Design Challenge:
Shielding a Magnetometer

Overview: Students will test various materials to determine if any can shield their "magnetometer" (compass) from an external magnetic field using their own experimental design. If no suitable material is available, they will devise another method to protect their instrument.

Target Grade Level: 3-5

Estimated Duration: 50 min.

Learning Goals: Students will…

- design an experiment to test materials for magnetic shielding suitability.
- determine which of various materials have magnetic properties and which do not.
- evaluate how magnetic strength varies over distance.

Standards Addressed:

Next Generation Science Standards ©

3-5. Engineering Design

ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3. Forces and Interactions

3-PS2-4: Define a simple design problem that can be solved by applying scientific ideas about magnets.

DCI PS2.B: Types of Interactions: Electric and magnetic forces between a pair of objects do not require that the objects be in contact. The sizes of the forces in each situation depend on the properties of the objects and their distances apart and, for forces between two magnets, on their orientation relative to each other.

Contents:

Background Science for the Teacher:

Figure 1. The identical Van Allen Probes follow similar orbits that take them through both the inner and outer radiation belts. Image courtesy: JHU/APL

To help us understand how the Earth responds to changes in the Sun's energy, and how that response affects life and society, NASA launched the twin Van Allen Probes on August 30, 2012. The Van Allen Probes spacecraft are investigating this extreme region of space, searching for answers to critical questions about the behavior of the Van Allen Radiation Belts. The spacecraft chase each other in nearly the same orbit, investigating the storms in the radiation belts caused by our Sun, gathering data to better understand this region and how it affects our modern way of life. The ability to model and predict the behaviors of the radiation belts will enable engineers and space weather forecasters to better protect our astronauts working in this region as well as our satellite investments that we depend upon for communication, defense, shipping, air and ground navigation and much more.

MORE! Learn more about the Van Allen Probes mission, the radiation belts in which they orbit, and the science behind the mission here: http://vanallenprobes.jhuapl.edu/

Exploring this Challenging Environment

Designing and building a spacecraft is a lengthy and iterative process that involves years of planning with countless scientists and engineers. Based on data from other spacecraft and satellites, Van Allen Probe team members knew that these spacecraft would require special consideration since they needed to capture data during even the most dramatic space weather events. Whereas other craft switch to "safe mode" or try to avoid the Van Allen radiation belts altogether, the Van Allen Probes spend most of their time orbiting within the radiation belts and have been specifically engineered to avoid "safe mode." All of the instruments on the Probes are shielded from fast-moving particles using thick aluminum. The paints and thermal blankets used on the Probes have been designed to withstand degradation. In order to enable very sensitive measurements by the instruments, the spacecraft components and subsystems were built so they don't generate net electric or magnetic fields of their own, which might cause interference in the data. In other words, careful planning helps ensure the instruments are collecting the data they were intended to collect rather than data that may be contaminated by nearby instruments. When designing a spacecraft to such exacting standards, teams of engineers and scientists follow the design process (see Figure 2).

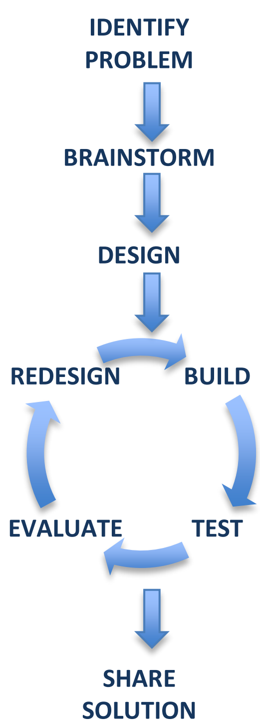

Figure 2. The Design Process. This process is fundamental to all types of engineering, from designing a spacecraft to creating more efficient toothpaste packaging.

MORE! Hear from a mission scientist about the challenges of designing a mission to study the Van Allen Radiation Belts: http://vanallenprobes.jhuapl.edu/radiationHardening/Videos.php

For example, when designing the magnetometers on board the Van Allen Probes, engineers had to ensure the instruments could detect very subtle changes in magnetic fields and *not detect* any magnetic fields generated by other instruments on the craft. Nearby solar panels had to be wired to ensure currents in the solar cell wires would not produce a magnetic signature. Two magnetometer sensors were mounted on very long booms that placed the sensors three meters from the spacecraft body and about four meters from the center of the spacecraft. The booms' overall design and materials were engineered to minimize or eliminate any magnetic signatures, but ultimately it was the *distance* from potential sources of magnetic contamination that ensured the sensors on the booms were measuring the intended external magnetic fields. All of this strategic planning was just for the magnetometers! Imagine how intricate and detailed the engineering must be for the entire spacecraft, with its five instrument suites, solar panels, fuel tanks, and all of the rest of the parts that enable these twin spacecraft to operate in the extreme environment of the Van Allen Radiation Belts!

