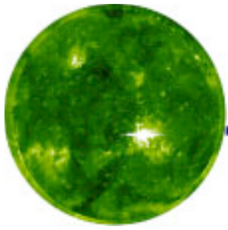


# Mapping the Field of Multiple Dipole Magnets

## High School Grades

**Lesson Summary**
Students use a simple magnetometer to map the union of magnetic fields for two dipole magnets.

**Prior Knowledge & Skills**
Completed the lesson:
- *Mapping the Ambient Magnetic Field*

**AAAS Science Benchmarks**
**The Nature of Science★**
*The Scientific World View*
*Scientific Inquiry*
**The Physical Setting**
*The Universe*
*The Structure of Matter*
*Motion*
*Forces of Nature ★*

**NSES Science Standards**
**Science as Inquiry**
*Abilities to do Scientific Inquiry ★*
*Understandings of Scientific Inquiry*
**Physical Science★**
*Motions and Forces*
**Science and Technology**
*Understandings about Science and Technology*
**History and Nature of Science**
*Science as a Human Endeavor*

**NCTM Mathematics Standards**
**Data Analysis & Probability**
**Problem Solving**
**Reasoning and Proof**

**Teaching Time**: One to two 45-minute periods

**Materials for Teacher**
- Clean and clear map of both parallel and anti-parallel dipole alignments

**Materials per Team**
- Cow magnets (2)
- Large sheets of paper (2)
- Magnetometer (1)

**Materials per Student**
- Homework sheet

**Advanced Planning**
**Preparation Time**: 20 minutes
1. Review lesson plan
2. Gather materials
3. Practice mapping magnet arrangements

***Editor's Note***
*Use the all or some of the eight homework examples provided at the end of this lesson as additional, in-class, laboratory activities.*

*Live from the Aurora*, pp. 57-58, NASA (2003)
http://sunearth.gsfc.nasa.gov/sunearthday/2003/educators_guide2003/pdf/lfa_educators_guide.pdf

## Background for Activities 3 and 4

The students have learned about simple mapping of magnetic dipole fields. In Activity 2, the students saw that along with the dipole field, there was an underlying ambient field, produced largely by the Earth and partially by minor sources within the lab area. In homework, the students have looked at how animals sense the magnetic fields around them and exploit the information in an effort to survive.

In these next two activities, students will look at the union of multiple magnetic fields. Activity 3 is to explicitly map the combined field of two aligned dipoles and two anti-aligned dipoles. For homework, students will predict what happens for other arrangements of two dipoles. In Activity 4, students will check their predictions and learn about the Sun-Earth magnetic interactions. Homework will be to look at the magnetic field mixing in the solar system between the solar wind and Earth. An extension activity is provided which looks at the solar wind interaction with Jupiter and the Jupiter-Io magnetic interaction leading to 20 MHz radio signals received by radio astronomers on Earth.

## Activity 3
## Mapping the Field of Multiple Dipoles

Teacher Instructions

**Goal:** Students will map fields of two dipoles in the same map. Students will understand the field representation does not allow field lines to cross. Students will be able to predict the field map resulting from increasingly complex arrangements of 2 dipole magnets.

Materials per student:

- 2 cow magnets per student
- 2 large sheets of paper
- Student magnetometer
- Pencil/pen

Teacher Preparation:

- Assemble materials
- Assemble homework sheets
- Check Web sites for inactive links
- Prepare a clean and clear map of both parallel and anti-parallel dipole alignments. This will be shown to the students at the end of class if discussion has not proceeded to the point of consensus agreement of what the student-made maps should look like.

Vocabulary

- Geomagnetic field
- Dynamo

1. Discuss homework with students.
2. Assign *Mapping of the Field of Multiple Dipoles*. In this activity, students will be asked if they can tell when the magnetic influence or field at the location of the magnetometer is nonexistent. They cannot. It is an important part of understanding the limits of the magnetometer and analyzing the data collected.

