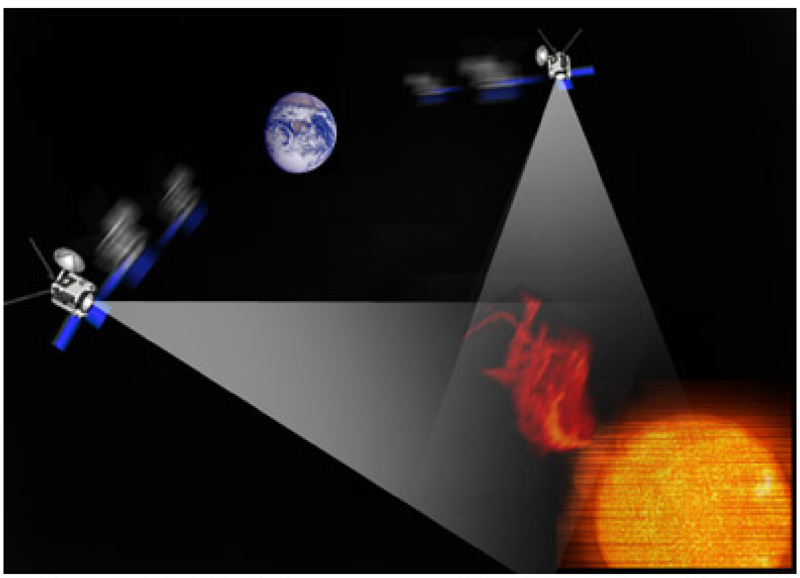
A Teacher’s Magnetism Activity Guide
For Grades 6-9

Exploring Magnetism

In the Solar Wind



stereo - impact
education and public outreach

The Center for Science Education at the
Space Sciences Laboratory
University of California at Berkeley

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Introduction

A Summary of the Teacher's Guide

This guide is a supplement to the guide *Exploring Magnetism*, in which students learn about the basic phenomenon of magnetism. The purpose of this guide is for students to apply their newfound knowledge in order to design an important part of a space science spacecraft: the magnetometer boom. The process of designing such a boom imitates the process of NASA engineers.

Included at the beginning of this session is a summary of the session, student objectives, a list of national standards that the session covers, and a list of materials required for the session. The session is broken into several activities, with each activity outlined for the teacher. In the Background Material section, you can find science background for the lesson, a NASA information sheet about the Sun and Earth's magnetic fields, and questions and answers that came from a discussion with a NASA IMPACT Boom Engineer, Paul Turin. A glossary can be found after the background section, and at the very end we recommend different resources for purchasing materials and learning more about the NASA mission and science in this guide.

The Science

The Sun sometimes stores so much energy in its magnetic field that when the energy is released, it can accelerate solar wind particles to nearly the speed of light. This tremendous release of energy is sometimes associated with large pressure pulses of solar wind that interact with Earth's magnetic field, accelerating particles to extremely high energies in the radiation belts, i.e. Van Allen Belts, in Earth's magnetic field. The solar wind particles moving at near the speed of light can harm astronauts not protected by their spacecraft. The energetic particles in the Van Allen Belts can damage or destroy human-made satellites. In order to understand and predict these phenomena, we need to understand what magnetic fields are.

Currently, NASA is funding the STEREO mission, which involves the building of multiple spacecraft and suites of instruments in order to understand these gigantic releases of energy from the Sun. Scientists involved in the

IMPACT instrument suite of the STEREO mission are specifically interested in the variation in the Sun's magnetic field that threads out from the Sun itself, through the planets, and past Pluto. In order to measure the weak magnetic field of the solar wind, an instrument known as a magnetometer is placed far away from the body of a satellite, near the end of a long cylinder called a boom. This magnetometer sits far from the satellite because currents generated in the electrical circuitry in the satellite make local magnetic fields that are larger than the magnetic field of the solar wind.

Using the Teacher's Guide

STEREO-IMPACT's education program provides this session and activities on magnetism to inspire your students to learn how electricity and magnetism are connected, and how to apply this knowledge. It is intended to be used following the activities of the teacher guide: *Exploring Magnetism*.

This session is designed so students can apply their knowledge of magnetic fields to the engineering problem of designing a spacecraft to measure small interplanetary magnetic fields. This is the same task that scientists and engineers have accomplished using the IMPACT instrument suite of the STEREO mission. Activity 1 is a question-answer activity in which the students learn about the magnetic fields of the Sun and Earth. Activity 2 has students experiment with different ways of measuring Earth's magnetic field direction, using a compass attached to a box with a strong magnet inside. Earth's magnetic field represents the interplanetary magnetic field and the box with a magnet represents a spacecraft with currents inside. In Activity 3, students act as scientists and engineers at a conference to explain and share their designs and discoveries with other students (scientists and engineers).

All of the activities are inquiry-based. One benefit of such inquiry learning is to teach the students how a scientist performs research by asking questions, testing their ideas, and collaborating with others. Another benefit of inquiry-based activities is to engage the students in the process of learning science.

We estimate that teaching all of the activities in this session would take 2.5 days in an 8th grade classroom with 50-minute class periods.

Session 3: The Interplanetary Magnetic Field (IMF)

"I've never encountered a magnetic field I didn't like." – George Craig

Session Summary

In light of their discoveries of electromagnetism from the *Exploring Magnetism* Guide, students will be charged with the task of designing an experiment for NASA's STEREO/IMPACT mission to measure the interplanetary magnetic field. The three main goals of this lesson are for students to:

1. know what the interplanetary magnetic field (IMF) and Earth's magnetosphere are;
2. know about spacecraft, booms, and magnetometers; and
3. understand why a magnetometer boom is needed on a spacecraft that is sent to space to measure the interplanetary magnetic field, i.e. that the currents associated with the spacecraft's electronics will cause local magnetic fields that are larger than the interplanetary magnetic field.

This lesson can also be used to assess a student's understanding of electromagnetism.

