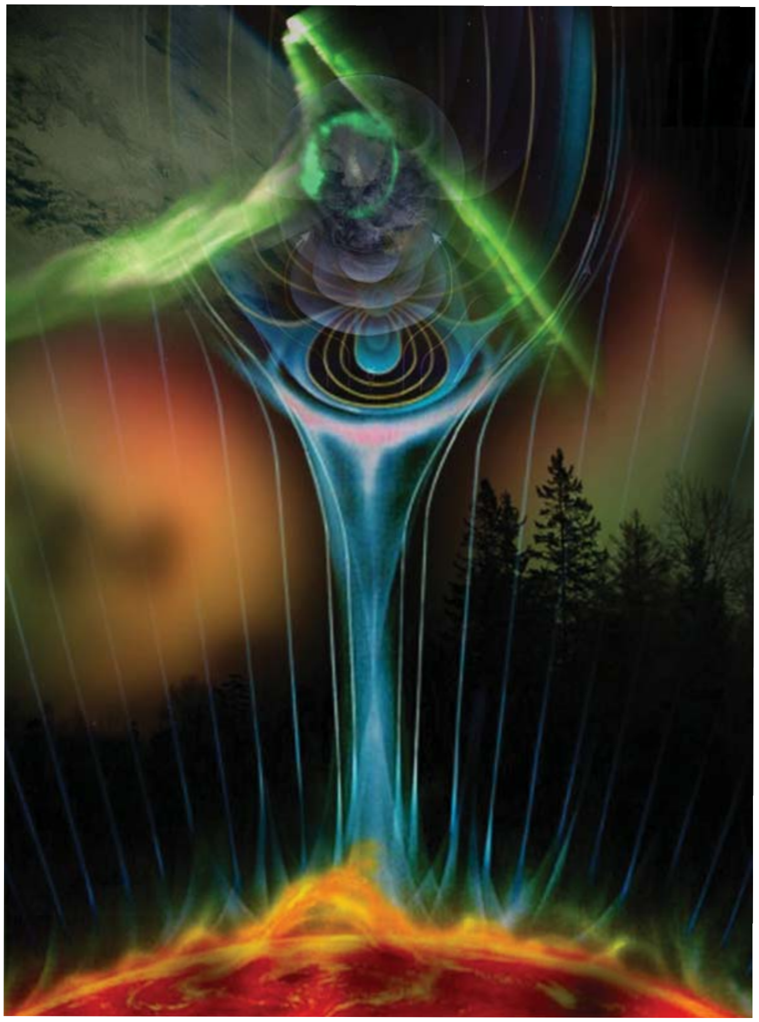
National Aeronautics and Space Administration

iMAGINETICspace

Where Imagination, Magnetism, and Space Collide



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NASA

MMS Book

Is Earth in danger? Millions of miles away in the sky a violent reaction is taking place that is sending massive amounts of energy hurtling through the void of space toward Earth. The Sun, in addition to the beneficial light and energy it provides Earth, also launches billion-ton clouds of heated plasma, and sometimes powerful X-ray flares, into space every few weeks or so spaced in time. While these are flung into space in all directions, occasionally, some of it is directed oward Earth!

On the bus ride home from his school, Marc checks his Twitter newsfeed on his iPhone. As he scrolls through the updates from his friends, his eye catches an alarming 140-character update from NASA. It reads, "Breaking News: Solar storm in progress and magnetic storm likely this evening."

Marc realizes the first thing he needs to do is learn more about solar storms and their impact on Earth. After doing some research, he finds out that solar storms are fairly common; however, when they are severe, they can affect millions of people. In fact, in 1989 there was a massive blackout in Canada that left over 6 million people without power due to circuits being tripped by variations in the Earth's magnetic field. Despite the substantial power loss, the Earth's magnetosphere was able to deflect most of the energy around the planet.

While surfing the Web for more information, Marc stumbles upon an event in 2006 where a solar flare interrupted GPS services for half of the globe. He also discovers more recently NASA launched the Solar Dynamics Observatory to study the interior and surface of the sun, including sunspots and solar flares. NASA hopes that the new data they collect will allow them to make more accurate predictions of when the next flares might happen.

With his interest now piqued, Marc is curious to find out about other recent NASA missions. He wonders if other current mission scientists are studying the invisible magnetic field around Earth. He quickly determines that NASA is also very interested in learning as much as they can about Earth's geomagnetic field. He finds that NASA is getting ready to launch the Magnetospheric Multiscale (MMS) mission that will allow scientists to study the process that determines how Earth is affected by the Sun's solar plasma attacks.

Later, while exploring the NASA website, Marc finds an opportunity for students to be involved in the MMS mission by having a NASA engineer visit their classroom. He clicks the link and brings the information to his teacher. They learn that one of the engineers lives in their area and would be willing to visit the class! However, before the visit the class needs to complete a series of investigations related to the MMS mission, involving using the scientific method and collecting data to test hypotheses.

Soda Bottle Magnetometer

Your Objective

Your first investigation requires that you build and test a tool, and experiment with collecting data. You will create a magnetometer to monitor changes in the Earth's magnetic field for signs of magnetic storms. Just as you could monitor a barometer for signs of bad weather approaching, this magnetometer will allow you to monitor the Earth's environment in space for signs of bad space weather. Think about how you will report data so it is useful to people.