In this mapping exercise, there may be several locations where the direction of the magnetic field is very sensitive to the position of the magnetometer. The limit of spatial resolution by a magnetometer is probably on the order of a centimeter. Students may not recognize until the discussion that they have encountered a limit of the equipment. This is a good opportunity to underscore the limits on the precision of the procedure and its effect on drawing conclusions, and finally the need to extrapolate through logic to make hypotheses and predictions for the areas where instrumental resolution does not allow observations.

3. Discuss activity and results as a class group.

- **Did removing the ambient field lead to significant changes in the field maps?**
  {Suggested response: Especially in regions between the anti-aligned dipoles, the removal is problematic as we are not sure of the relative strengths of the dipoles, and how the strength decreases with distance away from the dipole. We can make two guiding assumptions: (a) far from the dipoles, the field is completely background or ambient; (b) somewhere between two anti-aligned dipoles occurs a point where the total field strength is again only due to the background as the two dipoles contribute equal and opposite field

strengths. By logic, this point should be on a plane intersecting the line joining the dipoles. If we can find and identify these two regions, we can begin to make intelligent guesses about the relative strength of field contributions from each dipole at any point in the mapping area. While this is a difficult and imprecise process, it is also one that yields a reasonably accurate result.}

- **If two sources of magnetic field had equal strengths and opposite alignments at some location in space, and you placed a magnetometer at that location, what observation about the local magnetic field would you report? Can you distinguish between a location with no magnetic field and a location where all the magnetic fields exactly cancelled each other?** {Suggested response: At this time, no, the students cannot distinguish between these situations. The magnetometer magnet will have a natural position that is related to the torsional strength of the string, the details of the mass distribution of the hanging magnet structure, and the details of the attachment of the magnet to the string.}
- **Show how the magnetic fields of separate dipoles add to produce the 2-dipole fields you have mapped. That is, show through some means of adding directional indicators from the single dipole maps made two days ago how the 2-dipole (aligned and anti-aligned) maps are foreseeable results.** {Suggested response: By overlaying the single dipole maps, offset by the distance between the dipoles in the 2-dipole maps, and making an approximate addition of the nearby direction data on each layer, one can generate a procedure for predicting how a 2-dipole map should appear. Some simple rules should result, as follows.

For Parallel Alignment

Dipole 1 produces Field 1 while Dipole 2 produces Field 2 at the indicated point. The result of adding F1 and F2 is Sum, the actual observed orientation of the students' magnetometer. The arrow overlaying the smaller dipoles 1 and 2 indicates how aligned dipoles mimic a single larger dipole.

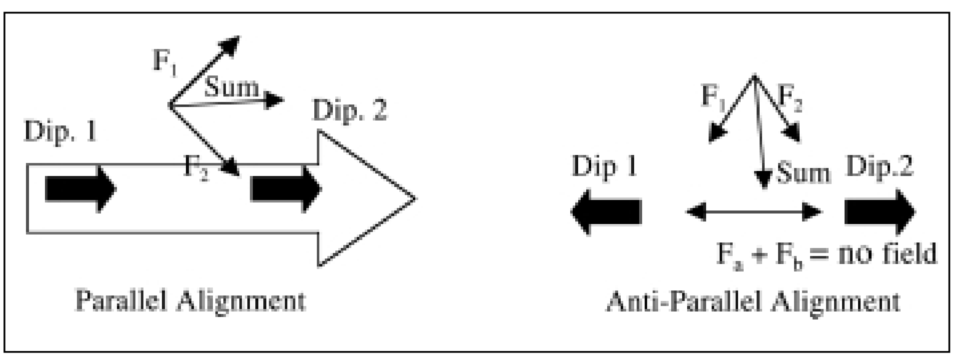
For the Anti-Parallel Alignment

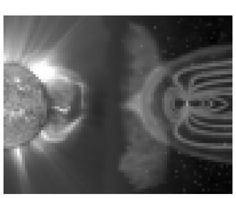
Notice in this example two locations are exhibited. Dipole 1 produces measured fields F1 and F-a, at the respective points, while Dipole 2 produces measured fields F2 and F-b at the respective points. The measured fields F1 and F2 add up to a measurement called Sum, which points between the source magnets. The measured fields F-a and F-b are in opposite directions. If they are of equal magnitude, they will combine to create a zero magnitude field at that point.

