- Scout the room for extraneous sources of magnetic fields. Computers, electrical lines, any operating electrical equipment, refrigerators, and of course magnets, are all items that will lead to systemic errors. While some can be minimized or removed, some cannot. Anticipate this when guiding the discussion following data collection.
- Practice before class using a magnetometer and making a dipole map for the recorded observations. Even a few minutes will give you significant insight for assisting students.

Activity 1
Mapping the Field of a Dipole Magnet

Teacher Instructions

1. Assignment for the evening before Activity 1

Please discover when magnetism was first noticed and exploited by human kind. What was done with the discovery? How was it explained? Was it put to general use or was it seen as a curiosity?

Suggested Web sites:

- Dr. David Stern (NASA) has an online book on magnetism at *http://www-spof.gsfc.nasa.gov/Education/Imagnet.html*
- From the official Web server of the State of Hawaii Schools *http://gamma.mhpcc.edu/schools/hoala/magnets/history.htm*
- A Timeline of Magnetism (and Optics) Phenomena *http://history.hyperjeff.net/electromagnetism.html*
- From the University of Washington, a Web site built by a graduate student *http://www.ocean.washington.edu/people/grads/mpruis/magnetics/*

2. Setting the Stage—opening discussion. Ask the question, "Where does a magnetic force begin and end in space around a magnet? What evidence reveals that a magnetic force is present." Try to elicit these responses from students' previous experience with magnets.
   - Magnets affect other magnets and metals.
   - Magnetic influence or strength is not related to size of magnet.
   - Magnetic influences extend through space, but get weaker with distance.
   - Magnets have well differentiated ends or poles. There are two poles.
   - Like poles repel; unlike poles attract.

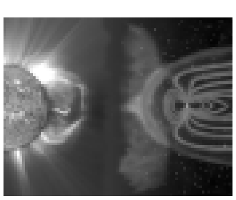
3. Handout materials and instructions for construction of magnetometer—see page 47.

When students have completed the magnetometer, hand out materials and instructions for remainder of activity. Give students 20-30 minutes to complete a map. Circulate, answering questions. Questions can be asked motivating students to think critically about the data and the data collection procedure. Some suggestions follow.

- Where on the line segment is the measured magnetic field direction best represented?
- Is the measured magnetic field parallel to the entire drawn directed line segment or just some part of the drawn arrow?
- What technique did you use to insure you made your arrow directly below the pivot or center point of the sensor magnet?
- Can you state the resolution (the smallest difference in position that also shows a difference in magnetic field direction) of your procedure?

One of the potentially challenging tasks is to draw a set of smooth curves on the maps representing the overall pattern revealed. Certain measurements may not fit the general curve. These individual measurements may have to be ignored, but a solid reason for doing so is required. It is pedagogically useful to prompt students to repeat measurements or to ask several other groups to make some measurements at the same location (but obscure the original troubling one to avoid bias!). This again gets back to the scientific method and it also raises the qualities of collegiality and cooperative effort, both celebrated qualities of work in groups and science labs.

The smooth curves should be approximately tangent to the arrow drawn at a location. This can be hard, and will be affected by such things as "lack of artistic talent," learning disabilities affecting hand-eye coordination and spatial awareness/representation. The goal is NOT a map that emulates the textbook



drawings of magnetic fields. The process is to have students collect data, identify patterns in the data, and to represent the patterns. The smooth curves are the representation of the pattern.

4. Assign the following questions for homework.

What is a dipole? It is the simplest representation of a magnetic field. Look at this site for some drawings of magnetic fields (ignore the formulas if you like) as produced by various sources. Do you recognize any? What is the difference between the field map for a single electric charge and for a bar magnet? A single electric charge is a source of electrostatic field, and is considered a monopole when it is not paired with an opposite charge.

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/elemag.html#c1

In class, you made a map of the magnetic field of a bar magnet. What is a field, as used in a physics statement like the previous statement? What, exactly, does the magnetic field map show someone looking at it?

What happens when two or more sources of magnetic field are interacting? How do they mutually influence space? Will an observer see each separate influence? Will an observer see some combination of the influence of the sources? How might someone with knowledge of the sources go about predicting what an observer with a magnetometer would record as the field of the combination? How would you represent the overlapping influences? If two magnetic field lines intersect, how would a magnetometer react (what direction would it choose to point) if placed at that location?

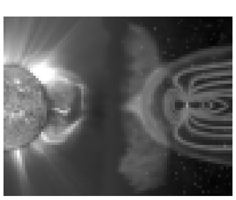
5. Conduct a discussion after students have completed all work and have answered the questions in the student activity.

Two approaches are possible to analyzing the data collected. One is to have student groups work with just the group map and compare answers across groups later, drawing out how data in isolation can lead to varying conclusions. An important part of science is cross-fertilization of thinking among separate groups. A second method is to place all maps on public display (perhaps with names obscured) and have the students examine all the results as they answer the questions. This will require that students add some set of information to the map, including orientation and symbol keys, a critical element of communication of scientific information.

Ask students to interpret, in writing and/or verbally, some or all of these questions.