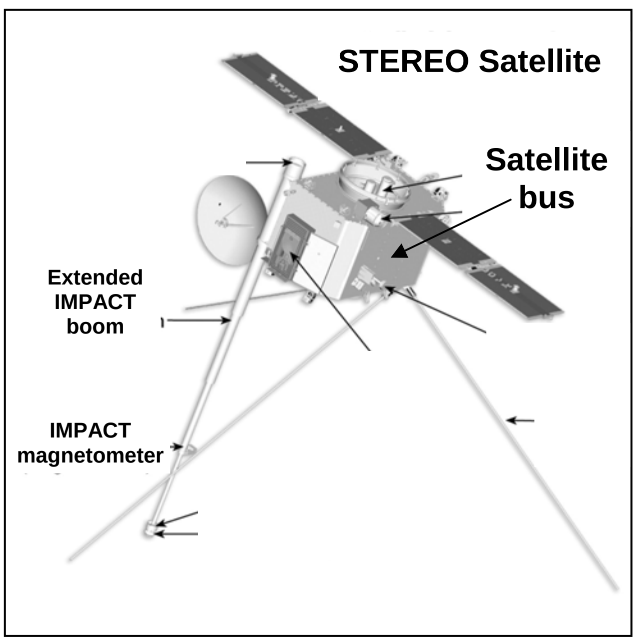


Figure 3.1: On the left, a diagram of one of the STEREO satellites is shown. Groups of scientific instruments are located on the side of the satellite body. The body of the satellite is called the satellite bus. The IMPACT boom is labeled and shown as it will look once it is in space and has been extended, i.e. deployed. Wait until the end of the lesson to show students this picture so that they can develop their own boom designs first. Drawing courtesy of NASA.

Student Objectives

1. Students will know the concept of the Interplanetary Magnetic Field (IMF).
2. Students will know why a magnetometer boom is needed on a spacecraft studying the IMF.
3. Students will be able to use their knowledge of magnets, magnetic fields, and electromagnetism to create a model of a real-world instrument used to measure magnetic fields from a NASA satellite.
4. Students will use real-world engineering techniques to create a practical and functioning NASA satellite that can study and accurately measure the IMF.

National Science Content Standards

- Unifying Concepts and Processes: Evidence, models, and explanation; Change, constancy, and measurement
- Science as Inquiry: Abilities necessary to do scientific inquiry; Understandings about scientific inquiry
- Earth and Space Science: Structure of the Earth System; Earth in the Solar System
- Science and Technology: Abilities of technological design

Previous Knowledge Required

It is important for this activity that students understand electromagnetism. Specifically, students should understand that:

- currents in electric circuits create magnetic fields,
- electric circuits (and thus magnetic fields) are found with anything that uses electricity to run,
- the strength of magnetic fields decrease rapidly the farther away you move from the source of the magnetic fields, and
- larger magnetic fields will dominate over smaller magnetic fields. This is because magnetic fields are vectors and thus add and subtract as vectors add and subtract. Introducing vector addition could be done prior to this lesson but is not at all necessary.

If your students do not know the properties of electromagnetism mentioned here, then it would be useful to have them go through at least Session 1: Activity 1, Session 2: Activity 1, and Session 2: Activity 3 of the *Exploring Magnetism* teacher's guide.

Materials Needed (per group of students)

- 2 Alnico bar Magnets
- 4 small compasses
- 20 paper clips
- 1 small cardboard box (about 6x3x3" in size)
- Construction paper
- Aluminum foil
- Wax paper
- Newspaper
- Scotch tape
- Glue
- Scissors
- Per Student: 1 copy of NASA STEREO mission story found in the Background Material section
- Per class: Transparency copies of Figures 3.2, 3.3, 3.4, and 3.5

Activity 1: Learning About Space Weather

Now that your students know about electromagnetism, they will learn about the magnetic fields of the Sun and Earth. This activity is a question-answer activity where the students are using "minds-on" rather than "hand-on" inquiry.

Your students should have already learned about atoms, phase transitions, and some basic information about the Sun. In particular, for this activity it is best to ensure that the students know that:

- Atoms are made up of electrons, protons, and neutrons.
- Hydrogen is a common element in the universe and it is made up of one electron and one proton.
- In the right pressure environment, as a solid is heated it turns to liquid. As a liquid is heated it turns to a gas.
- The Sun is made up mostly of hydrogen.
- The Sun is hot because gravity acts to pull the mass together so much that near the core of the Sun atoms are pushed together and join together in fusion reactions. These fusion reactions mostly convert hydrogen into helium plus light energy (in the form of gamma-rays). This light energy interacts with matter and is transformed into heat.

- The Sun is so hot that the electrons cannot stay attached to the nucleus of the atom. This means the Sun is mostly a hot, electrically charged gas, which is known as "plasma."
- The Sun has different layers and its outer layer is called the corona.

It is possible to include in the activity a lecture about these things but it is more meaningful if they have learned them in another context and you can remind them about those lessons in this activity.

Introducing the Interplanetary Magnetic Field (IMF) and Solar Wind

1. First have the students answer the question: "What objects in space have magnetic fields?" [The Sun, Earth, the Moon, Mars, Jupiter, Saturn, Uranus, and Neptune all have magnetic fields. Other planets and objects, such as Venus, do not have magnetic fields because there is not a fluid or gas dynamo in their core; or because the crust of the planet or object does not contain magnetic material.]

2. Review with your students what they know about the Sun. [The Sun is a star. A Star is a big ball of dense gas made up mostly of hydrogen that generates its own energy through nuclear fusion.]

3. After some discussion, emphasize that Earth and the Sun have large-scale magnetic fields near their surfaces that are similar to the magnetic field of a bar magnet. Have the students look at their magnetic field maps from Session 1: Activity 1, and Session 2: Activity 3 of *Exploring Magnetism*. Then have them draw a circle around the region where the bar magnet was located, making the diameter of the circle the same as the length of the bar magnet.

4. Discuss that this circle and the surrounding magnetic field lines approximately represent the Sun and its large magnetic field lines.

5. Ask your students: "Where does the Sun's magnetic field come from?" Remind your students about the activities with the electric circuits. [The Sun's magnetic field comes from currents in and around the Sun that are caused by the moving plasma.]

6. Explain to your students that close to the surface of the Sun, the magnetic fields can be complicated with many north and south poles close to one another. Show the image of such magnetic fields taken by an instrument viewing the Sun in ultraviolet light, located on the NASA TRACE satellite (Figure 3.2).

7. Far from the surface of the Sun, the magnetic fields are also different from the bar magnet. They look more like someone's very long hair flowing out and away from the Sun with a very flat doughnut of current circling around the Sun. This magnetic field is called the "Interplanetary Magnetic Field."

8. Give a short lecture (5-10 minutes) about the solar wind and explain that it is connected to the Sun's magnetic field. [The corona is the outer-most layer of the Sun that is so hot that it streams out and away from the Sun's gravitational pull, producing the solar wind. This wind is not a neutral wind and nothing like wind on Earth. It is an electric wind with a very low density. The solar wind is attached to the Sun's magnetic fields and together they stream out into space, past all the planets.] See the background resources to learn more about the solar wind and to obtain movies of the corona and features flowing out into the solar wind.