We note that zero magnitude magnetic field is a very hard spot to find, however, as the magnetometer does not distinguish a zero strength field, and a slight movement of the magnetometer lets it line up on the closer of the dipoles. That is, at this location, it should seem as if the magnetometer cannot "make up its mind" about what direction to point.

When you have a completed map of the anti-aligned orientation, you will have mapped a Quadrapole field.

3. Assign *Magnetic Field Mapping Exercise*



## Student Activity 3
## Mapping the Field of Multiple Dipoles

**Goal:** If two dipole magnets are positioned near each other, what will the map of the field look like? How does the orientation of the magnets affect the shape of the field? How can you predict the field map resulting from increasingly complex arrangements of 2 dipole magnets?

**Background:** The minimum source of magnetic field is the dipole. That is, there are no individual poles of magnetic "charge." One must get a South attached to every North. The magnetic field encountered in life and industry is rarely just a single dipole field. The fields seen are combinations of many dipoles. This is analogous to the field produced by a large amount of positive charge: The electrostatic field seen is a combination or "sum" of all the single charge fields. The shape of the field is symptomatic of the arrangement of the charges forming it.

Basic task:

In groups of two, map the field of two dipoles in a given arrangement and remove the effect of the background field to get a more accurate map.

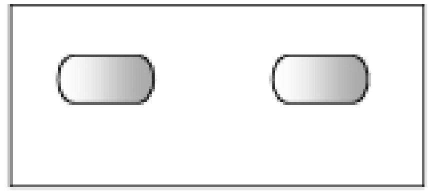
Lab supplies:

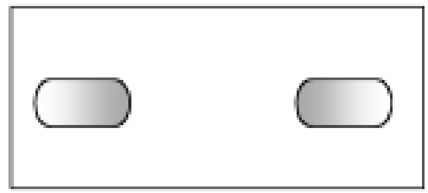
Each student group will need the following materials:

- 3 large sheets of paper
- 2 cow magnets
- 1 magnetometer
- Pencil and tape

Procedure for mapping two dipoles

1. Determine and label the ends of the cow magnets as N/S.
2. Mark off a 10-cm grid on all sheets.
3. Identify the specific location where you will be making your maps. Mark the edges carefully with tape.
4. Map background field at this location.
5. Map the combined magnetic field of the pair of parallel, aligned dipoles on the same sheet of paper as used in (4).
6. Repeat (4) and (5) on a new sheet of paper with the poles oppositely aligned, as shown in the diagram below.





The dark part of the oval is the opposite pole of the lighter part. The poles are not close enough to cause one magnet to move away from the other one.

7. Using your knowledge of the ambient field, can you correct the maps made in (5) and (6) so that they show just the field of the dipole arrangements? Estimate what the corrected field would look like.
8. Draw smooth curves showing the shape of the combined dipole magnetic fields and add arrows to indicate field direction.
9. Title the maps with date, time, group names, and information about the orientation of the map in the room, the alignment of the dipoles, and whether the ambient field has been removed.

Questions to be answered in your lab notebook before class discussion.

a. Write down the procedure you used to insure that the dipole field maps were made in the same location as the ambient field maps.
b. Write down the procedure you used to remove the effect of the ambient field map from the dipole fields. Write down the factors that make you confident in your results and those that make you less confident.

c. Make a chart of the similarities and differences between the maps. Look for big things and look for details.

d. Present your work to the teacher for checking.

### Student Activity 3
### Magnetic Field Mapping Exercise

You have mapped the magnetic field of aligned and anti-aligned dipoles. Using what you have observed and the understanding your class came to in the discussion, please predict what a mapping exercise would show for the following configurations of dipole magnets. Note: the ovals are the magnets and the white-to-gray gradient denotes the magnetic poles. All magnets are the same strength. Draw a sufficiently large set of lines to show the field map at all points.