- **What is a map representing? Is this data?** {Suggested response: The source magnet has created a preferred direction in the space represented by the map. The arrows show the direction a magnetic pole will point at that location.}
- **What is happening at locations between map arrows?** {Suggested response: Similar patterns of change of direction would be seen. These patterns would line up with those documented by direct observation.}
- **Is the change of directionality continuous or are there places where sudden changes or breaks occur?** {Suggested response: While the change of directionality ought to be continuous, concentrations of metal, other magnets disturbing the local field during the observations, current sources being accessed or stopped could all produce an odd or discontinuous change in field direction. Repeating the observation for the point and surrounding points may lead to an adjustment. Repeating the observation after moving the mapping station to a different location may lead to an adjustment but would also require redoing the entire map.}
- **By connecting adjacent observations in a smooth curve, sketch out the complete map appearance.** {Suggested response: This ought to result in the commonly seen dipole field graphic. In any event, the critical discussion questions should be, "How is this consistent? How do you explain the regularity (or irregularity) represented? Is this the most elegant (or simple) explanation or extrapolation consistent with the data that can be made? Is this the only possible appearance of the extrapolation of the data? How do you choose between different representations?"}

- **Place your map on the wall next to those made by others. Identify similarities and differences. Decide if the trends seen across all the maps reveal a generally applicable phenomenon or not. Give significant reasons for your decision.** {Suggested response: Barring excessive error or egregiously sloppy data collection, the maps should be very similar in appearance. The conclusion ought to be that as different observers using different magnets and magnetometers got very similar maps, the standard of repeatability has been met for this observational technique. That suggests that we are seeing a real phenomenon and not some sort of random effect.}
- **If you rotated your source magnet 90 degrees, what sort of changes would you expect in the map if you did new observations?** {Suggested response: The map would be rotated 90 degrees in the same direction. But, the observation lines would not be rotated exactly 90 degrees as the field of a magnet is not circular but rather lobe shaped.}
- **You were not able to do this, but what would you expect to see if you made observations at points inside the source magnet?** {Suggested response: A continuation of the field connecting the poles.}
- **Suppose you were able to map the field in a plane 30 cm above the plane of the source. What sort of a map would you predict seeing? Can you use the map you have made to demonstrate your prediction is reasonable?** {Suggested response: Similar map. You can simply rotate the plane of the map already made to make a reasonable prediction for what the map would look like for different planes in space. This assumes, naturally, that the magnet is a symmetrical shape.}
- **How much has the magnetic field of the Earth altered the map of the field produced by the source?** {Suggested response: The effect will depend on the orientation of the source relative to geomagnetic north. At the outer edges of the map, a trend may be seen which is slightly different from the trend seen near the source. It is possible that students will not see this if they were not particularly precise in recording observations.}
- **How might we identify and remove the effect of the Earth's magnetic field on the map you produced?** The goal of this question is to develop an experimental design and technique for handling combined data sets. This is a lead-in for strategies to combine field maps. {Suggested response: If we make a map of the field of a source magnet, then remove the source from the room and map the Earth's magnetic field at the same location as the original map, we will have an indication of the directional influence of the Earth's field on the map of the source magnet. N.B.: Without knowing the strengths of the magnetic fields mapped, we cannot directly add or subtract these measurements}.



Student Activity
Constructing the Magnetometer

1. Obtain a dry label-free 2-liter soda bottle. Slice the bottle 1/3 the way from the top.
2. Cut the index card so that it fits inside the bottle without touching the sides to create a sensor card.
3. Glue magnet at the center of the top edge of the card. Cut a 1-inch piece of a soda straw and glue to top of the magnet. (See Figure 1.)

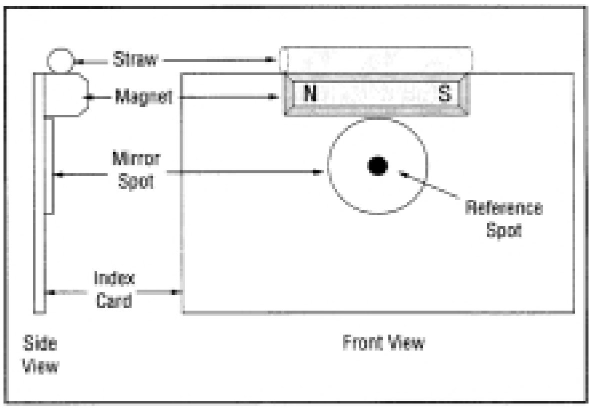


Figure 1. Sensor card set-up, IMAGE poetry

4. Glue the mirror sequin to the front of the magnet. Mark a spot in the middle of the sequin with a permanent marker. This is called the reference spot that will be seen as a dark spot on the wall.
5. Pull the thread through the soda straw and tie it into a small triangle with 2-inch sides.
6. Tie a 6-inch piece of thread to top of the triangle in #5 and thread it through the hole in the cap. Secure the string on the outside of the bottle with tape.
7. Put the bottle top and bottom together so that the "Sensor Card" is free to swing (not touching the bottle) with the mirror spot above the seam.
8. Tape the bottle together and glue the thread through the cap. (Figure 2)

