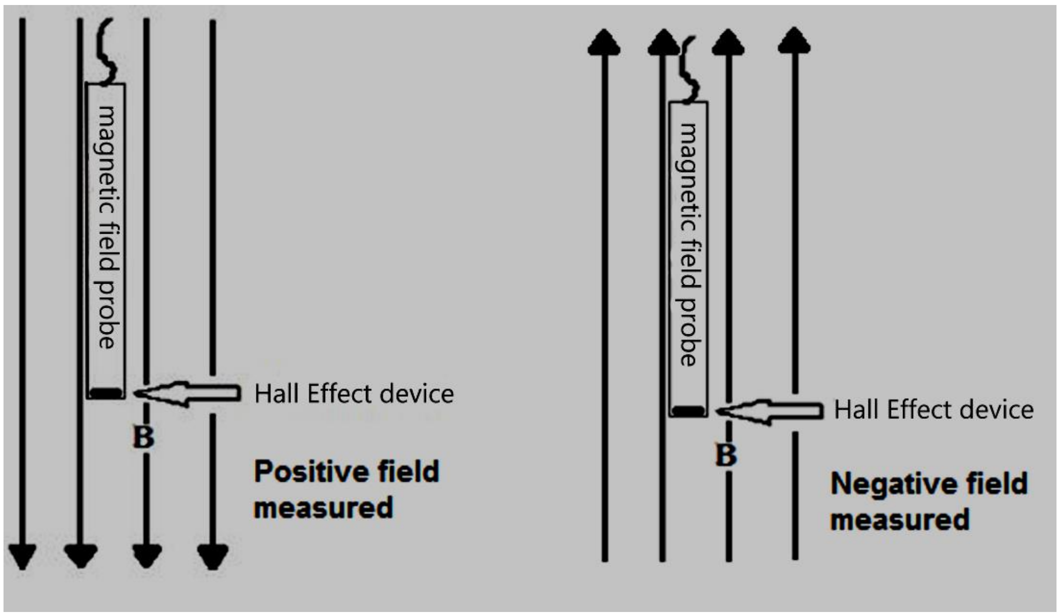
Note: Don’t put the zero-gauss chamber near any magnet (whether it’s strong or not)!

- Roughly know the earth’s magnetic field direction using the following method (**choose 100X and zero it**):

    a.) Click Record button, hold the probe with the tip facing west, east, north, south, up and down.

    b.) Using the readout of the field on the computer, find and make a mental note of the direction of the earth’s magnetic field.

2. Try the probe with some magnets. (**Choose the proper range 1X!**)
   - Observe the readout on the computer while probing around both ends of one of your permanent magnets. Rotate the probe so that you get a good feel for how it works - how to maximize its reading and how to reverse its reading. Remember to orient your probe along the lines of the field arrows you drew previously. Verify the correct orientation of the "square chip" on the tip of the probe.



   - Make some simple measurements.

   Field about 1 cm away from the North End __________ [G]

   Field about 1 cm away from the South End __________ [G]

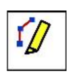
   Reading in the middle, about 1 cm above the magnet

   __________ [G]

3. Once again, set up the field mapping template which features the North and South poles facing (Configuration 2). We will now test the prediction.
   - Choose one of your group's unused Configuration 2 templates.
   - Make a measurement plan. If you want to obtain the field strength along the y-axis on the plot, how can you do it?

Go ahead and talk about this now. Write down your method in the box on the next page and then compare it to the method we devised (outlined after the box for your plan).