Introducing the Magnetosphere

9. Now have the students look again at their drawings of the bar magnetic field with the circle. Tell them that this circle and the field lines could also approximate Earth and Earth's large magnetic field lines.

10. Ask "where does Earth's magnetic field come from?" [Earth's magnetic field comes from the currents in the molten Iron core inside Earth's crust. These currents create a complex magnetic field that is approximated by a dipole magnetic field, like that of a bar magnet].

11. Explain that far from Earth, the magnetic field lines are modified by something blowing through space. Show a transparency of Figure 3.3 on an overhead projector. Explain that this is a cartoon of Earth's magnetosphere if we could look at it with "compass eyes."

Figure 3.2: On the left, an image of magnetic field lines near the surface of the Sun (the photosphere) is shown. This image was taken by collecting ultraviolet light in an imager on the NASA TRACE satellite.

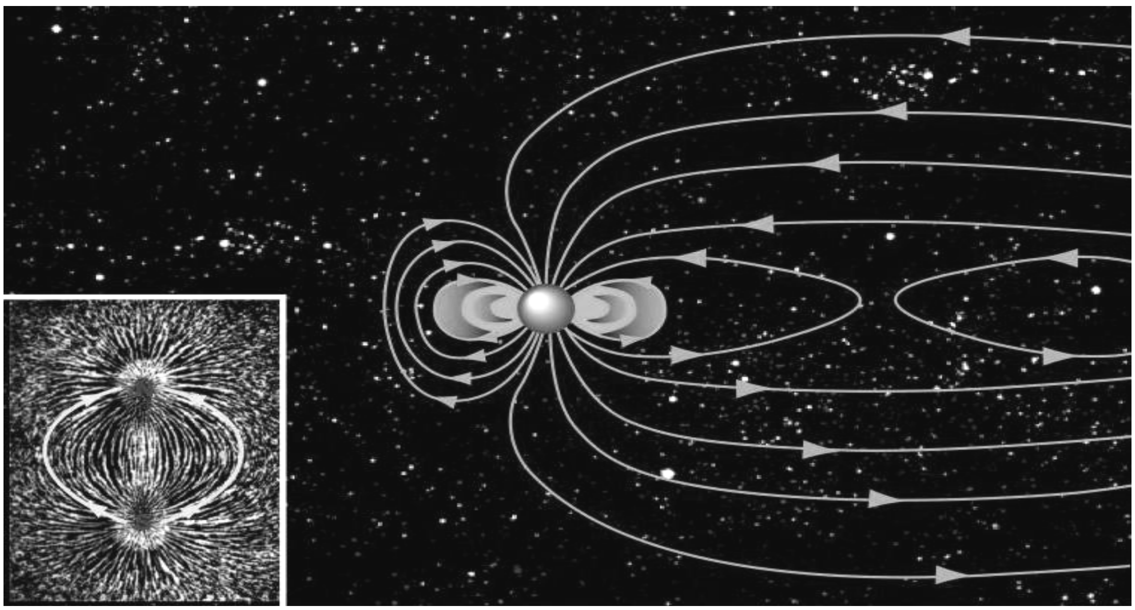


Figure 3.3: Above, a depiction of the magnetic fields around Earth, known as the Magnetosphere, is shown as viewed from the ecliptic plane. The “North” pole is really a magnetic south pole which attracts the north poles of compasses. The solar wind modifies the dipole field lines far from Earth. Image courtesy of NASA.

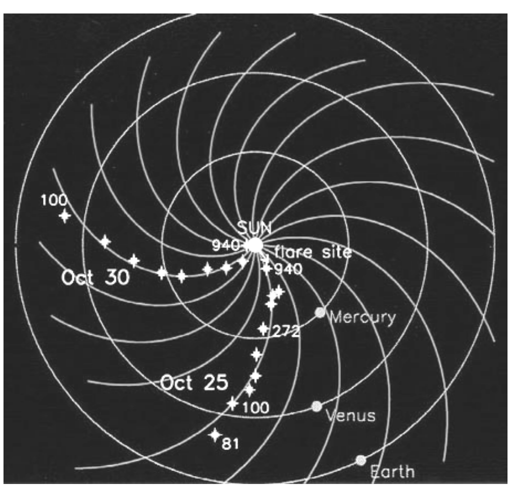


Figure 3.4: On the left, a model of the magnetic field (spiral lines) of the Sun (in the middle) is shown as one looks down on the Sun’s axis of rotation. This magnetic field is known as the interplanetary magnetic field (IMF). The orbits of Mercury, Venus, and Earth are shown as circles. The spiral of the IMF shown here is due to the fact that the IMF is attached to the rotating Sun, but we draw it from a non-rotating perspective from above. Image courtesy of NASA.

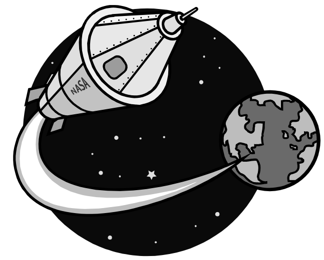
12. Ask "what in space is making the magnetosphere look different from the bar magnet dipole field?" [The solar wind! It blows past Earth's magnetic field from the left on this image and pushes the magnetic field lines on the side facing the Sun and lengthens the field-lines on the side opposite from the Sun.]

13. Show a transparency of Figure 3.4 on an overhead projector and explain that if we did not rotate with the Sun and we looked down on the "top" of the Sun, the solar wind and the interplanetary magnetic field would look like a giant spiral coming off of the Sun, like the water coming off of a sprinkler.

14. Hand out to students "A NASA story of STEREO/IMPACT: Introductory Material," found in the Background Material section. Have the students read these pages at home and write a paragraph explaining in their own words one concept that they learned from the handout.

15. Collect the students' paragraphs the following day and read them to assess their understanding of the lecture and the reading.

Activity 2: Measuring the IMF



In this activity, your students will discuss how they would measure the Interplanetary Magnetic Field (IMF). They will experiment with different ways of measuring Earth's magnetic field direction using a compass that is in some way attached to a box with a strong magnet inside. Earth's magnetic field represents the interplanetary magnetic field and the box with a magnet represents a spacecraft with currents inside. The currents inside the spacecraft create a magnetic field stronger than the magnetic field of the interplanetary magnetic field, just as the magnet inside the box has a stronger magnetic field than Earth's magnetic field.

The day before this activity, you can have your students bring materials in from their home that they might want to use in their experiment, such as a cardboard box, cardboard, aluminum foil, or newspaper.