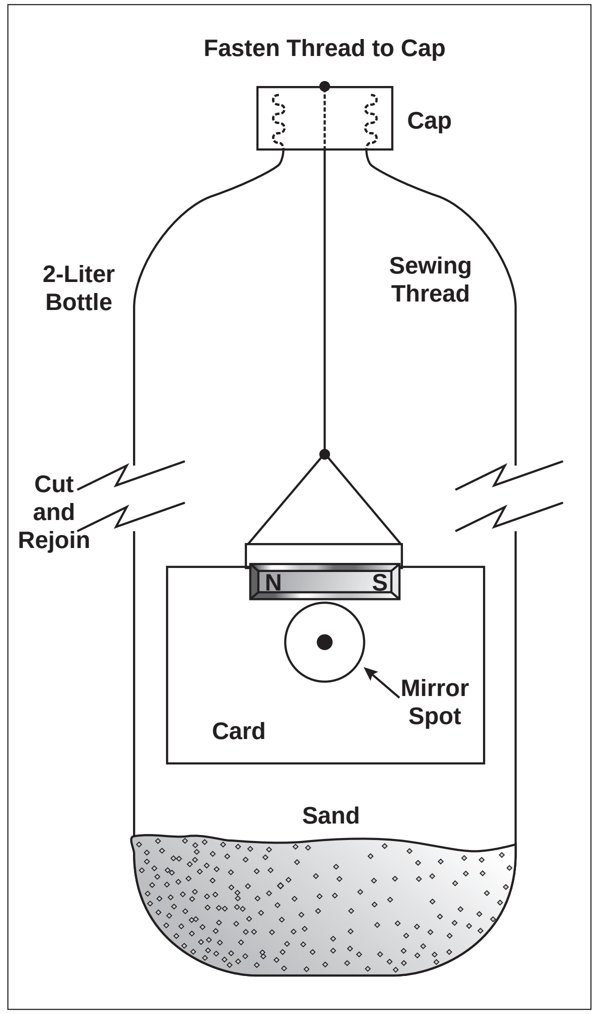


Figure 2. Constructed soda bottle magnetometer, IMAGE poetry

Student Activity 1
Mapping the Field of a Dipole Magnet

Goal: Obtain a good quality representation of the total magnetic field around a bar or dipole magnet.

In today's activity, you will work with a partner using a magnetometer to collect data on how a source magnet affects a test magnet in its vicinity. The test magnet will be the magnet in your magnetometer. The source magnet will be a magnet provided by your teacher. The data you will collect is the direction along which the test magnet lines up at different locations in the vicinity of the source magnet.

What you are mapping is the magnetic field in the vicinity of the source magnet.

Materials:

1. Magnetometer
2. Bar magnet
3. Large sheet of paper
4. Meter stick
5. Pencil

Data Collection Procedure:

- Along all edges of the paper, mark points separated by 10 cm and use them to draw a grid on the paper.
- Place the paper on a lab desk. Use tape to mark the position of the 4 corners so that you could place another paper in exactly the same position. Also use the tape to help keep the map in place.
- Place a source magnet horizontally in center of paper. Tape it to paper.
- Outline the position of the source magnet on the paper. The particular orientation you choose is not under experimental control. That is, place the magnet at any angle you desire relative to the grid you drew. The orientation of the source relative to the paper and the room should be noted.
- Decide which ends of the test magnet in the magnetometer are the front and back.
- Use the magnetometer to determine the direction of the magnetic field at each grid point.
- Record the direction of alignment by drawing a short directed line segment that accurately shows the direction the magnetometer magnet is pointing at that location. The line segment should be centered on the point directly below the center of the magnetometer and should be about an inch long.
- Repeat at each grid intersection.
- Put a legend on the completed map that includes information about the orientation of the map relative to some fixed reference point in the room (a wall clock or a door for instance).
- Put a title on the map as follows: Bar Magnet Map, date, and your group identification

Data analysis questions to be completed by you and your partner. Write out your answers in your notebook..

1. Are all the arrows on your map pointing in the same direction? Why or why not?
2. How did you define the direction of an arrow? What observation was translated into the arrow direction?
3. Explain why you think your data are correct or incorrect. Are there any individual measurements that don't seem to fit the general pattern? Explain how they don't fit the pattern and what the causes might be.
4. If you put one magnet near the magnetometer, the direction the magnetometer points is changed. If you put two magnets near the magnetometer but at different locations, will you measure the combination of the effect of the two magnets or just the effect of one of them? Which one? Write a convincing argument!
5. While gathering data, did you record the effect of just the source magnet or the source magnet and other things contributing interfering sources of magnetic influence? Name the things that might have affected your measurements and state how they changed the direction the magnetometer indicated. Look closely at the lab table, top and bottom, for possible sources of these effects. Consider what you know about magnets from previous experiences for hints about what could be an interfering source of magnetic influence.
6. Can you subtract or otherwise remove the unwanted effects to get the effect of just the bar magnet? Design a procedure to do this. Identify assumptions you are making about magnetism in the design of the procedure. Identify the limitations of your procedure.
7. The magnetometer measures direction. Based on the map, what might you conclude about the strength of the magnet at different distances from a particular pole?