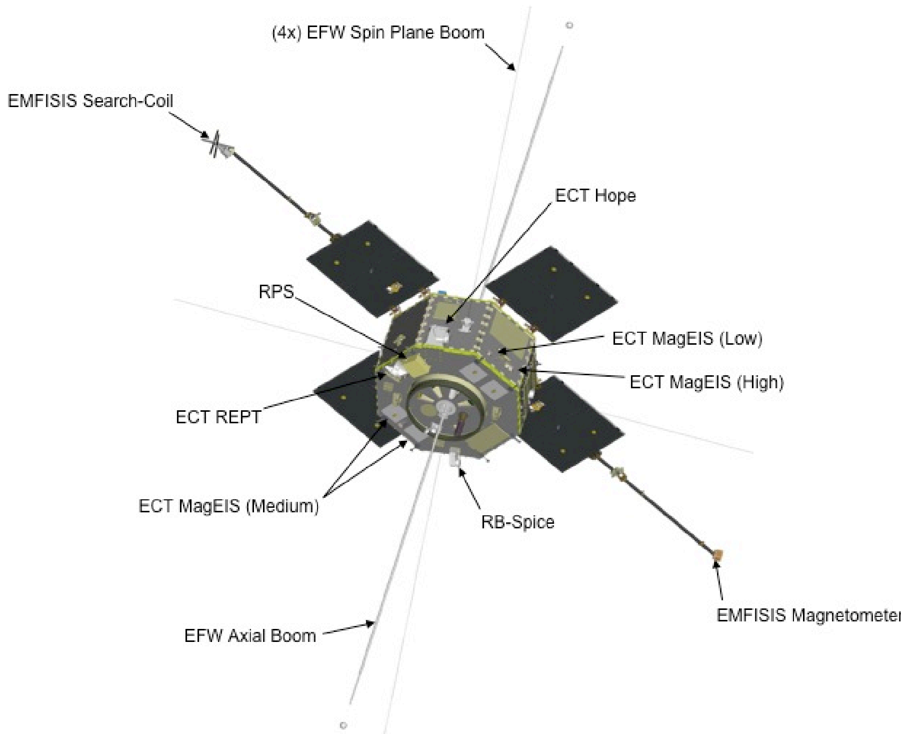

Figure 3. Each of the twin Van Allen Probes has five suites of instruments that measure particle numbers, type, speed, direction, and energy, as well as electric and magnetic fields and waves. The instrument suites are called: Energetic Particle, Composition, and thermal Plasma Suite (ECT), Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS), Electric Field and Waves Suite (EFW), Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE), and Relativistic Proton Spectrometer (RPS). (Image courtesy: APL)

NOTE! Additional science background about basic magnetism concepts is provided within the prerequisite simple magnetism activities suggested in the **Resources** section, below. Please be sure you and you students are comfortable with that content before conducting this activity.

MORE! Challenge your students to build a virtual spacecraft to study the Van Allen Radiation Belts in this interactive activity: http://vanallenprobes.jhuapl.edu/radiationHardening/index.php (NOTE: this is a separate resource exploring how the Van Allen Probes must be protected from radiation. If you choose to introduce students to this resource, ensure they understand it is about radiation hardening, NOT magnetic shielding.)

Materials:

- Prerequisite simple magnetism activity; see **Resources** for suggestions
- Copies of the Magnetic Shielding worksheet (1 per group)
- Magnetic compass (1 per group)
- Bar magnets (1 per group)
- Labels for each bar magnet saying “Solar Panel” (and tape to adhere the label if necessary)
- Metric ruler
- Thin rectangular/square pieces of various materials to test for shielding suitability. Choose at least two from the “magnetic materials” list and several from the “non-magnetic materials” list. *It is helpful to include some of the non-magnetic metals to illustrate that not all metals are ferromagnetic. (Lists below are not exhaustive):
  - Magnetic materials: sheet metal, galvanized metal, iron, nickel
  - Non-magnetic materials: paper, fabric, wood, *aluminum foil, *copper, glass, *brass sheet, flat piece of (recycled) plastic (such as pre-packaged salad container lid), cardboard, stone, *stainless steel

Procedure:

Generally speaking…

The teacher will conduct a prerequisite activity about simple magnetism (see **Resources** section for suggestions) and ensure students understand how magnetic field strength decreases with increasing distance from the magnet. Following that, the teacher will divide the class into small groups and provide each group with a magnetic compass, a bar magnet labeled “Solar Panel”, a ruler and a selection of magnetic and nonmagnetic materials as indicated in the **Materials** section, above. The teacher will help groups as necessary as they complete their Magnetic Shielding worksheet, allowing about 30 minutes. After completion, the teacher will lead a discussion about the interesting challenge to create a shield for a sensitive instrument such as a magnetometer.