Our Plan: (it’s better to use the radial sensing element)

- Here's a convenient method:
  - → Place the probe such that the tip of the probe is exactly centered on the **x**-axis at y = 0 cm.
  - → **Next, make sure that the flat tip of the probe is kept as perpendicular to the field lines as possible. Note that it will be at a slight angle due to the geometry of the setup – try to maintain this angle for all your measurements in this activity**.
  - → Start the program with the **Record** button. Hold the probe in its initial position for 5 seconds, then abruptly move it by 0.5 cm.
  - → Keep it there 5 seconds, then move it 0.5 cm more.
  - → Repeat this procedure as necessary. You should get a good idea of what is going on from your plot.
  - → Your data should look like steps. To get an average for each step, choose the  and Σ (because of the setting of the accuracy of Capstone, the software maybe won’t give you a correct value, then you need estimate it yourself).
- Carry out the method preferred by your group and make a graphical representation of your investigation. Plot your data points on Figure 2 and connect them with a smooth line. Make sure you put the appropriate scales on the axes in addition to any other notation.

Workspace for data and observations:

(These lines may help you locate the sensor and magnets, mark the scales in the lines.)

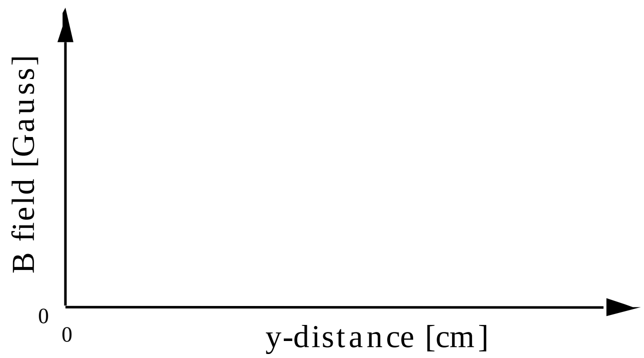


Figure 2. Our results

Q7 How does your prediction compare with the actual data?

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Q8 Consider the *density* of the magnetic fields lines you mapped out, and the *strength* of the magnetic field. Can you make an association between them?

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Q9 We know that the magnetic field of a dipole has a $1/r^3$ falloff with distance, for r large compared to the size of the dipole. Our dipole is about 10 cm in size so we might expect the $1/r^3$ behavior to become evident only when r is 20 - 30 cm or more. Why would we not get a $1/r^3$ falloff at the distances in this experiment?

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Activity 3 Magnetic Fields and Materials

You should now be familiar with the shape of a magnetic field due to a magnet and how other magnets interact with and shape an applied field. Now you will investigate the ways in which other types of materials interact with and shape an applied magnetic field. Materials can be classified according to the dominant internal effect that occurs when they are placed in a magnetic field. *Paramagnetic* materials have intrinsic magnetic dipole moments that tend to align with an applied magnetic field. This alignment causes the internal magnetic field to be slightly higher than the applied field so that paramagnets are slightly attracted to very strong magnets. *Ferromagnetic* materials also have intrinsic magnetic dipole moments. However, in contrast to paramagnets, a ferromagnetic material will have a much larger degree of alignment of its dipoles when it is placed in a magnetic field. The internal field can become much higher than the applied field, and the ferromagnetic material will be strongly attracted to a magnet. Ferromagnetic materials can be characterized further by whether or not they retain the alignment of their magnetic dipoles after the external field is removed. Those that do are called permanent magnets or hard ferromagnetic materials. The bar magnets you are using in this lab are permanent magnets. In contrast, soft ferromagnetic materials quickly lose the alignment after the external field is removed. *Diamagnetic* materials have no intrinsic magnetic dipole moments. However, an applied magnetic field induces dipoles in diamagnets. The field of these dipoles is opposite that of the applied field. Thus, diamagnets repel magnets. This is a weak effect for all materials except for superconductors, which are perfect diamagnets.

In this activity we will explore the magnetic shielding effects of soft ferromagnets. One property of these materials is that they tend to “suck” magnetic field lines into them. More precisely, the total energy stored in the magnetic field is less if it is in a ferromagnet. A consequence of this is that soft ferromagnetic materials will be attracted to regions of greater field strength (thereby lowering the energy). You can observe this using the steel cylinder.

Do this: Bring the cylinder close to one pole of one of the bar magnets and observe what happens.