Materials

- One clean 2 liter transparent soda bottle
- Sand
- Thread
- 2 cm piece of soda straw
- 5 cm clear packing tape
- A meter stick
- A 3x5 index card (7 cm x 12 cm)
- A small bar magnet
- A small mirror
- Scissors
- Light source (high intensity)
- Laser Pointer
- (Optional) Ring stand
- (Optional) Clamp

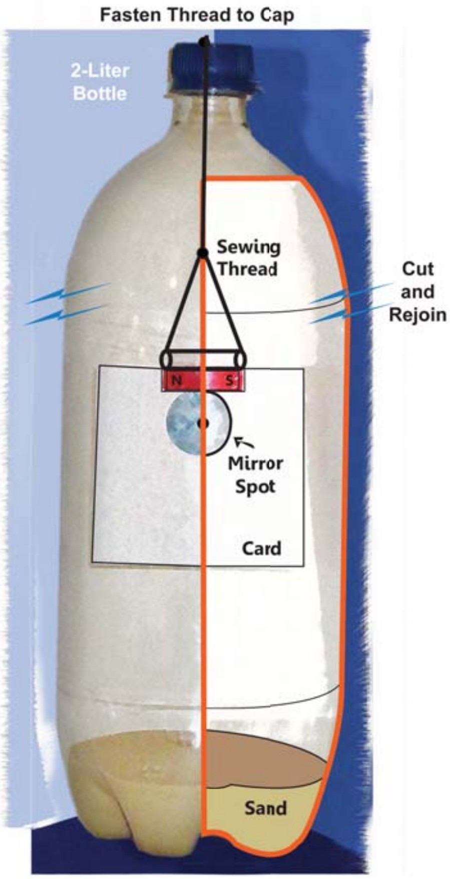


Figure 1

Procedure

1. Clean the soda bottle thoroughly and remove labeling.
2. Slice the bottle 1/3 of the way from the top.
3. Pierce a small hole in the center of the cap.
4. Fill the bottom section with sand.
5. Create a ‘sensor card’ by cutting the index card so that it swings freely inside the bottle (See Figure 1).
6. Tape the magnet to the center of the top edge of the card.
7. Tape a 2 cm piece of soda straw to the top of the magnet.
8. Tape the mirror to the front of the card below the magnet.
9. Pull the thread through the soda straw and tie it so that the straw is at the bottom end with the string forming a triangle with 5 cm sides.
10. Tie a thread to the top of the triangle in step 9 and pull it through the hole in the cap.
11. Put the bottle top and bottom together so that the 'sensor card' is free to swing with the mirror below the seam.
12. Using packing tape, tape the bottle together, and after the thread has been pulled through the cap, tape it in place.*

13. Place the bottle on a level surface and point the lamp so that a reflected spot shows on a nearby wall about 2 meters away.
14. Measure the changes in this spot position to detect magnetic storm events.