This is an inquiry activity, so you should not reveal to the students how scientists and engineers have solved the puzzle. Emphasize to the students that they are to experiment and come up with their own ideas. To learn more about how scientists and engineers design a spacecraft boom so that the spacecraft magnetic fields do not interfere with the experiment to measure the IMF, see the Background Material section. In addition to a boom, engineers sometimes also use "mu-materials" to shield magnetic fields from motors. These materials are not readily available for the classroom, however.

16. Tell the students to imagine that they are NASA scientists who want to better understand the interplanetary magnetic field (IMF). They want to learn more about the magnetic fields that are ejected from the Sun. Ask the students: "How would you measure the IMF?" Continue probing until someone suggests that they would put a satellite into space with some way to measure the magnetic field direction (such as using a compass). [If a student asks why we have to go to space to measure the IMF, explain that the IMF at Earth's distance from the sun is 10,000 times less strong than Earth's own magnetic field and there are continuous variations in Earth's magnetic field that are much larger than the IMF strength.]

17. Tell the students that an instrument to measure magnetic fields is called a magnetometer. This word can be broken down into its two basic parts: magnet and meter, meter meaning a device used to make measurements. A compass is a very simple magnetometer; it is also an incomplete magnetometer since it cannot measure the strength of the field.

Designing an experiment to measure the IMF

18. Tell your students that they will now design a simplified experiment to measure the IMF. Explain the puzzle that scientists and engineers have when they want to measure the interplanetary magnetic field (IMF): The electricity on the spacecraft that is needed to run the instruments creates a magnetic field (see Figure 3.4). This magnetic field is stronger than the interplanetary magnetic field. If they put their magnetometer on the spacecraft body, called a "spacecraft bus," they will measure the magnetic field of the spacecraft and not of the IMF.

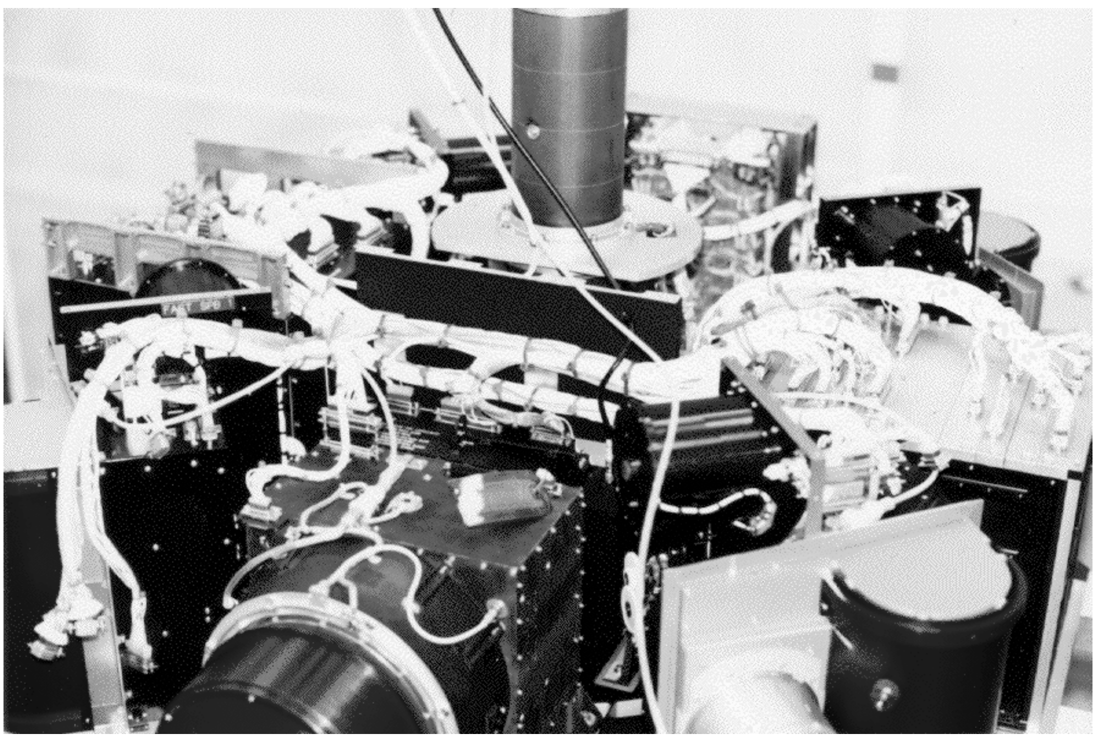


Figure 3.5: Shown above are the instruments and the wires that carry the electricity to run the instruments on the Fast Auroral SnapshoT (FAST) satellite. A magnetic field is associated with the current running through the wires and so the satellite has an overall magnetic field. Photograph courtesy of NASA.

19. Tell the students that they will solve this puzzle by pretending a box with a magnet inside is the spacecraft and Earth's magnetic field is the IMF. They will have available many materials to use for their designs, such as construction paper, aluminum foil, tape or glue, a compass, and any other materials they have brought from home.

20. Next, have your students get into groups. Each group should have a small box (on the order of a 6x3x3" box), a strong bar magnet, and several compasses. Have each group put the bar magnet inside the box and close the box.

21. Now tell the students that they have to solve the same puzzle that the scientists and engineers have to solve when they want to measure the IMF: they must somehow attach the compass or compasses to the box but they have to measure the direction of Earth's magnetic field and not the magnetic field of the bar magnet inside the box. To solve this puzzle first they must answer the question: "How would you determine which magnetic field you are measuring (Earth's or the bar magnet)?" Have a small discussion so that the students understand the question.

22. Next ask the students: "How might you design your experiment to keep the compass attached to the box, but make sure the compass is measuring Earth's magnetic field and not the magnetic field of the bar magnet inside the box?" Again have a short discussion so that students understand the question.

23. Now have the students discuss with the others in their group what experiment they are going to design and how they will determine what magnetic field direction they are measuring.

24. After the groups are finished deciding their approach to the puzzle, give them at least 30 minutes to experiment and build their design.

25. Tell them that they will share their discoveries with the class in the next class period (activity).

Activity 3: Science and Engineering Conference

In this activity, your students will act as scientists and engineers at a conference to explain and share their designs and discoveries with other students (scientists and engineers).

26. Have a representative from each group tell the class:
    a. How they designed their experiment to measure Earth's magnetic field while having the compass attached to the box with the magnet.
    b. Whether or not their design worked and how they could tell whether or not it worked.
    c. How their experiment represents measuring the interplanetary magnetic field from a satellite.

27. After each group has shared their design with the class, have a general discussion about which design seemed to be the best and which experiment did the best job of determining which design was the best.

