Objectives

- To learn (by experience) the basic rules of how magnetic dipoles interact with each other
- To gain experience with the magnetic properties (or lack thereof) of materials
- To observe the influence of a magnetic field on moving charges
- To observe how moving charges can generate a magnetic field

Useful background reading

Young and Freedman, sections 27.1, 27.2, 27.3, 27.6, 27.7, 28.5

Introduction

Magnetism has been known of since ancient times, but it was not until the 17th century that a systematic study of magnetism was performed. In these laboratory activities we will be exploring many of the observations that were made historically as an understanding of magnetism was developed. Some of the activities are very simple and perhaps are similar to activities that you have tried in your past schooling. Although they are simple their explanations are often not simple and it took several hundred years of careful observations to come to our current understanding.
Ph 2306 Experiment 8: Prelab assignment (complete and turn in at the beginning of your lab session)

1a). Which of these materials will feel a force from a permanent magnet — wood, aluminum, or steel?

b) Will the materials in a) that are attracted by the magnet be attracted to the positive pole of the magnet, the negative pole, or both?

2 a). In the figure below, an electron is moving parallel to a uniform magnetic field in the direction shown. Is there a force on the electron; if so what direction does it point? Explain your reasoning.

2 b). In the figure below, an electron is moving perpendicular to a uniform magnetic field in the direction shown. Is there a force on the electron; if so what direction does it point? Explain your reasoning.
3. In the figure below, a square loop of wire with positive current flow clockwise around the loop is suspended between the poles of a permanent magnet.

\[ \text{Diagram of a square loop with current flow} \]

a) Is there a net force on the loop of wire from the magnetic field interacting with the current segments? If so, what direction does it point? Explain your reasoning.

b) Is there a net torque on the loop of wire from the magnetic field interacting with the current segments? If so, what direction does it point? Explain your reasoning.
Equipment

You will use the following equipment:

1. Pasco 750 Lab interface with the following sensors:
   a. Pasco Magnetic Field sensor (Analog A)
   b. Pasco Power Amplifier II (Analog B)
2. 2 cylindrical permanent magnets
3. 2-Small compasses
4. Various materials to test their magnetic properties
   a. Aluminum cylinder with hook
   b. Wooden cylinder with hook
   c. Black Plastic cylinder with hook
   d. Brass cylinder with hook
   e. Iron cylinder
   f. Steel paper clip
5. Plastic pivoting stands for holding magnets
6. Clear tape dispenser
7. Banana Plug cables
   a. 2-red
   b. 2-black
   c. 4-alligator clip ends
8. 1.5 meter long piece of stranded 22 GA wire.
10. BK Precision 1670A Adjustable Power Supply
11. Pasco variable gap lab magnet
12. 2-square loops of wire mounted on a pendulum clamp.
13. Wire mounted on plexiglass plate.

On the instructor’s tables:
1. e/m Apparatus (1 per quadrant)
   a. Model SF-9585 power supply only is needed.
   b. Bar magnet
Activity 1: Permanent Magnets and the magnetic properties of various materials

**Prediction 1-1:** What do you predict will happen when two “unlike” (one green and one red) ends of the rod magnets are brought near each other?

**Prediction 1-2:** What do you predict will happen when two “like” (two green or two red) ends of the rod magnets are brought near each other?

**Question 1-3:** Locate the two cylindrical bar magnet rods on your lab table. Test your predictions 1-1 and 1-2. How do “like” ends of the magnets interact with each other? How do “unlike” ends of the magnets interact with each other?

**Question 1-4:** State a rule for the interaction of magnetic “poles”. Compare this rule to the one that you developed in the laboratory activity on static electric charges. What are their similarities or differences?

**Prediction 1-5:** You have available to you a variety of different materials which you will test for their magnetic interaction with the permanent magnets. Predict what will happen when you bring one end of the permanent magnet toward each of the pieces of material? What will happen when the other end of the magnet is brought toward the materials?