see the tips and tricks in Figures 1, 2 and 3

Soda Bottle Magnetometer

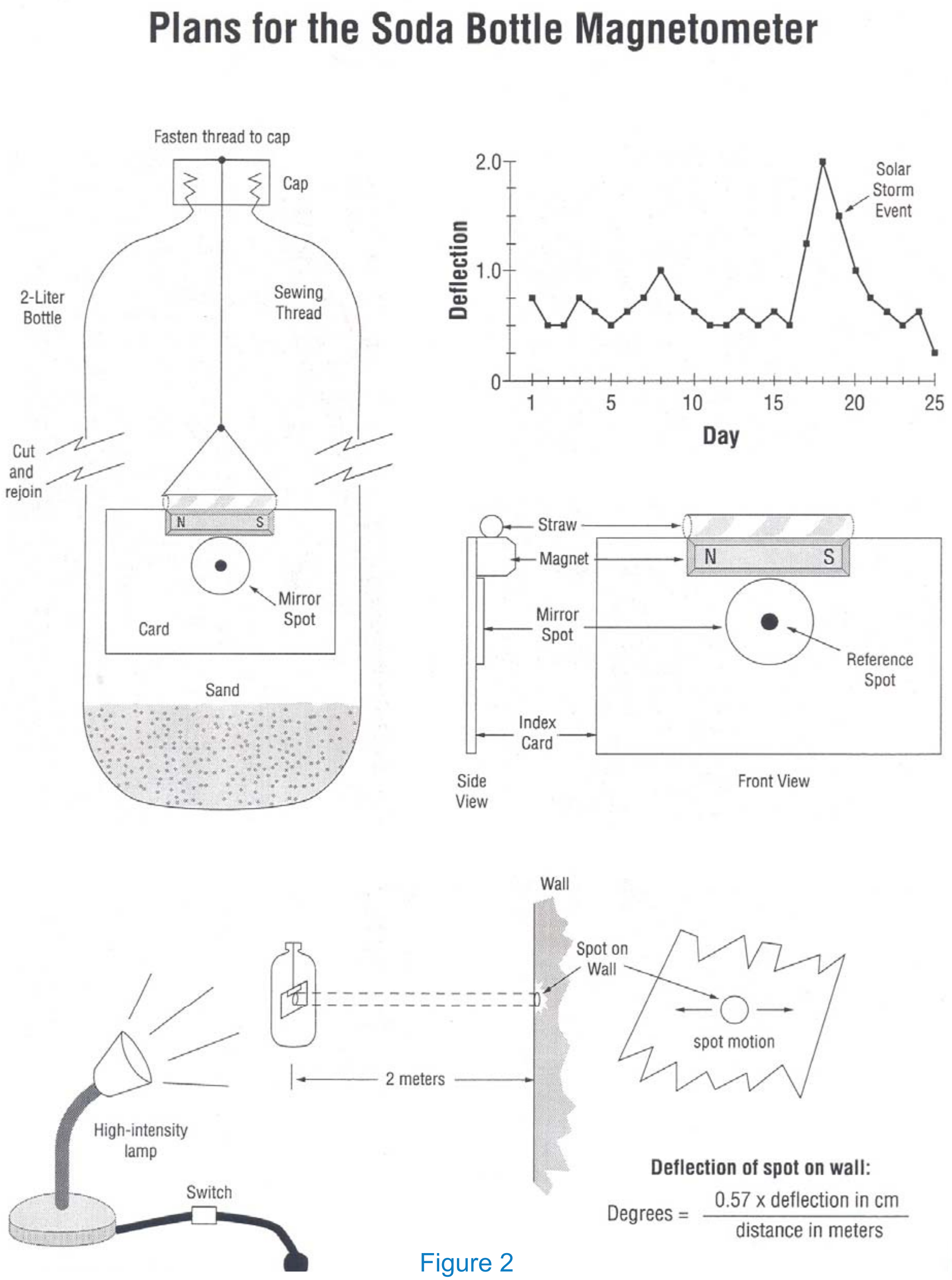


Figure 2

Tips

When adjusting the location of the sensor card inside the bottle, it is important that its edges do not touch the bottle. Be sure that the mirror is below the seam and the tape that joins the seam so that it is unobstructed and free to spin on the suspension thread.

Alternative Light Source:

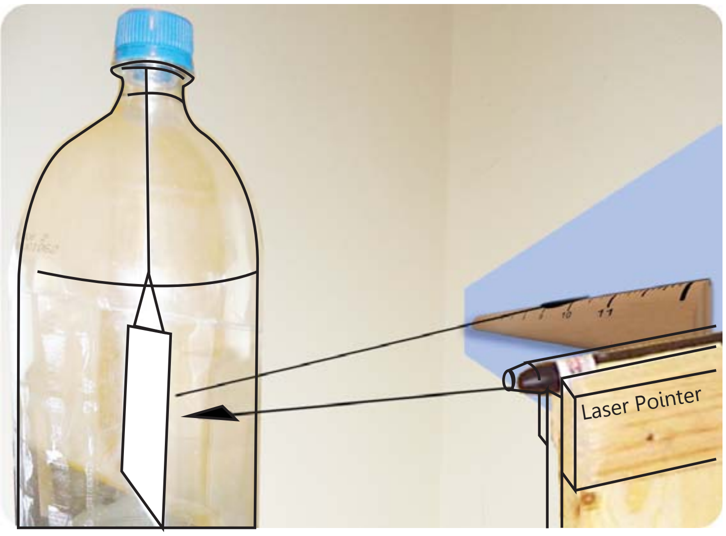


Figure 3
The alternative light source will be a laser pointer. You will need a test tube ring stand and a clamp to hold it securely.

Place the magnetometer in an undisturbed location of the classroom. Keep the soda magnetometer far away from any high power/high current devices (e.g. water heaters, electrical panels, or junction boxes).The cycling of large currents in these devices generates a “spurious” magnetic field contribution that will “artificially” deflect the mirror. You must also set up the high intensity lamp so it casts a reflected spot on a wall within 1 meter of the center of the bottle. This set up allows a 1 centimeter change in the light spot position to equal 1/4 degree in angular shift of the magnetic north pole. At half of this distance, 1 centimeter will equal 1/2 a degree. Because magnetic storms produce shifts of up to 5 degrees or more for some geographic locations, you will not need to measure angular shifts smaller than 1/4 degrees. Typically, these magnetic storms last up to a few hours.

To begin a measuring session, which could last for several months, note the location of the spot on the wall with a small pencil mark. Measure the magnetic activity from day to day by measuring the distance between this reference spot and the current spot by placing a mark there. Be sure to note the date and the time of day.
Measure the distance to the reference mark and the new spot in centimeters. Convert this number into degrees of deflection for a 1-meter distance by multiplying by 1/4 of a degree for each centimeter of displacement.

You can check that this magnetometer is working by comparing the card's pointing direction with an ordinary compass needle; it should point parallel to the magnet in the soda bottle. You can also note this direction by marking the position of the light spot on the wall.

If you must move the soda bottle, you will have to note a new reference mark for the light spot. You will resume measuring deflections from the new reference mark as before.

Sticky Tape Static Electricity

Marc and his classmates built the magnetometer and recorded their initial data. Now it is time for them to move on to the next task. This activity directs them to begin the exploration of how forces can act over a distance.

Your Objective

Use tape to investigate how charges interact.

Materials

Four strips of Scotch Magic Tape™or other brand of plastic tape, each about 8 cm long.

Procedure

1. Fold approximately 1 cm of the top of each strip to form a non-sticky tab. This makes it easier to grip and pull the tape strips.
2. Stick two pieces of tape to a flat surface, such as your desk (Figure 3). Run your finger along each strip to be sure that it is in full contact with the surface.
3. Label each strip "B" for bottom.
4. Place a third strip of tape down on top of one of the Bottom strips of tape. Run your finger along the tape to make full contact between the two strips. Label this strip "T" for top
5. Repeat step 4 with the remaining piece of tape, so that you end up with 2 double strips of tape on the table (Figure 4).
6. Carefully pull up one set of both top and bottom tape strips together (Figure 5). If the double strip tends to curl toward your hand, carefully rub the strips between your fingers until they no longer are attracted to you.
7. Have a partner repeat step 6 with the other double strip.
8. Gripping the tabs, rapidly pull the two strips apart and hold one in each hand. Your partner should do the same, so that the two of you have a top tape in one hand and a bottom tape in the other.