28. Last, share with the class how scientists and engineers working with the NASA STEREO-IMPACT mission have solved this puzzle. If you have an internet connection, show them the STEREO-IMPACT web pages, http://cse.ssl.berkeley.edu/impact, to find out more about the STEREO mission.

Going Further: Writing a scientific report

29. As an assessment to this session, have the students write a technical report on their design. They should include in their report:
    a. An introduction section that says why they want to measure the interplanetary magnetic field and how their experiment is analogous to that of a spacecraft in the interplanetary magnetic field.
    b. A design section that explains what the design was and what materials they used, and why they chose this design.
    c. An experiment section that explains how they tested their design.
    d. A discussion section that says whether or not their design worked and what they would do differently the next time they did this design.

A NASA "Story" of STEREO/IMPACT: Introductory Material

There are many scientists who want to understand more about the Sun. They know that the Sun is a fiery ball of gas that gets so hot that gas flies out from the Sun at very high speeds. Many of the **electrons** in the Sun's atoms have enough energy to leave the atoms. These new particles are called **ions**. These **ions** and **electrons** are flowing from the Sun and together they are known as the **solar wind**. The **ions** and **electrons** dance in the Sun's magnetic field. Scientists discovered that the solar wind and its magnetic field flow together out past Mercury, past Earth, and continue out past Pluto. Because the magnetic field is threaded throughout the solar system, we call it the **interplanetary magnetic field**, that is the magnetic field found between (inter) the planets (planetary).

Scientists have also noticed that the Sun goes through different cycles, just like moody people who are calm and quiet some days but other days, they explode with anger. But of course the Sun doesn't have emotions to drive its cycles! Physical principles, such as magnetic and electric forces, drive its cycles. During the Sun's active cycle, parts of the Sun will explode, sending out even more **solar wind** and magnetic fields than it typically sends out.

What happens to the **solar wind** and magnetic fields that the explosions send flying out into space? Well, sometimes the explosive **solar wind** will flow by Earth, where we all live. Luckily Earth has a magnetic field and a thick layer of atmosphere, which protect all living creatures on Earth from the particles and radiation that can come from such solar explosions. But when astronauts are up in space, sometimes the magnetic field isn't strong enough to protect them and they have to run, or rather float, back into their space vehicles, such as the space station. Scientists asked themselves: "What triggers these explosions?" How do these explosions flow out and away from the Sun? How do these explosions make **ions** and **electrons** go so fast?"

How are the scientists going to answer these questions? Well, they have studied the solar explosions while sitting (or standing) on Earth using telescopes. They named these explosions **coronal mass ejections**. Scientists like to give names to specific types of events so that everyone knows what they are talking about using only a couple of words. That is efficient. NASA scientists like to make it even easier by making an **acronym** out of the name. An **acronym** is made with the first letter of each word in the name. What acronym would you use for the term: **interplanetary magnetic field**? What does the acronym NASA stand for? NASA scientists make a Coronal Mass Ejection into an acronym too: a **CME**.

With just one satellite, scientists can only measure magnetic fields at one point in space, and that's just what they have done. And with one satellite at a time, they have discovered many things about the Sun. But really, scientists need to measure the **interplanetary magnetic field** and the **solar wind** at more than just one point. Two instruments studying the Sun from two different places will help them understand better how the explosions move outward.

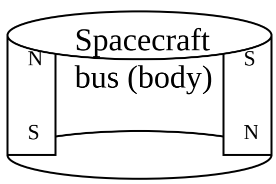
So, several scientists proposed to put up two satellites at the same time. These two satellites would be able to take photographs of the Sun from two perspectives, and instruments on the satellites would measure the interplanetary magnetic field in two locations. If we converted the data into sound and listened through headphones, the data could come out in stereo! And so, this mission was named STEREO, which is short for Solar Terrestrial Relations Observatory. As they say, "Two ears are better than one!" The reviewers at NASA, who are other space scientists, said: "Yes! These are good science questions and a feasible mission. Let's do it!" And the U.S. Congress agreed to pay for it.   And so instruments and a satellite are being built for the NASA STEREO mission in order to study the Sun's explosions.   And now you too can be a part of this mission.

We never really answered the question: "How are the scientists going to measure the interplanetary magnetic field?" This is what you are going to answer in the next activities centered on electromagnetism. First, you have to remember what you know about magnetic fields and how to measure them. Then you have to design a model experiment that could work on a spacecraft to measure the **interplanetary magnetic field**. And then you have to create your design, test it, and share your design and model with your fellow scientists and engineers, that is — your fellow students. This is exactly what scientists and engineers working on the STEREO/IMPACT NASA mission have had to do.

Worksheet 3.1

Name: ________________________________
Date: ________________________________

1. Draw a design of your magnetometer (instrument to measure a magnetic field) system, which will measure the interplanetary magnetic field (IMF). Your magnetometer has to be attached in some way to the spacecraft bus, drawn for you below. Indicate what materials you will use on your design.



2. Write down why you designed the magnetometer experiment the way you did. Why did you choose particular materials? Why did you put the magnetometer where you did?

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Additive Assessment Rubric: Session 3 - The Interplanetary Magnetic Field

With an additive rubric, students have to learn more content in greater depth to achieve higher levels. Teachers should introduce the rubric before the activities begin and encourage students to achieve to their highest potential.

	1	+2	+3	+4	+5
Science Content: Student understands the concept of the interplanetary magnetic field and the design of a NASA satellite whose purpose is to study the IMF.	*Level 2 tasks attempted but not completed or mastered.	*Student successfully recalls their prior knowledge of magnets, magnetic fields, and electromagnetic fields.	*Student knows the concept of interplanetary magnetic fields. *Student, through successful completion of activity 1, can make strong connections between the Sun and Earth's magnetic fields and knows the effects of solar wind on Earth's magnetic field.	*Student, through successful completion of activity 2, understands the purpose of a magnetometer and the magnetometer boom. *Students can draw their own model of a magnetometer using their knowledge of magnetic fields.	*Student, through successful completion of activity 3, draws and creates their magnetometer using real world engineering techniques and creates a practical and functioning model NASA satellite that can accurately measure interplanetary magnetic fields. *Student fully demonstrates comprehension of interplanetary magnetic fields through successful exploration of activities, 90% and above correctness in activity worksheets, and completion of a technical report detailing the student(s) design.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2.	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

Background Material

[*Note: To do a 7-day lesson on the Sun-Earth connection, which was briefly described in the previous story section, we recommend using the LHS GEMS guide, "Living with a Star." See the "Resource" section at the end of this guide.*]

More Information about the STEREO/IMPACT Experiment

The STEREO mission consists of two spacecrafts positioned on either side of Earth in its orbit around the Sun. The spacecrafts study the Sun, the Solar Wind, and the interplanetary magnetic field (IMF) from two perspectives in space. This makes it possible to make 3-dimensional (3-D) images, as depicted in Figure B1. Since the spacecrafts are physically located in the Solar Wind they can make direct measurements of its magnetic field using a magnetometer that detects the strength and direction of a magnetic field. The spacecrafts have many instruments aboard that use electricity to operate. As has been discussed, these electronic components of other instruments will produce magnetic fields of their own. These magnetic fields will interfere with the magnetometers' measurements of the Solar Wind's magnetic field (the IMF).