Q10: Does the attractive nature of the force depend on which pole of the bar magnet was used?

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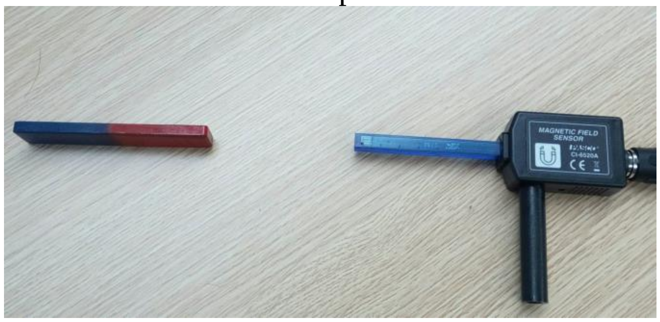
Another consequence of this field-sucking tendency is that such materials can be used as magnetic shields. This is analogous to the way an electrical conductor can be used to protect a region of space from electric fields.

1. Set up the experiment (choose axial mode).
    - Set up a bar magnet (if the magnetic field of one magnet is small, use two) on its edge (as shown in the picture below) with the probe facing the North Pole approximately 8 cm away.
    - Note that for all measurements the probe should be held at this initial position – only the cylinder position should be changed.

Setup 1



Setup 2

Setup 3 move the steel cylinder

2. Measure the magnetic field for three different setups.
    - Record the magnetic field below for the setup in the first setup above.
    - Now place the steel cylinder on the table at the midpoint between the probe and the magnet as in the second setup pictured above. Record the magnetic field below.
    - Now bring the cylinder close to the probe. Record the magnetic field below.
    - Now move the cylinder in the direction toward the probe such that the probe is inserted through the hole in the side of the cylinder and the sensor at the tip of the probe is about in the middle of the cylinder. Record the magnetic field below.

Data: Measured field from: Setup one: __________

Setup two (cylinder in the middle): __________

Setup two (cylinder near probe): __________

Setup three: __________

Q11: What do you observe about the magnetic field strengths detected by the sensor (i.e., how did the presence of the cylinder affect the field measurements for setups two, three with respect to setup one)? Can you now think of a better way to calibrate the zero point of the probe? If so, what would you do?

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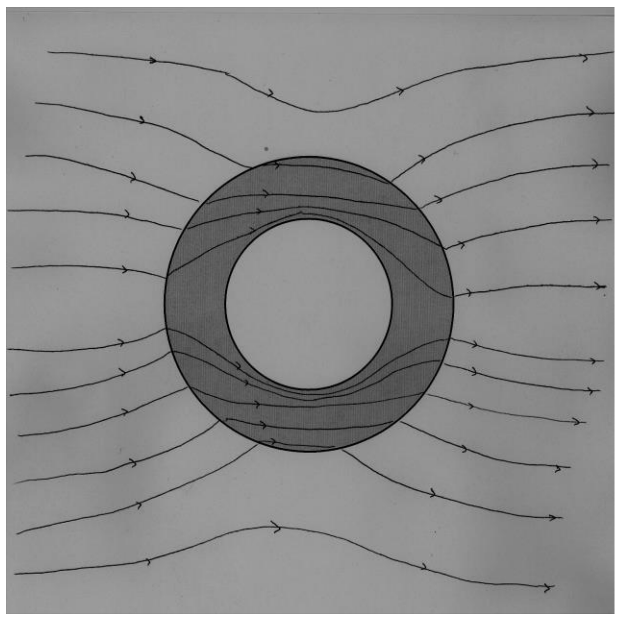

Figure 4. Magnetic field lines in a ferromagnetic material.

In Figure 4, we show a cross section of the magnetic field lines in the presence of such a ferromagnetic material.

Do conductors such as the steel cylinder always have this shielding effect on magnetic fields (as you likely saw in previous labs with electric fields)? Replace the steel cylinder in your setup with the aluminum cylinder (also a good conductor), and try the same experiment as above.