<table>
<thead>
<tr>
<th>Material</th>
<th>Predictions</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green Pole</td>
<td>Red Pole</td>
</tr>
<tr>
<td>1 Aluminum cylinder</td>
<td>Green Pole</td>
<td>Red Pole</td>
</tr>
<tr>
<td>2 Wooden cylinder</td>
<td>Green Pole</td>
<td>Red Pole</td>
</tr>
<tr>
<td>3 Black Plastic cylinder</td>
<td>Green Pole</td>
<td>Red Pole</td>
</tr>
<tr>
<td>4 Brass cylinder</td>
<td>Green Pole</td>
<td>Red Pole</td>
</tr>
<tr>
<td>5 Iron rod</td>
<td>Green Pole</td>
<td>Red Pole</td>
</tr>
<tr>
<td>6 Steel paper clip</td>
<td>Green Pole</td>
<td>Red Pole</td>
</tr>
</tbody>
</table>
**Question 1-6:** In the above table record your actual observations of how each material interacts with each end of the magnet. Comment on any row where your predictions and observations disagree.

**Question 1-7:** Make a general statement about what types of materials interact with a permanent magnet.

**Activity 2: What is the meaning of “North”?**

**Prediction 2-1:** Place one of the cylindrical permanent magnets on the plastic pivot so that it can spin freely. Assume that you place the other cylindrical magnet slightly above the magnet on the pivot (BUT don’t do it yet). Do you predict that the magnet on the pivot will orient itself parallel or antiparallel to the other magnet?

**Question 2-2:** Place the other cylindrical magnet above the one on the pivot (about 5 cm above; if you go any closer the force will lift the magnet off the pivot). Observe the magnets and circle the diagram below that matches what you actually observe. Cross out the diagram that doesn’t represent what you observed.

![Diagram of magnet orientations](image)
**Question 2-3:** Pick up the plastic pivot with the magnet on it, hold it in the palm of your hand, and step away from the table (to move away from any magnetic materials either in or on the table; note that the large columns in the room contain magnetic materials, so stay away from them too). Give the magnet a small spin and let it orient itself to the earth’s magnetic field. As you may have already studied, the magnet orients itself relative the earth’s geography. How are the magnet’s ends oriented to the earth’s geography? (Note that geographic north in the room is marked on a whiteboard.)

By convention, we call the end of the magnet that is attracted to geographic north the north pole of the magnet. That is also the direction that we define to be the positive magnetic field direction.

**Question 2-4:** Now use one of the small compasses at nearly the same location where you had the magnet on the pivot (but take the magnet on the pivot away so it doesn’t influence the compass). Record how the arrow on the compass orients itself relative to how the permanent magnet poles were oriented. What can you infer about the material that the compass needle is made out of? **Note:** The small compasses can easily be accidentally remagnetized by being placed near a strong magnet such as the large lab magnet. Check each of you compasses to make sure that they give you the correct sense of “North”. You need a least one compass that has the correct sense of North for later use; if none of your compasses give the correct North, consult with your TA.

**Question 2-5:** It was postulated by William Gilbert in the 17th century that the earth might act as if it contained a large permanent bar magnet. Although our current understanding of the earth’s magnetic field is not consistent with Gilbert’s postulate, it is still convenient to think of the earth as if it contained a large bar magnet. If the earth did contain a large bar magnet, write on the diagram how the Earth’s magnetic poles should be labeled. Explain your choice based on the observations you made in the previous questions.
Activity 3: Representing the magnetic field around a permanent magnet.

Question 3-1: Place the cylindrical bar magnet in the rectangle below. Mark the poles of the magnet on the diagram. Move a small compass around the magnet on the paper and draw arrows indicating the direction of the compass needle (and therefore the magnetic field) at several points around all sides of the magnet. Recall that (by convention) we define the positive magnetic field direction to be along the north seeking compass direction.