The students will complete their Magnetic Shielding worksheets in groups and participate in a discussion about their design challenge afterward.

<u>In-class Procedure</u>

1. Remind students of some of the concepts they learned about magnetism in the prerequisite activity, including how the magnetic field strength decreasing with increasing distance from the magnet (see **Resources** section for prerequisite activities). You can reinforce this concept using the PhET interactive simulation provided in the **Resources** section, where magnetic field strength can be measured at various distances from the magnet.
2. Distribute to each group the following: copies of the **Magnetic Shielding** worksheet, a compass, a bar magnet labeled “Solar Panel,” a ruler, and various magnetic and nonmagnetic materials (as indicated in the **Materials** section).
3. Ask students to proceed through the Magnetic Shielding worksheet for about 30 minutes. Facilitate group discussion and answer questions as necessary. It might be helpful to talk to the groups about when the compass needle is actually deflected and how perceptions can vary when conditions aren’t quantified. Also consider:

- Students may need help designing their experiment, but encourage them to work through the first three questions on the worksheet before offering them help.
- The basic design should allow them to use the compass to detect the Earth's magnetic field, which it does by default—it's a compass! Students could rotate the compass so that the needle points to N, which is geographically north and is referred to as "magnetic north" even though it is actually has the polarity of south. Confused? Earth's magnetic north pole (geographically north) is the place on Earth to which the north pole of a magnet points, and since in magnetism opposites attract, the north pole of a magnet points to the south pole of another magnet. So if you imagine Earth as a giant bar magnet, the "S" would be up near Canada and the "N" would be down near Antarctica!
- Their design should also include the distance from the magnetometer to the shield, which is easily accomplished by aligning the needle point of the magnetometer (compass) with the zero on the ruler and the shield perpendicular to the ruler (see Figure 4, below).
- The shield should be between the magnetometer and the solar panel (bar magnet) (Fig. 4).

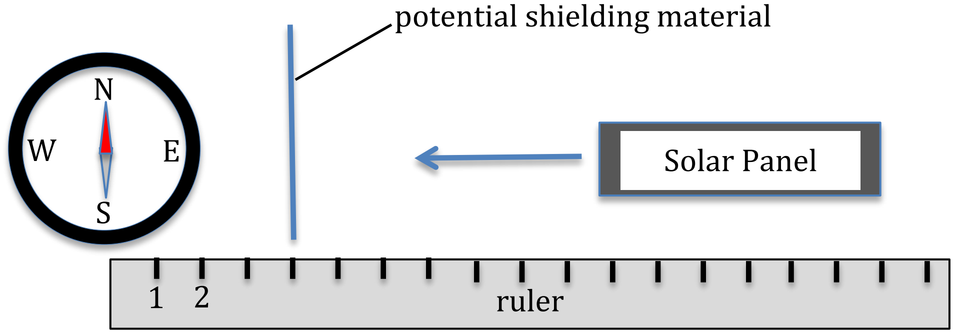

Figure 4. An example experimental design. Potential designs will vary from this, but the ruler should originate at the magnetometer (compass) and the shielding material should be perpendicular to the ruler and between the magnetometer and solar panel.

4. After students have completed their worksheets, lead a discussion about their magnetic shielding design challenge. Use the following questions to guide your discussion:
   Q: Were you able to successfully shield the "magnetometer" (compass) from an external magnetic field? (No.)
   Q: What did you observe when you tried to shield a "magnetometer" from a magnetic field? (Bringing a magnet close to a nonmagnetic material provided no shielding and bringing a magnet close to a magnetic material caused the magnetic field to actually *increase* in strength.)
   Q: Was there anything you could do to prevent the magnetic field from influencing the "magnetometer"? (You could move the magnet far away from the "magnetometer" since magnetic field strength decreases with increasing distance from the magnet.)

5. In closing, explain that the magnetometer sensors on the Van Allen Probes spacecraft are mounted on long booms that place the sensors about five meters from the center of the spacecraft. Indeed, even NASA engineers haven't found a method preferable to distance to help protect the sensitive instruments from potential magnetic fields generated on the spacecraft.