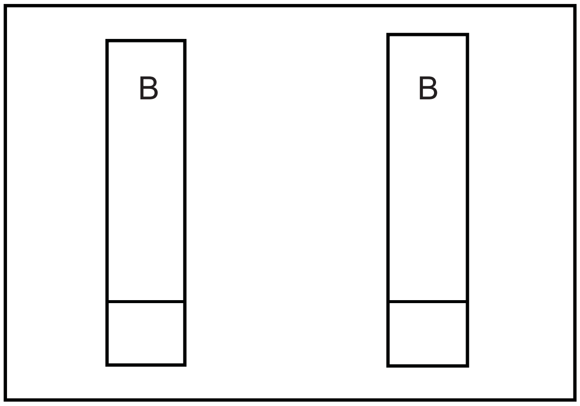


Figure 3
Two strips of tape on a table labeled "B".

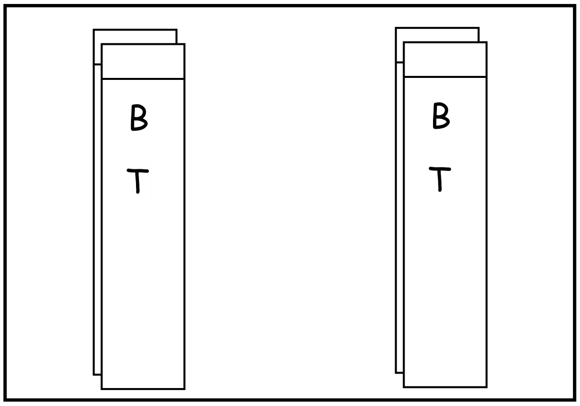


Figure 4
Press a top tape lapeled "T" on each bottom tape.

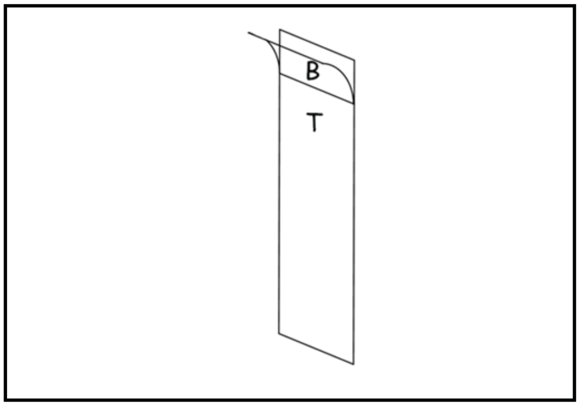


Figure 5
Top and bottom strips ready to be pulled apart.

9. Now, work with your partner to carefully bring your top strips of tape together. Be carefully not to let them touch. What do you notice as the two strips approach each other?
    - You should notice that as you bring them together, an invisible force causes them to swerve and gyrate—they repel each other.
10. Repeat step 9 with your bottom strips of tape.
    - What do you notice this time as the two strips approach each other?
    - What can you conclude from these observations?
11. Next, approach your partner's top tape strip with your bottom tape.
    - What do you notice as the top and bottom strips approach each other?
12. Summarize your results in (Table 1)

What's going on here?
Current understandings of electric charge indicate that there are two types of charges, positive charge (+) and negative charge (-). Typically, these charges exist in equal numbers so that they balance out. Thus, normal matter is uncharged.

Tape Strips	Repel or Attract?
Two Top Tapes	
Two Bottom Tapes	
Top and Bottom Tapes	

Table 1. Tape strip interactions

Matter can become charged when different types of material are rubbed against each other. Such contact between different materials transfers some electrical charge from one object to the other. Use these facts to explain the results of your investigation.

Introduction to Magnetism

Marc is surprised that the static electricity allows the two pieces of plastic tape to affect one another without touching. As he and the class begin the next activity, he is curious to see if this concept also applies to magnets.

Your Objective:

What can you learn about magnets through experimenting?

Materials

- Horseshoe magnet
- Bar magnet
- Magnetic stir bar
- Paper clips
- Rulers
- Copper
- Aluminum wire
- Pencils
- Other common classroom objects

Directions

As a group, use all of the supplies provided to answer the following questions.

What are magnets attracted to?

What are they not attracted to?

Do magnets have to touch things they are attracted to in order to make them move?

Why do you think this happens? Draw what a picture of what you believe is happening.