Question 3-2: Attached to the computer is a magnetic field sensor that can be used to measure the magnetic field. This probe works on the Hall Effect. Load the DataStudio setup file “Magnetism1.ds from the class notes folder. Set the Magnetic Field Sensor to “Radial” mode and to “1X” range. With the Magnetic Field Sensor far away from any strong magnetic source press the “TARE” button to zero out the sensor. Notice that on the switch where you selected radial, there is a little picture that shows the direction the probe measures field and what positive corresponds to. On the end and the side there are two small white dots. They indicate the direction that the magnetic field is pointing when measuring with the axial or radial modes, respectively. You want the dot on the side to be next to the point where you want to measure the field. Use the Magnetic Field Sensor to record the magnetic field strength and direction at both the poles and on both sides of the cylindrical magnet and record your readings on the diagram above. How does the sign of the reading of the Magnetic Field Sensor compare to the magnetic field direction you determined using the small compass?

Question 3-3: At what two points is the magnitude of the magnetic field the greatest around the magnet?
**Activity 4: A Model for why some material can be magnetized.**

**Prediction 4-1:** You should have already observed that an iron rod is attracted to both ends of a permanent magnet. Therefore we can conclude that iron has a magnetic property. If you bring an iron rod near a paper clip will the paper clip be attracted to the rod?

**Question 4-2:** Test your prediction in 4-1 and record what you observe.

**Question 4-3:** Attach the iron rod to the “North” end of the cylindrical magnet. Is the paper clip now attracted to the iron rod?

**Question 4-4:** Now disconnect the magnet and iron rod and try to attract the paper clip. Has the iron rod retained its magnetism?

**Question 4-5:** If we postulate that each of the atoms of iron is inherently magnetic, we have a situation very similar to the inherent electrical nature of matter. Recall from your electrostatics lab that you were able to induce into an electrically neutral object a static electric effect. In the space below draw a diagram showing how the magnetic iron atoms might be induced to show a magnetic effect in the iron rod when it is attached to the “North” end of the cylindrical magnet. You should represent the atoms with arrows, where the tip of the arrow is the North pole of the tiny “atomic magnet”.

Activity 5: Is there an interaction between moving electric charges and magnetism?

As you observed above there seems to not be a connection between static charges and magnetic poles. After the invention of the voltaic cell (battery) in about 1800 it was possible to study not only static electric effects but also sustained electric currents. Perhaps there is a connection between moving electric charges and magnetism? In 1819 the Danish physicist H. C. Oersted hypothesized that such a connection might exist. He set up a demonstration of a current carrying wire next to a compass needle.

Question 5-1: You should have a rectangular piece of Plexiglas with wire fastened to it as shown in the diagram below. Lay the Plexiglas flat on the table and attach the two ends of the wire to the adjustable power supply using banana plug cables. Connect the positive lead to the red terminal and the negative lead to the black terminal of the wire on the Plexiglass. Before turning on the power supply, place a small compass on top of the wire at location A. Rotate the Plexiglas until the compass needle is parallel to the wire. Now turn on the power supply with the voltage and the current knob turned to full scale. Describe the effect on the compass needle. Leave the power supply on while you answer questions 5-1 through 5-5, and then turn it off. Draw on the diagram the direction that the compass needle points at locations A, B, C, and D when it is placed on top of the wire (or wires) at that location. (Note: the current limit light on the power supply will be on throughout this exercise; that is okay.)

Question 5-2: How did the observed effect at point B and point C differ? Explain why you saw a difference.
**Question 5-3:** How did the observed effect at point A and point C differ? Explain why you saw a difference.

**Question 5-4:** Place the small compass once again above the wire at position A. Note the direction of the arrow with the power supply on. Now place the small compass under the wire and note what direction the arrow points. Explain the difference.

**Question 5-5:** There are two holes cut in the Plexiglas sheet to allow you to test the magnetic field around the wire at locations A and C. With the Plexiglas sheet standing vertically move the compass in a horizontal circle around the wire at locations A, and C. Describe the direction of the magnetic field around the wire.