Names: ____

Magnetic Shielding

The Problem: You have a sensitive instrument that is used to detect the Earth's magnetic field, which we will call a *magnetometer* (even though it looks a lot like a compass). You also have a solar panel that generates a magnetic field. Your spacecraft needs both of these instruments to study Earth from space. However, you don't want to measure the magnetic field generated by the solar panel; you only want to measure small fluctuations in Earth's magnetic field. Can you find a material to shield your sensitive magnetometer from the magnetic field generated by the solar panel?

Part 1. Experimental Design

Your supplies:

Magnetometer: (Ok, so really it is a compass, but today we'll call it a magnetometer!). Like a magnetometer your instrument detects a magnetic field. In particular, we want it to detect the Earth's magnetic field and not another magnetic field, such as perhaps the one generated by the solar panel.

Solar Panel: (Ok, so really this is a bar magnet, but today let's call it a solar panel!). Solar panels are used to power the spacecraft. They do, however, produce a magnetic field due to the electric current in their wires.

Ruler: You'll actually use this as it is intended…to measure distances!

Various materials: One of these could just be the magnetic shielding material you are looking for! You'll have to test them all to find out…

Your objective: Test each of the various materials to determine if it could be used to shield the magnetometer from the magnetic field generated by the solar panel so that both can perform as expected on your spacecraft.

1. How will you set up your experiment to test the various materials to determine if any would be a good magnetic shield? Explain your experimental design and include a labeled drawing that illustrates the location of the magnetometer, the solar panel, the ruler, and a potential shielding material. Use arrows to indicate movement if necessary.

2. In your experiment, how will you know if the magnetometer (compass) is detecting the Earth's magnetic field?

3. How will you know if the magnetometer is detecting a field other than the Earth's magnetic field?

4. After considering these two questions above, do you need to revise your experimental design? Are you sure the experiment as you have designed it will demonstrate if a material is shielding the magnetometer from the magnetic field generated by the solar panel or not? If you need to modify your experimental design do so here:

Part 2. The Experiment

5. Now actually set up your experiment as you designed it above and begin testing materials, recording your results in the table below. You can test the same material at different distances, too!

	potential shield material	distance from magnetometer to material (cm)	distance between magnetometer and solar panel when needle was first deflected (cm)	suitable shield? (y/ n)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				

6. After reading the column headings in the table above did you modify your experimental design? If so, please indicate why and how.

7. What did the magnetometer do when you placed a ***nonmagnetic*** material (cardboard, paper, fabric, plastic, etc.) between the magnetometer and the solar panel and you moved the solar panel toward the magnetometer?

8. What did the magnetometer do when you placed a ***magnetic*** material (galvanized metal, sheet metal, iron, etc.) between the magnetometer and the solar panel and you moved the solar panel toward the magnetometer?

9. Did any material shield the magnetometer from the magnetic field of the solar panel? (In other words, did any of the materials allow you to bring the solar panel toward the magnetometer without the magnetometer needle deflecting (moving) when placed between them?)

10. Looking back at your table, if you couldn't use a material to shield the magnetometer from the magnetic field of the solar panel, is there anything else you could do so that the magnetometer and solar panel could fly on the same spacecraft and yet the magnetometer would not detect the magnetic field of the solar panel? How would you engineer such a solution?

11. Our pretend magnetometer (a compass!) only detects the direction of a magnetic field. What other important information about a magnetic field do you think a real magnetometer measures?

Magnetic Shielding:
Teacher Answer Key

1. How will you set up your experiment to test the various materials for magnetic shielding potential? Explain your experimental design and include a drawing that illustrates the location of the magnetometer, the solar panel, the ruler, and a potential shielding material. Use arrows to indicate movement if necessary.

   See Figure 4 in the Procedures section for a diagram of set up. This question is just to get them thinking about experimental design, so all answers are correct. Assess question 4 with more scrutiny.
2. In your experiment, how will you know if the magnetometer is detecting the Earth's magnetic field?

   The needle in the compass/magnetometer should be stable and if the compass is rotated properly the needle points to Earth's magnetic north pole (geographically to the north).
3. How will you know if the magnetometer is detecting a field other than the Earth's magnetic field?

   The needle in the compass/magnetometer will deflect away from magnetic north and could spin. When the external magnetic field (from the magnet/solar panel) moves away the needle in the compass should return to magnetic north.
4. After considering these two questions above, do you need to revise your experimental design? Are you sure the experiment as you have designed it will demonstrate if a material is shielding the magnetometer from the magnetic field generated by the solar panel or not? If you need to modify your experimental design do so here:

   Questions 2 and 3 above may have triggered some deeper thinking about the experimental design. If so, students should record their revised design here. Again, refer to Figure 4 in the Procedures section for an example of a correct set-up (although designs can vary from that as long as the ruler originates at the compass/magnetometer and the potential shielding material is perpendicular to the ruler and is between the compass/magnetometer and magnet/solar panel.)