The engineers who designed the magnetometer experiment had to come up with a way to allow the magnetometers to measure the IMF, uncontaminated by the fields created by the spacecrafts' own electronics. NASA engineers came up with a two-fold design. The inside of the boom is a telescoping "stacer" made out of metal that is wrapped around itself, much like a rolled up poster that is taped shut. The only way for the stacer to move is to push out, making a longer cylinder, like a rolled poster would if you pulled on each end of the cylinder. This is the same mechanism as a Chinese yo-yo. The stacer protects the wires that are wound together to go out to the magnetometer.

Outside of the stacer is another telescoping boom with individual cylinders tucked within each other. When the boom deploys in space, each section moves out along runners with little tiny wheels (see the photographs in the Boom Photograph section below) until each section locks into place with several pins. This outside boom keeps the magnetometers far away from the spacecraft. The boom must be fairly stiff (rigid) and will house several other instruments beside the magnetometers.

See the Resource Section to find out more about the STEREO mission and the IMPACT instrument suite.

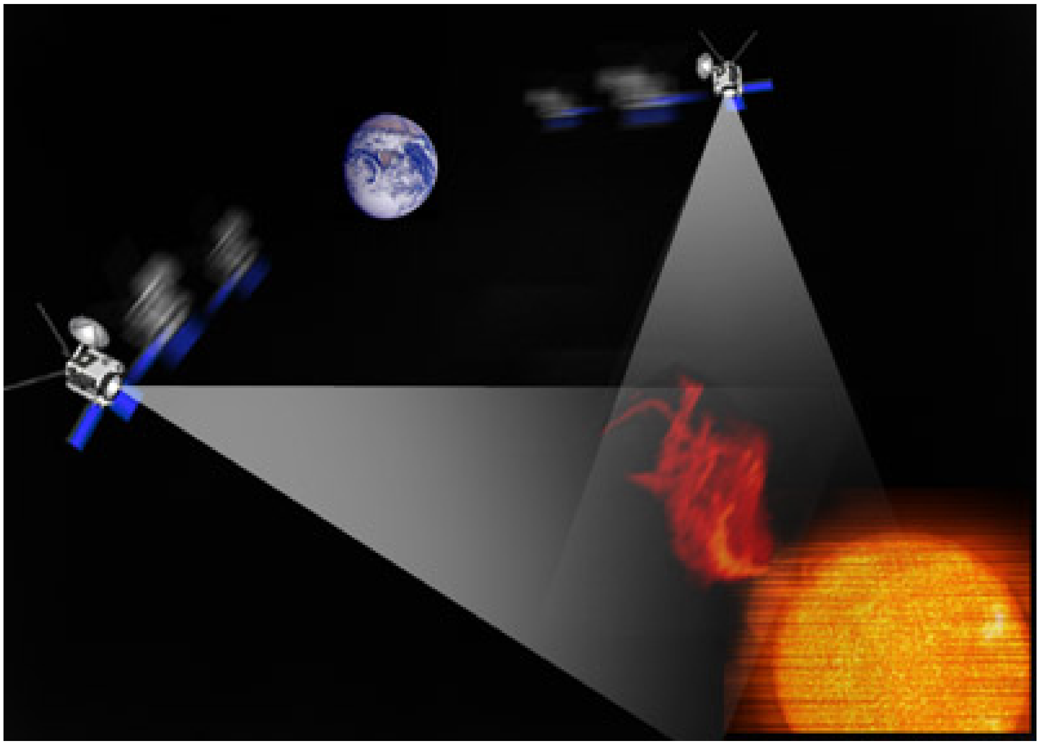


Figure B1: An artist's rendition of how the STEREO satellites will orbit the Sun with Earth. They will observe the Sun's surface and take measurements of the solar wind flowing past the satellites. Note that this image is not to scale: the Sun is much farther away and larger than indicated here and the spacecrafts are vastly smaller than Earth.

Questions and Answers with Paul Turin on Boom design:

Paul Turin is an engineer who works on designing and building booms for NASA spacecraft. He works at the University of California at Berkeley, and by answering our questions, he helped to design the third session in this lesson plan. Here are the questions we asked, and some of his answers.

In terms of strength, stiffness, and end-play, which is most important in the engineering of the boom design?

> In launch, the strength and stiffness of the boom are the most important. In actual operation in space, that the boom is stiff and play-free (does not sway about) is most important, and strength does

not usually matter. In relation to the spacecraft, stiffness and lack of play are important to think about in this way: if the satellite moves, you don't want the boom to bend or to move (to some specified accuracy). This means that once the boom is deployed from the spacecraft, it will remain in only one position relative to the spacecraft. You want the boom to end up in a known position and to not move from that position because an instrument, such as a magnetometer, is sitting near the end of the boom and scientists need to know the exact location and orientation of that instrument.

Have the kind of materials used for booms changed over the past years?

20-30 years ago, booms were made out of aluminum because aluminum is light, which is important for the cost of launching the satellite, and because it is strong and stiff. Now, booms are usually made of carbon fiber because of its versatility and because it is stronger and stiffer than metals. Carbon fiber can be molded to many different shapes. It starts as a cloth-like fiber and is then put in epoxy and wrapped around a form, often made out of metal, such as a cylinder. As the epoxy-covered carbon fiber hardens, it takes on the shape of the form around which it is wrapped. Another benefit is that a shape made of carbon fiber that has the same stiffness and strength as an aluminum one will be considerably lighter.

What are the main difficulties in designing a boom?

Deploying a boom is one of the most difficult tasks. How can we deploy something so long and stiff without much play? The design of any joints in the boom is critical to its performance. When the joint latches close, it must not be able to move again – the boom needs to act as if it were made of a single piece of material.

How are such stiff booms deployed?