**Question 5-6:** In the diagram below draw the magnetic field around a wire that has a positive current out of the page and for one that has a positive current into the page. Make sure to indicate (with arrows) the direction of the magnetic field. Base what you draw on your observations from above.

![Diagram](image)

If a current carrying wire will exert a force on a compass needle then from Newton’s Third law we would expect that a magnet should exert a force on a current carrying wire. You will now test to see if this is true. Hanging from the pendulum clamp should be two rectangular pieces of wire, one about 6 cm wide at the base and the other about 1 cm wide at the base. Place the lab magnet on its end so that its poles are vertical. Adjust the pendulum clamp so that the horizontal piece of the 6 cm wire passes through the poles of the lab magnet. See the photo to the right.
**Prediction 5-7:** On the diagram below draw an arrow to indicate the direction of the magnetic field between the poles of the magnet. On the diagram below, mark an arrow on each diagram showing the direction of the force you expect on the wire a current is flowing in each of the two cases. Hint: Use the Right hand rule discussed in the text.

![Diagram of a magnet with arrows indicating magnetic field and force directions.]

**Question 5-8:** Connect the wire loop to the power supply so that the direction of positive current flow is as in the left part of the diagram above. Turn on the current and record the movement of the wire. Is the force on the wire consistent with your prediction?

**Question 5-9:** Connect the wire loop to the power supply so that the current is as in the right part of the diagram above. Turn on the current and record the movement of the wire. Is the force on the wire consistent with your prediction?

**Prediction 5-10:** If the magnet is flipped over so that the direction of the magnetic field is reversed, what will be the direction of the force (for the current configuration in the right part of the diagram above)?
**Question 5-11:** Test your prediction in 5-10 (You will have to support the magnet with your hand when you do this). Explain your results below.

**Prediction 5-12:** Lay the lab magnet flat on its feet on the table. Position the lab magnet so that the 1 cm wire is in the poles, running parallel to its poles as shown in the diagram below and the photo on the right. Connect to the ends of the wire to the leads from the power supply. On the diagram below, draw an arrow to indicate the direction of the magnetic field between the poles of the magnet and label the polarity of the connection to the power supply. Mark your prediction of the forces that each of the segments of the wire that are in the poles of the magnet will experience when the current is turned on. Do you expect a net force on the wire? Do you expect a net torque on the wire?

**Question 5-13:** Test your prediction by turning on the power supply. Describe the forces that the wire experiences. Is there a net force on the wire? Is there a net torque on the wire?

*Be sure to turn off your power supply when you are finished with this section.*
Activity 6: Magnetic forces on a moving electric charge.

The electric current flowing in a wire is an example of moving electric charges and their interaction with a magnetic field. Can electric charges that are moving outside of a wire also interact with a magnetic field? In the next activity you will test this idea on an electron beam.

**Question 6-1:** Take one of your cylindrical bar magnets (one of the green and red ones) and go to the demonstration “E/M Experimental Apparatus” on the instructor’s table. Test if the electron beam is deflected when it interacts with the magnetic field of a bar magnet. Place the magnet perpendicular to the beam with the “North” pole pointing to the back of the apparatus and record your observation of the effect on the electron beam. (See the photo to the right.)

**Question 6-2:** Reverse the direction of the magnet so that the “south” pole is pointing to the back of the apparatus and record your observations of the effect on the electron beam.

**Question 6-3:** Place the magnet parallel to the beam near where the beam strikes the glass wall and record your observation of the effect on the beam. You may need to move the magnet around a little bit to get it really parallel to the beam; you should be able to find an orientation where you have very little deflection of the electron beam; see photo to the right.
**Question 6-4:** In what orientation is the force on the electron beam the greatest (ie. the “perpendicular” orientation you used for questions 6-1 and 6-2 or the “parallel” orientation you used in question 6-3)? Draw a vector diagram of the force on the electrons, the velocity of the electrons, and the magnetic field in this orientation. (Use a dot to indicate any vector coming out of the page and a cross to indicate any vector going into the page).