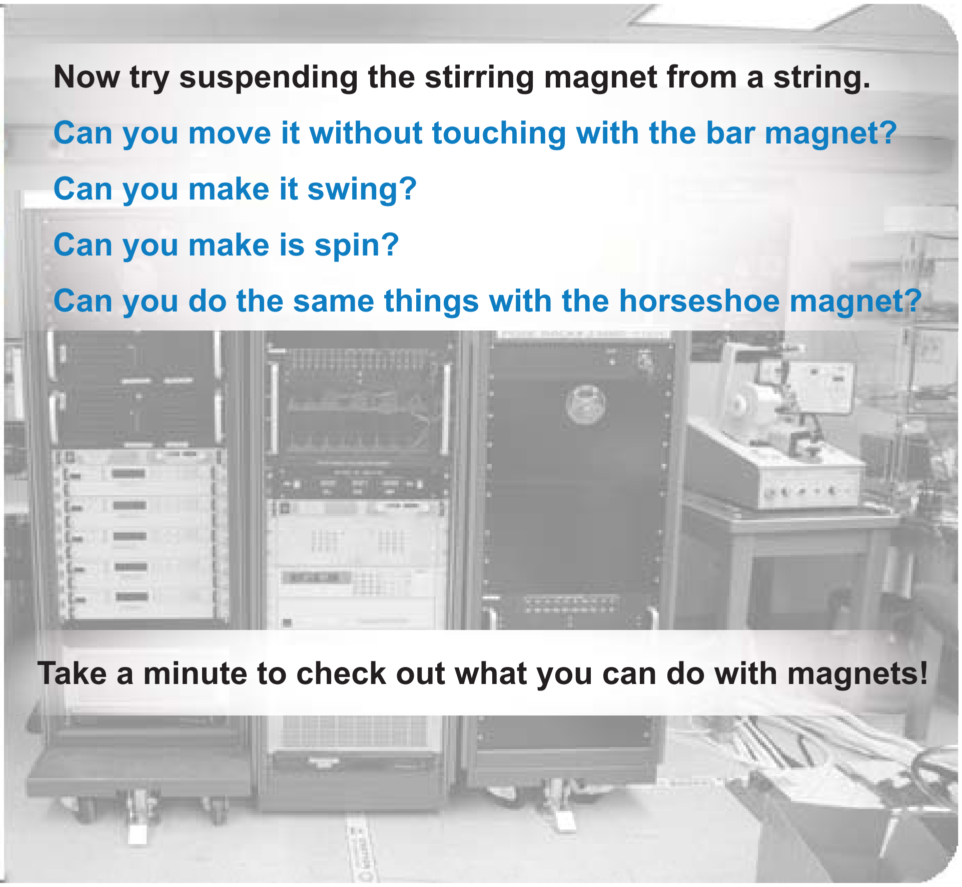
How do magnets compare to each other? Look at the bar magnet and the horseshoe magnet. What is the difference between them?

Now look at the magnets used with the magnetic stirrers. How do they compare to the bar magnets and horseshoe magnets?

How do all the magnets interact with each other?

Answer these questions:

- If you had only one magnet, and the poles weren't labeled, could you identify the north and south poles?
- If you were given two unlabeled magnets could you identify all the poles?
- If you were given one labeled and one unlabeled magnet could you identify them?
- How?



Now try suspending the stirring magnet from a string.

Can you move it without touching with the bar magnet?

Can you make it swing?

Can you make is spin?

Can you do the same things with the horseshoe magnet?

Take a minute to check out what you can do with magnets!

Introduction to Magnetic Fields

It astonishes Marc that such small magnets create a large force that can be transmitted over a distance. He begins to imagine how strong the forces may be if the magnets were the size of a table, a house, a state, a country, or the Earth. Even though Marc has seen these interactions across a distance, he wonders what they look like. As the class prepares for the next activity, Marc is excited to see that he will have the opportunity to explore this invisible realm.

Your Objective

Figure out what the magnetic fields around a magnet ‘look’ like.

Supplies

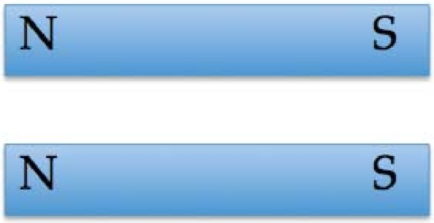
- Bar magnets
- Computer paper
- Magnetic film (such as: http://www.arborsci.com/magnetic-field-viewer-film-9in-x-7-2in)
- Pencil
- Compass
- Other magnets

Directions:

As a group, use the supplies provided to answer the following questions.

Place a single bar magnet on the table. Place a sheet of magnetic film over the magnet.

1. Sketch or trace the pattern that appears on the film.
2. Place two bar magnets under the film in the arrangements shown below.



3. Move the magnets around under the paper and watch what happens. Try putting the magnets under some notebook paper or in a folder. Place the magnetic film over the paper and folder, can you find the magnet? Use the magnet film to look for magnets hidden in other objects (check out an iPad2 cover!).

4. Try placing the horseshoe magnets, the magnetic stirrers, strip (refrigerator) magnets, and other magnets under the magnetic film. Sketch each arrangement that you try below.

5. Go to the Internet and launch this PhET simulation.
   http://phet.colorado.edu/en/simulation/magnet-and-compass
   Play with the magnets and compass. Be sure to click the box to include the Earth!

   You can also look at this one:
   http://phet.colorado.edu/en/simulation/magnets-and-electromagnets

   If you have extra time, you can also take a look at:
   http://phet.colorado.edu/en/simulation/generator
   or
   http://phet.colorado.edu/en/simulation/faraday

6. Now, watch these videos about magnetic field lines!

After completing these investigations, the last thing Marc and his classmates have to do is write a 250-word essay on why they should be selected to have an engineer from the NASA MMS mission visit their classroom. They should include some questions they that build on what they have learned in their investigations and that will help them understand the MMS design challenges.

What should Marc say to get an engineer from the NASA MMS mission to come to his school? Before you start writing, work with your group members to generate a list of ideas he should discuss in his essay.