Q12 What did you observe? Does aluminum shield magnetic fields?

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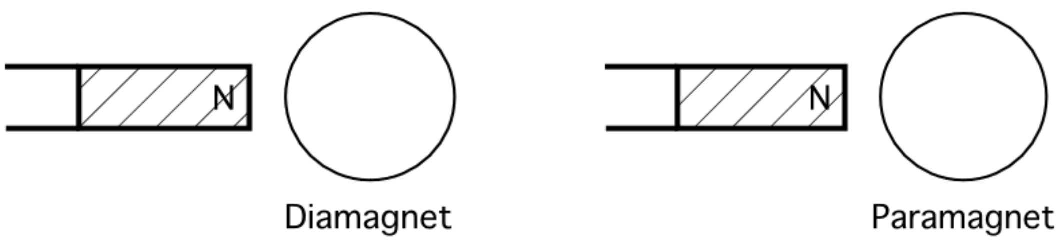
Important!

You will be using a rare-earth magnet for the rest of this activity and also for activity 4. It is located at the front of the lab, where it should stay; you may need to wait for another group to be finished with it. Be careful! This magnet is very powerful. Do not let it get close to your credit cards, calculators, cell phones, etc.

Next you will explore the interaction of paramagnetic and diamagnetic materials with a magnetic field. Because these effects are typically 10^{-5} times smaller than ferromagnetic effects, we will need to use a much stronger magnet and a more sensitive measuring system. As discussed previously, in paramagnets an external magnetic field will tend to induce a magnetic dipole *in the same direction as the field,* while in diamagnets the induced dipole moment will tend to oppose the external magnetic field.

On the drawing below, sketch the field lines for the bar magnet (they are essentially unaffected by the balls) and indicate the direction of the induced magnetic dipole moment for the diamagnetic and paramagnetic balls.



You can think of the induced dipole moments as though they were actually tiny bar magnets themselves. Indicate on your drawing the north and south pole of the induced "magnets" for each of the balls.

Prediction: Based on your knowledge of how magnets attract and repel each other, will the paramagnetic ball be attracted or repelled from the bar magnets? Will the diamagnetic ball be attracted or repelled? Does the sign of the force depend on whether the north or south pole of the bar magnet was used?

1. At the front of the room are two torsion pendulums, one is made of aluminum, the other is made of organic glass.
   - Firstly, put North (or South) pole of rare-earth magnet near organic glass rod and aluminum rod respectively. You will see how the rods response.
   - Next, put the organic rod between the two poles of two rare-earth magnets, as shown in figure 5 below (thus the field can be much stronger). Be careful not to touch the organic rod with the magnet.
   - After a moment, when the rod doesn't swing (when it doesn't move), rotate the rare-earth magnets, you'll see the organic will rotate according to the direction of the rare-earth magnets.
   - Repeat the process with aluminum rod.

Q13 What's the response of the organic glass rod? How does it go when the magnet rotates? Why? (Organic glass is known to be a *diamagnetic* substance.)

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Figure 5. A rare-earth magnet causing the dumbbell to rotate in both directions

Q14 Did your results agree with your predictions?

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2. Repeat the experiment with an aluminum pendulum.

Q15 What's the response of aluminum rod? Was the aluminum attracted or repelled by the north pole of the magnet? The south pole? (Note that aluminum is a typical paramagnetic material.)

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Q16 Did your results agree with your predictions?

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CLEAN UP CHECKLIST

- ☐ Quit all computer programs and do not save any data. Turn off all the equipment except the computer.
- ☐ Make your setup look neat for the next group.
- ☐ Collect all printouts, annotate them, and attach them to the lab report of the designated member of your group.
- ☐ Staple everything together, make sure you have answered all the questions and done all the activities, make sure the first page is completed with lab partners' names and check boxes. Hand in your work before leaving the laboratory.