Part 2. The Experiment

5. Now actually set up your experiment as you designed it above and begin testing materials, recording your results in the table below. You can test the same material at different distances, too!

   (Answer) Table values will vary, but in the last column all should indicate "no" as a suitable shielding material.
6. After reading the column headings in the table above did you modify your experimental design? If so, please indicate why and how.

   (A) Answers will vary, but the column headings may have helped some students further clarify the important elements in this experimental design. This continued refinement is an essential element to the design process!

7. What did the magnetometer do when you placed a ***nonmagnetic*** material (cardboard, paper, fabric, plastic, etc.) between the magnetometer and the solar panel and you moved the solar panel toward the magnetometer?
   (A) The needle on the compass/magnetometer should deflect or move when the magnet/solar panel is moved toward the compass/magnetometer. Some students might indicate which direction the needle deflected, and both directions are correct since it simply depends on which pole of the magnet was closest to the compass.
8. What did the magnetometer do when you placed a ***magnetic*** material (galvanized metal, sheet metal, iron, etc.) between the magnetometer and the solar panel and you moved the solar panel toward the magnetometer?
   (A) The needle on the compass/magnetometer should deflect or move when the magnet/solar panel is moved toward the compass/magnetometer and in fact the presence of a magnetic material will increase the deflection since the magnetic fields of the magnetic material and the magnet add together to make an overall stronger magnetic field (although the relationship is not simply linear, so the strength won't double. This is because magnetic field strength is (roughly) inversely related to distance squared, meaning the distance between the closest point of the magnet and the furthest point of the magnet is important in the overall equation). As in question 7, the direction of the deflection is not important.
9. Did any material shield the magnetometer from the magnetic field of the solar panel? (In other words, did any of the materials allow you to bring the solar panel toward the magnetometer without the magnetometer needle deflecting (moving) when placed between them?)
   (A) No! Nonmagnetic materials basically do nothing to protect the compass from detecting the magnetic field of the magnet and, as indicated in 8, the magnetic materials actually increase the field strength of the magnet and therefore the deflection of the compass.
10. Looking back at your table, if you couldn't use a material to shield the magnetometer from the magnetic field of the solar panel, is there anything else you could do so that the magnetometer and solar panel could fly on the same spacecraft and yet the magnetometer would not detect the magnetic field of the solar panel? How would you engineer such a solution?
    (A) Hopefully students will see that when the magnet is far away from the compass the compass only detects the Earth's magnetic field, not the magnetic field from the magnet. Therefore, if one could increase the distance between the magnetometer and the solar panel beyond the influence of the solar panel's magnetic field the two instruments could happily coexist on the spacecraft and do the jobs they are intended to do. This could be accomplished by placing the magnetometer sensor on a long boom (or arm) that extends from the body of the spacecraft. Students could also suggest that the solar panel is placed on an arm that extends away from the spacecraft.
11. Our pretend magnetometer (a compass!) only detects the direction of a magnetic field. What other important information about a magnetic field do you think a real magnetometer measures?
    (A) Variations in magnetic field *strength*.

Extensions and Adaptations:

- This activity could be extended to compare the magnetic properties of the Sun and Earth with 3-D magnetic fields: http://www.nasa.gov/pdf/626531main_Solar_System_Magnetism.pdf
- This activity could be extended to quantify the relationship between field strength and distance using this PhET interactive simulation, which shows the interaction between a compass and a bar magnet with the options to measure the field with a field meter and vary the magnet's strength: http://phet.colorado.edu/en/simulation/magnet-and-compass
  - This activity could be used along with the interactive simulation: http://phet.colorado.edu/en/contributions/view/4041

Resources:

- Van Allen Probes Mission website: http://vanallenprobes.jhuapl.edu
- Simple magnetism activities that could be used as a prerequisite for this activity:
  - Exploring Magnetism: http://cse.ssl.berkeley.edu/SEGwayed/lessons/exploring_magnetism/Exploring_Magnetism/s1.html#act1
  - Mapping Magnetic Influence: http://sunearthday.nasa.gov/swac/materials/Mapping_Magnetic_Influence.pdf
- PhET interactive simulation showing the interaction between a compass and a bar magnet with the options to measure the field with a field meter and vary the magnet's strength: http://phet.colorado.edu/en/simulation/magnet-and-compass
  - This activity could be used along with the interactive simulation: http://phet.colorado.edu/en/contributions/view/4041