Essay:

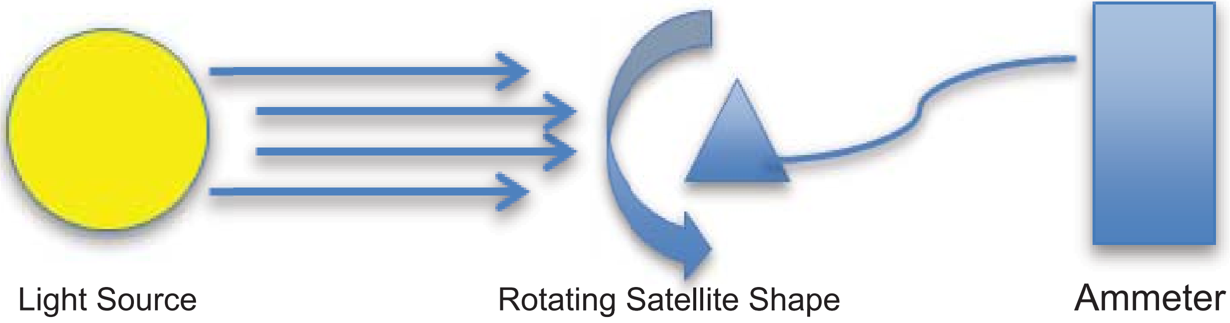
Design Challenge - Shape of the Satellites

After anxiously waiting to discover if his school has been selected, Marc's teacher finally recieves word from the MMS engineer at NASA. She was very impressed
written by Marc and his class and she is coming from NASA's Goddard Spa
Flight Center in Greenbelt, Maryland to visit their school!

After meeting the class, the engineer gives them a brief introduction to the MMS mission and immediately starts the class on their first design task.

Your Objective:

Consider the functions of a rotating satellite. Determine which shape will provide a steady minimum current output from solar panels on the outside, given a fixed position light source.



Supplies

- Light source
- Solar panel kit
- Ammeter
- Wires
- Fabrication equipment (refer to 'About this book' at the end to learn more about fabrication)

Designs and Constraints

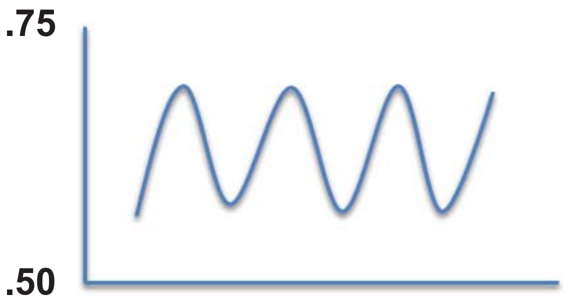
- Design and develop a satellite shape. Use the 2D Fabricator to construct a series of basic 3D shapes that have sides that are large enough to hold the solar panels.
- Build a rotating surface to place the satellite on.
    - o How will you build your surface in the 3D fabricator? How will you create gears and an arm?
    - o Will you use something pre-made? An old record turntable could be an option. What other found materials could you use?
- Design a way to connect the solar panels to an ammeter without getting the wires tangled as the platform and satellite rotate.
- Since you are attaching flat solar panels, do not test a disc shape, instead test shape with two or more sides on which you can attach the solar panels.
- Your shape must maintain a minimum current output while it is rotating.

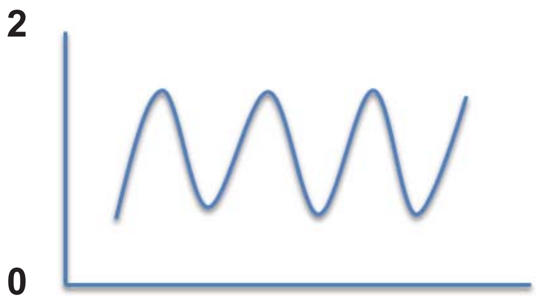
Questions to think about

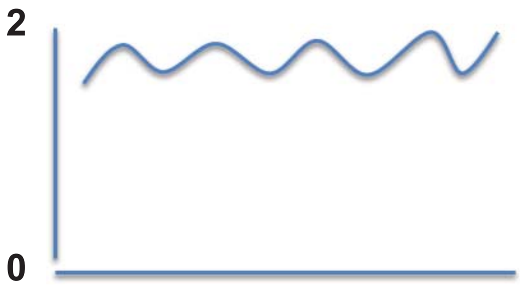
1. When will you get a maximum current output? What angle between the light source and solar panels would create this output?

2. When will you get a minimum current output? What angle between the light source and solar panels would create this output?

3. Which graph is the smoothest?







Example: Need some help getting started with an idea? Here is an example of what a setup could look like:

Data Table:

Shape	Number of Panels	Max Current	Min Current

Discuss in your group.

What do your graph's crests/amplitudes show about your model's current?

Would a smooth and more consistent current be created with more or less solar cells? How could you redesign your model to create a this type of current?

Do you think your group's design would work in real life? Why or why not?

What were you doing that engineers do?

What skills do you think you would need to have a career as an engineer?

Design Challenge 2 - Stacking the Satellites

Armed with his new knowledge, Marc anxiously returns to class the next day to learn of his next task. Once the class is ready, the engineer prepares to deliver their next assignment.

"Class, good work on completing the first design challenge. Now that you have determined an octagonal prism is the most efficient shape for the solar panel arrays, our next design challenge is to get the satellites into space. We need to send up a group of four satellites for this mission. The only way to get them into space is to fit them into a rocket. The rocket has very limited space. The specific details will be explained in your next design challenge."