In the STEREO IMPACT boom, for example, there is a compressed spring called a stacer inside and when the time comes, the boom is deployed by allowing the spring to push the telescoping boom out. This boom has several nesting tubes with three grooves in each tube (see picture) and little wheels that follow along the grooves. When each tube gets to the end of the next larger tube, pegs fall into holes and the boom becomes long, play-free, and stiff.

Are the currents carried in the wires out to the end of the boom ever a problem for magnetometer measurements?

Not if they are handled properly. The wires are twisted pairs and so their magnetic fields tend to cancel each other out. Also there is the metal stacer that shields the wire. This stacer is a sheet of metal rolled up tight enough that when released, pushes out into a long tube, generating the force to deploy the boom as it does so. It is very similar to a Chinese yo-yo made out of a beryllium-copper alloy.

How long does it take to design and build a boom?

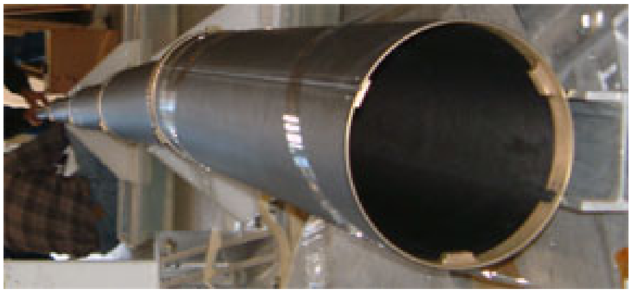
The entire process typically takes three years from concept to delivery of the boom to the satellite. First, a concept of a design is considered. Then certain ideas that are new are tested by building parts to see if the idea is feasible. Then a beginning design is finalized and an ETU (Engineering Test Unit) unit is built. Any changes that are deemed necessary as a result of the ETU testing are made, and then a proto-flight unit is built (this becomes a flight spare). If that works, then the flight units are built, tested and delivered.

What are some of the problems that occur while building a boom?

There are always many problems. For example on the STEREO-IMPACT boom, problems arose when we were trying to create the grooves in the tubes. We had a hard time getting the carbon fiber cloth to stay in the grooves in the metal form while wrapping the cloth around it. The grooves had to be nice and smooth so the wheels would ride smoothly in them, and it took many tries to work out how to get them to come out smooth enough. Carbon fiber as a material is difficult to use in general because it comes as a cloth that then you put a glue-like substance on it to make it harden to the shape you want. This becomes a sticky situation, literally!

Photographs of the STEREO/IMPACT boom

Beginning model:



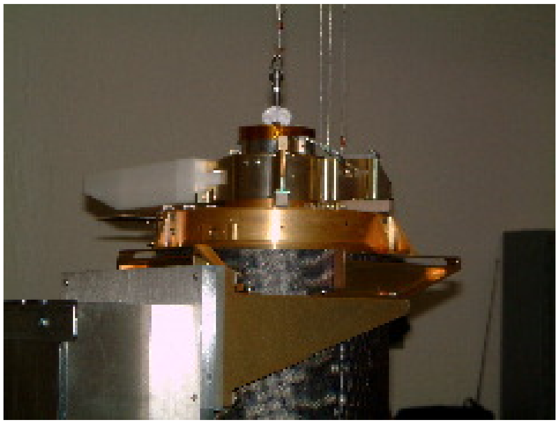
The parts of the boom laid out in a telescoping fashion

Engineering model:

The boom, almost put together with a hand for size comparison

A close up of the wheels and pegs on the engineering model

Deployment of the boom:

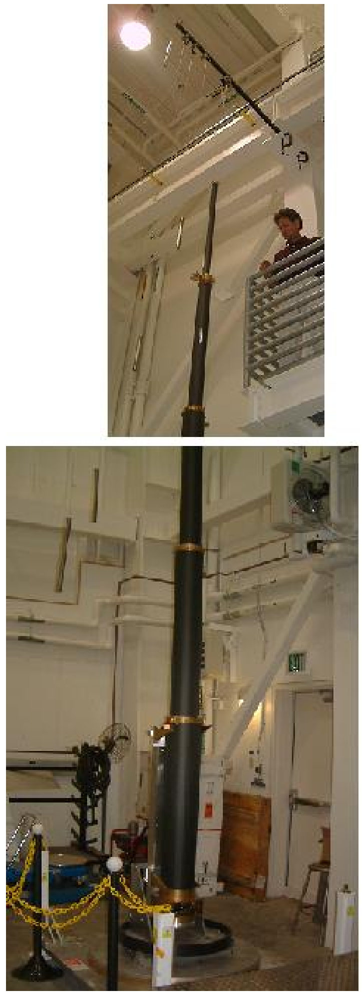


A zoom in on the top of the boom

The STEREO-IMPACT boom team:
Ken McKee, Bill Donakowski, Mario Marckwordt, Jeremy McCauley, Paul Turin, Robert Ullrich

Paul is getting ready to deploy the boom…

And the boom is going up, up, up until it snaps completely into place and is fully deployed.



The boom deployed. Weights can be seen at the top. They are used to counter-balance the force on the booms due to gravity since in space the spacecraft will be far from Earth's gravity when the boom is deployed.

Glossary[1]

Atmosphere: The mixture of gases that surround an object in space, such as a planet, moon or star, held near it by gravity.

Atom: A basic unit of matter. Every atom has a positively charged center called a nucleus that is surrounded by a number of negatively charged electrons.

Attract: To draw to or toward itself.

Aurora: (plural = **aurorae**) Light radiated by ions and atoms in Earth's upper atmosphere, in the region of Earth's poles. Aurora can be an extremely impressive spectacle. The *Aurora australis*, or "Southern Lights," occur near the South Pole while the *Aurora borealis*, or "Northern Lights," occur near the North Pole.

Boom: A part of a spacecraft that is long and cylindrical to hold instruments far from the satellite bus when it is in space.

Cause: Something that produces an effect.

Compass: A device that determines the presence of a magnetic field and its direction.

Corona: The outer part of the Sun's "atmosphere." In the outer region of the corona, particles travel away from the Sun and stretch far out into space. The corona can only be seen during total solar eclipses, appearing as a halo around the moon.

Coronal mass ejections (CMEs): Huge bursts of solar wind rising above the Sun's corona. These are one of the biggest explosions in the Solar System.

Dipole: Two electric charges or magnetic poles that have the same strength but are opposite in sign or polarity (North versus South) and are separated by a small distance.

Earth: The third planet from the Sun on which we all live.

Eclipse: The blocking of some or all of the light from one object by another.

Effect: Something brought about by a cause; a result.

Electric charge: A physical state based on the amount and location of electrons and protons in matter. Matter with more electrons than protons is negatively charged. Matter that attracts free electrons is positively charged.