**Question 6-5:** What is the mathematical relationship between these three vectors?

**Question 6-6:** Use the Lorentz force law and the right hand rule to “prove” that the beam of particles, that we call electrons, moving in the “E/M Experimental Apparatus” is negatively charged.

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**Activity 7: The magnetic field in a solenoid.**

An important device in magnetic applications is a device known as a solenoid. A solenoid consists of a series of loops of wire wrapped around an axis in a cylindrical fashion. Each loop creates a magnetic field as you observed in Activity 5.

**Prediction 7-1:** If magnetic fields superimpose as electric fields do, what do you expect the magnetic field to be if you have two loops of wire in a solenoid (assuming it is $B_0$ for one loop)? What if you have three loops? What do you expect the relationship to be between the strength of the magnetic field and the number of loops in a solenoid?
**Question 7-2:** You will now test your prediction. Find the loose piece of wire with yellow insulation on your lab tabletop. Use cables with banana plugs on one end and alligator clips on the other end to connect the wire to the adjustable power supply. Turn the supply on and turn the current and voltage knobs all the way to maximum. Load the DataStudio setup file “Magnetism2.ds” from the class notes folder on the desktop. Set the magnetic field sensor to “axial” mode, and to “1X” range. Tare the sensor away from any strong magnetic sources. Start the program and click the “keep” button. This logs the zero point of the magnetic field. Wrap one loop around the end of the Magnetic field probe and then click the “keep” button. Wrap two loops and click the “keep” button. Continue until you have wrapped five loops around the end of the probe. Try to keep the loops as close to the end as possible (this is important because the actual field sensor is located right near the end of the probe). Print out your plot and include it after this sheet. What is the relationship between the magnetic field’s strength and the number of loops?

**Prediction 7-3:** In the next step, you will vary the current in the solenoid and observe how the strength of the magnetic field varies. What do you predict is the relationship between magnetic field strength and the current flowing through the solenoid?

Find the solenoid on your lab tabletop. Connect it to the Pasco Power Amplifier II using banana plug cables (connect one end to the red Pasco terminal and the other end to the black Pasco terminal). Set the magnetic field sensor to axial mode, and to 1X range. Put the probe inside the solenoid so that the end of the probe is in the region of the middle of the solenoid. Turn on the Pasco Power Amplifier II (switch in the back). Load the DataStudio setup file “Magnetism3.ds”. In the “Signal Generator” window, click on AUTO. Then click on “ON”. This will apply 5 volts to the solenoid, which will cause a current to flow through it. Start data-taking by clicking the “Start” button. The current being sent through the solenoid is displayed in the Current box, while the magnetic field measured at the center of the solenoid is displayed in the Magnetic Field box. To change the voltage across the solenoid (and therefore the current flowing through it), click on the “-“ button in the Signal Generator box. As you repeatedly click it, you will trace out a plot of...
magnetic field strength at the center of the solenoid versus the current through it. Take
data for positive and negative values of the current. Print out your plot and include it
after this sheet.

**Question 7-4:** From your data, what do you conclude about the relationship between the
magnetic field strength and the current in a solenoid?

Be sure to turn off your BK Precision power supply and the Pasco Power Amplifier
II when you are finished with the lab. Disconnect all your cables, put you magnetic
material samples back into the Ziploc bag they came in and generally straighten
your lab station for the next group.
Post Lab questions (complete these after you are done with the lab activities or when there is only 10 minutes left in the lab)

1. Given a permanent magnet with known magnetic poles and a beam of electrons, how can you show that the electrons are negatively charged? (it may be easiest to make a little sketch of what you have in mind to demonstrate this)

2. What two factors determine the strength of the magnetic field in a solenoid?

3. If the earth’s magnetic field were produced from a big bar magnet inside of the earth, where would the magnet’s “North” magnetic pole be located – at the Earth’s geographic north or south pole?