Your Objective:

Create the four largest satellites possible that can still fit in the cylinder.

Materials

- Computers
- Fabrication Software (FabLab ModelMaker is an example)
- Fabrication equipment (refer to 'About this Book' at the end to learn more about fabrication)
- Tape
- Cylinder (a half of a potato chip can works well) about 7 cm diameter

After determining the optimal size for the satellite, use the software to determine the surface area. Identifying the surface area is an important step because this space will hold the solar-panel arrays. Now, use the software to calculate the volume of the satellite. This step will help determine the maximum amount of space available to put any instruments and equipment in the satellite.

Design Challenge - Deploying the satellites' antennae

As Marc and his classmates are leaving for the day, they all receive a message from the MMS engineer. She tells them to be sure to watch the news tonight because Scientists are detecting solar flares on a more frequent basis, leading them to believe that the Earth is entering a cycle of increased solar activity. Magnetic reconnections on the Sun causes solar flares, the same phenomena the MMS mission is trying to study.

The next day in class, she quickly calls them to order and brings them up to speed on the increased solar activity showing the urgency and need for the MMS mission. In order for the satellites to collect the data needed to understand the magnetic reconnections near Earth, they must deploy a variety of sensors. Some of these sensors will be on booms attached to four of the eight sides. The deployment of these booms is the basis of the next design challenge.

Your Objective:

Determine if the centrifugal force of the rotating model satellite is sufficient to push the booms out of the body of the satellite. If successful, determine the minimum rotational speed for the satellite to successfully deploy the booms. Be able to explain your thinking.

Materials

- A previously built MMS satellite model
- Two feet of wire, up to four pieces
- A method of rotating the satellite

Designs and Constraints

- Determine a way to rotate the satellite and measure the rotational speed.
- Find a way to place the wire in the satellite
- Determine and record the minimum rotational speed for consistent deployment
- When successful with one wire, determine if the same speed works for four wires, one coming out of every other panel.

Safety Consideration: When rotating the satellite wear eye gear and do not spin the satellite at high speeds near other students. Adult supervision and eye protection are required.

Design Challenge - Arrangement in Space

After several exciting days of testing, Marc and his fellow classmates have learned a great deal! They've learned about magnetism, the optimal shape and surface area-to-volume ratio for satellites, deployment of sensitive equipment, and about magnetic reconnection in Earth's magnetic field. The MMS engineer brings them one last challenge: to uncover the best arrangement of satellites in space.

Your Objective:

Build four model satellites with booms and antennae using the fabricator. Be albe to explain to someone what you did.