Electric circuit: A system that connects electrical components so that they will operate.

[1] This Glossary was adopted from the Helios glossary found at the URL: http://helios.gsfc.nasa.gov/gloss_ab.html. Underlined words represent words that are defined in this Glossary.

Electric current: A flow of electric charge.

Electromagnetism: See the definition of magnetism

Electron: The negatively charged part of an atom and one of the smallest particles in the universe. It orbits the atom's nucleus. Electrons are very light compared to protons and neutrons.

Element: A material consisting of atoms, all with the same atomic number. Approximately 90 different elements are known to exist in nature and several others have been created in nuclear reactions. For more information about the elements, see the Periodic Table of the Elements.

Experiment: A test under controlled conditions that is made to determine how something in nature works.

Gas: A low number of atoms or molecules in a relatively large volume of space so that their interaction is small.

Geographic North Pole: The northern point on Earth around which Earth rotates.

Gravity: A physical force that attracts objects to one another. This force is very weak and only objects made of a lot of protons and electrons will have enough gravity to affect other objects. For example Earth has enough atoms that its gravity holds us on this planet. But a teacher does not have enough atoms to attract a coffee mug with gravity.

Hydrogen: The most common element in the universe. Each atom of hydrogen contains one proton and one electron.

Interplanetary: Between the planets in our solar system.

Instrument: An electrical and/or mechanical device that collects data as part of an experiment.

Ion: An atom that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

Iron: An element that has an un-paired electron making it able to align with a nearby magnetic field.

Magnet, solenoid: A solenoid magnet is a coil of insulated wire, usually cylindrical in shape and with a length greater than its diameter. An electric current passing through the solenoid produces a magnetic field similar to that of a bar magnet.

Magnetic field: A region of space near a magnetized body or electrical current where magnetic forces can be detected.

Magnetic field lines: These lines are a way to show the structure of a magnetic field. A compass needle will always point along a field line.

The lines are close together where the magnetic force is strong, and spread out where it is weak.

Magnetism (Electromagnetism): A physical property of an object that shows attraction for iron, as in a magnet. Electromagnetism acts between particles with an electric charge, such as electrons, protons, and ions. It is associated with moving electricity, and it creates fields of force.

Magnetometer: An instrument that measures the magnitude (strength) and direction of a magnetic field.

Magnetosphere: The region surrounding a planet where the planet's magnetic field dominates.

Molecule: Two or more atoms bound together. As an example, a molecule of water consists of two atoms of hydrogen and one of oxygen.

Neutron: The part of an atom that has no charge. It is often part of the nucleus.

Nucleus: (plural=nuclei) The small, massive center of an atom containing its protons and neutrons bound together by nuclear force, the strongest force known in nature.

Orbit: The path a body takes around another object or point in space under the influence of various physical forces, including gravity.

Physics: The science dealing with matter and energy and their interaction.

Planet: A body that orbits a star such as the Sun.

Proton: The positively charged part of an atom.

Satellite: An object that revolves around a larger object. Planetary moons are natural satellites.

Satellite bus: The body of a man-made satellite that the control functions of the satellite and most of the scientific instruments.

Solar: Having to do with the Sun.

Solar wind: Ions and electrons that come out of the Sun in all directions at very fast speeds.

Solar system: The Sun and its associated planets and their moons, and all other objects that are held by the Sun's gravity and orbit around it.

Space: The area between all of the bodies in the universe. It is not empty! It contains magnetic fields, electromagnetic radiation (i.e. light), gases, dust and other particles.

Sun: The star at the center of our solar system. It is made mostly of hydrogen and helium with a very small amount of heavier elements.

Resources

Online Vendors with Classroom Supplies

Arbor Scientific: http://www.arborsci.com/

Edmund Scientifics: http://www.scientificsonline.com/

Educational Innovations: http://www.teachersource.com/

Ward's Natural Scientific: http://wardsci.com/

Science Kit & Boreal Laboratories: http://www.sciencekit.com/

1 on 1 School Supplies: http://www.1on1schoolsupplies.com/index.html

Home Training Tools: http://www.hometrainingtools.com/index.php

The PhysLink eStore: http://www.physlink.com/estore/

Cow Magnets can be purchased cheapest from pet/farm supply stores:
E.g. http://www.petvetsupply.com , http://www.valleyvet.com , http://www.americanlivestock.com
Slaughter houses may also give away recovered magnets.

Related Curriculum Materials

Exploring Magnetism, Center for Science Education, Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA 2004

Electric Circuits, National Science Resources Center, Carolina Biological Supply Company, Burlington, NC.

Magnets and Motors, National Science Resources Center, Carolina Biological Supply Company, Burlington, NC, 2002.

Stop Faking It! Electricity & Magnetism, William Robertson, National Science Teachers Association, Arlington, VA, 2004

NSTA
1840 Wilson Boulevard
Arlington VA 22201-3000 USA
Phone: 703.243.7100
Web: http://store.nsta.org/

Electric Circuits: Inventive Physical Science Activities, Great Explorations in Math and Science (GEMS), Lawrence Hall of Science, University of California at Berkeley, CA, 2004, grades 3-6.

Living with a Star: From Sunscreen to Space Weather, Great Explorations in Math and Science (GEMS), Lawrence Hall of Science, University of California at Berkeley, CA, 2003.

Web Pages

[*Note: Web pages come and go but some are more reliable than others. We have put the most reliable pages in the first "Reliable" category and the others in the "May be gone but worth citing" category.*]

Reliable

http://cse.ssl.berkeley.edu/impact/: the STEREO/IMPACT Education and Public Outreach web page with links to explanations of the science, to other k-12 events or activities, to news about the Sun, and to the IMPACT mission itself

http://sprg.ssl.berkeley.edu/impact: the STEREO-IMPACT science website

http://stereo.gsfc.nasa.gov: the STEREO mission website

http://www.nasa.gov: NASA's web page with links to information on NASA missions and educational materials

http://www-spof.gsfc.nasa.gov/Education/Intro.html: David Stern's overview of space physics with good links to other educational web sites

http://www.spaceweather.com/glossary/imf.html: Spaceweather.com's page on the interplanetary magnetic field (IMF) http://www.agu.org/sci_soc/cowley.html: A guide to Earth's Magnetosphere.

http://www.windows.ucar.edu/tour/link=/teacher_resources/magnetometer_edu.html&edu=high: K-12 lesson to make a magnetometer

http://my.execpc.com/~rhoadley/magindex.htm: Rick Hoadley's very extensive web page on magnetism with experiments you can do and many explanations (*It may be gone, but it is worth citing.*)