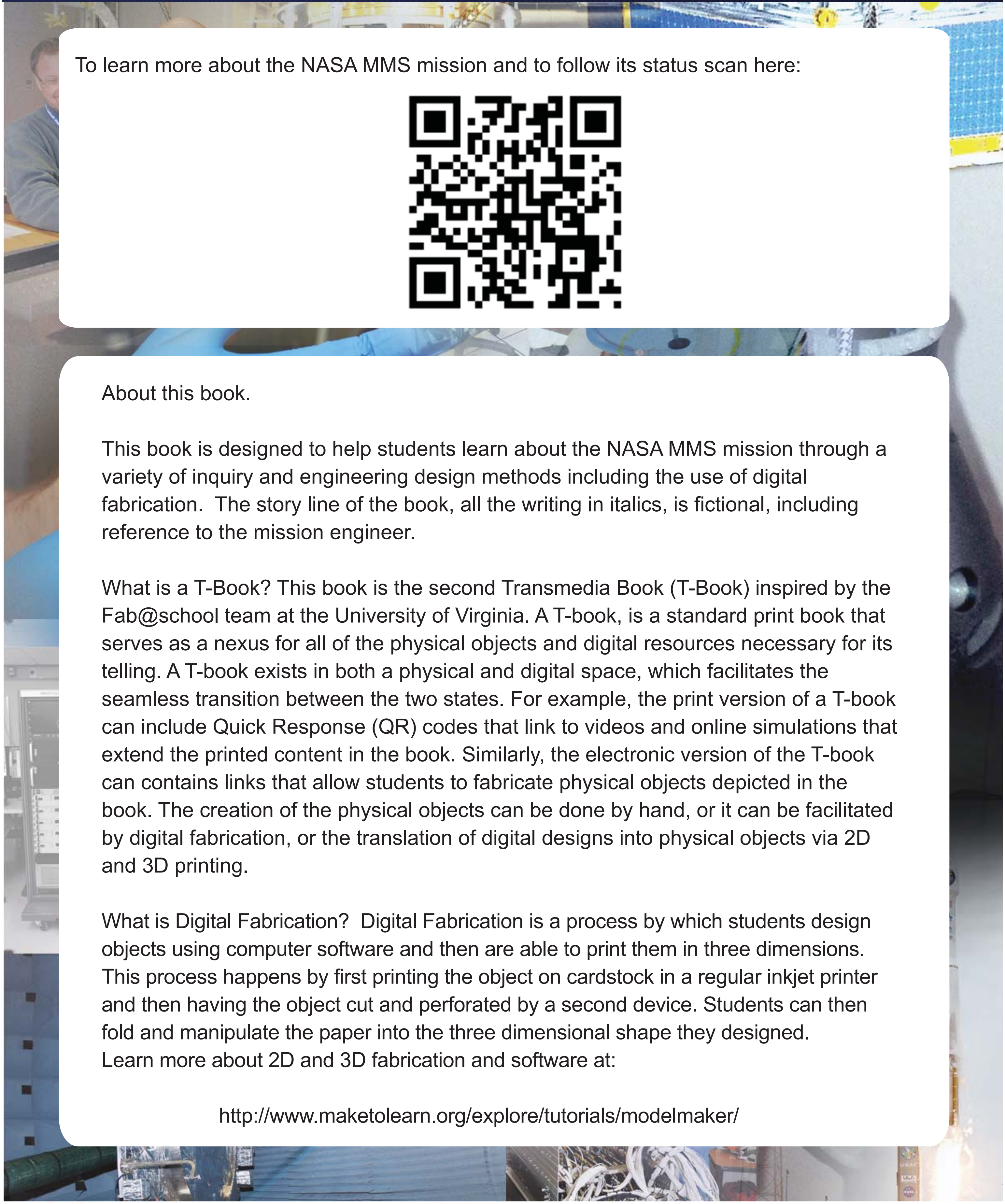
Materials

- Wire, 2 gauges.
  - o Thicker wire for the booms
  - o Thinner wire for the antennae
- Computers
- Fabrication equipment (refer to 'About this Book' at the end to learn more about fabrication)

Designs and Constraints

Build the satellites and find a way to suspend them in the pyramidal array of their deployment.

Marc is excited about what he has learned about magnetism, NASA missions, and the effects of space weather on Earth. Now, he is more confident when he hears of a 'solar storm' approaching; he thinks of it as a learning opportunity instead of something to fear. He has learned that while he is in no immediate danger from the sun, magnetic reconnection sparks solar flares, and powers auroras and that it is the ultimate driver of space weather impacting human technologies such as communications, navigation, and power grids. Marc realizes that his investigation into space weather and the MMS mission has raised even more questions that he would like to explore. Perhaps a career at NASA is just what he's looking for!



To learn more about the NASA MMS mission and to follow its status scan here:

About this book.

This book is designed to help students learn about the NASA MMS mission through a variety of inquiry and engineering design methods including the use of digital fabrication. The story line of the book, all the writing in italics, is fictional, including reference to the mission engineer.

What is a T-Book? This book is the second Transmedia Book (T-Book) inspired by the Fab@school team at the University of Virginia. A T-book, is a standard print book that serves as a nexus for all of the physical objects and digital resources necessary for its telling. A T-book exists in both a physical and digital space, which facilitates the seamless transition between the two states. For example, the print version of a T-book can include Quick Response (QR) codes that link to videos and online simulations that extend the printed content in the book. Similarly, the electronic version of the T-book can contains links that allow students to fabricate physical objects depicted in the book. The creation of the physical objects can be done by hand, or it can be facilitated by digital fabrication, or the translation of digital designs into physical objects via 2D and 3D printing.

What is Digital Fabrication? Digital Fabrication is a process by which students design objects using computer software and then are able to print them in three dimensions. This process happens by first printing the object on cardstock in a regular inkjet printer and then having the object cut and perforated by a second device. Students can then fold and manipulate the paper into the three dimensional shape they designed.
Learn more about 2D and 3D fabrication and software at:

http://www.maketolearn.org/explore/tutorials/modelmaker/

- What are the objectives of the NASA MMS mission? Investigate how the Sun Earth's magnetic fields connect, disconnect, and explosively transfer energy from one to the other (a process that occurs throughout the universe, known as magnetic reconnection).

- Reveal, for the first time, the small-scale 3D structure and dynamics of the key reconnection regions where the most energetic events originate.

- Observe magnetic reconnection. MMS studies the ultimate driver of space weather, which affects modern technological systems such as communications networks, GPS navigation, and electrical power grids.

This book was a massive collaborative effort that was first conceived at the National Technology Leadership Summit in Washington, DC in the fall of 2011. The ideas were the collective effort of David Slykhuis, Troy Cline, David Thornburg, Cecilia Lenk, Randy Bell, Michael Spector, and Willy Kjellstrom.

David Slykhuis and Troy Cline completed authoring the storyline and design activities to bring the book into its current form.

Others deserving thanks for their time and effort working on the book:

From James Madison University: Casey Siron, Marc McCann, and Shelby Kardon.

From Harrisonburg City Schools: Carol Hall, Sarah Arenas, Ashley Lambert, Richard Frutuozo, Andy Jackson, and Amy Sabarre.

From the University of Virginia: Glen Bull, Daniel Tillman, and Crystal DeJaegher.

Graphics and Layout: Jeff DeJaegher

For more information about the NASA/IMAGE soda bottle magnetometer visit Dr. Sten Odenwald’s website for this resources at: image.gsfc.nasa.gov/poetry/workbook/page9.html

QR Codes and associated URL’s.

p. 8 – http://youtu.be/Seo8ZOjxn2M

p. 10 - http://www.youtube.com/watch?v=Dn6VVZ3mrs4&feature=related, http://youtu.be/kdomJQvxPZE

p. 14 - http://www.youtube.com/watch?v=_LG8Y7B2ZBI&feature=youtu.be

p. 18- http://mms.gsfc.nasa.gov/

For information regarding the science standards addressed by this book and for pre and post assessments please visit:
http://tbookpre.questionpro.com/
http://tbookpost.questionpro.com/

Thanks also to any others who had a hand in making this book a reality and whose names I forgot to add!

David Slykhuis