Planetary Magnetism

Teacher Guide

How crucial is a planet's magnetic field?

Overview:

This activity teaches students about the importance of a planet's magnetic properties, especially in relation to Mars and Earth. Students experiment with a simple model of a planet surface, its atmosphere, and the Sun's magnetic field. The model includes hidden magnets underneath the surface. In the process of their guided experimentation, students learn about the sometimes competing forces of gravity and magnetism. Ultimately they discover that the underlying magnetic field protects charged particles in the atmosphere from being carried away by the Sun's magnetic field. The *Going Further* section includes an extension to Venus, and the *Going Even Further* section has math problems to calculate the forces of gravity and magnetism, all of which can be graded.

Grade Levels:

Primary focus is on grades 6-8, but applicable for 9-12 (especially the *Going Even Further* section).

Time Required:

Initial reading of lesson plan and PowerPoint presentation, 20-30 min. Initial setup of activity, 15 min. *Reading of detailed background information PowerPoint presentation (optional), 30 min.*

In class time:

Activity (student guide up to p.5) and clean up, 20-30 min.
PowerPoint presentation, 15-30 min.
Going Further/*Going Even Further* math activity, 10-20 min.

Science Standards:

See the last page for Next Generation Science Standards covered in this activity.

Lesson Objectives:

Upon completion of the activity students will understand:

- That a planet's magnetic field can help to protect its atmosphere from being stripped away by the Sun's magnetic field.
- That the charged particles in a planet's upper atmosphere (ionosphere) are pulled down by gravity, and are sometimes also pulled up and/or away by magnetism.
- Unlike Earth, Mars has no strong global magnetic field, which is likely a key reason why its atmosphere is much thinner.

Connections to NASA research:

- The Mars Atmospheric and Volatile EvolutioN (MAVEN) mission will orbit Mars and collect data about how magnetic processes (among other things) affect its ongoing atmospheric loss, including over its very weak and scattered magnetic fields. This will help scientists trace Mars' atmospheric history to determine what happened to the once-flowing water.
- Why do we care about water? Every known life form on Earth requires water to survive, and wherever we find water on Earth, we find life. Finding liquid water on another planet is exciting, not because it means life does exist, but that it could exist. It's that possibility that motivates missions like MAVEN to keep searching for clues about Mars's early history.

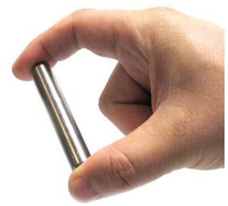
Materials:

Per class:

1. A way to show digital slides to the class (i.e. projector or TV screen)
2. A magnetic compass (used for navigating)

Per group of students: (we recommend groups of 3, but it is variable based on available materials)

3. Two sheets of clear acrylic (about ¼" thick, enough to be rigid, and 8.5"x11")
4. One red sheet of cardboard or heavy paper
5. One translucent plastic sheet (like the kind used for laminating, or a sheet protector)
6. Heavy duty tape or masking tape
7. 2 x very-strong circular magnets[1]
8. 1 x cow magnet[2] (see picture to the right)
9. Golf pencil (or any pencil that is small and without metal)
10. 4 x DVD cases, or something of similar depth e.g. books.
11. Iron filings[3]
12. Optional: base board (e.g. cutting board, card board. Should be at least letter-sized)



Per student:

13. Copy of the student guide and something to write with

Warning: keep all electronics, credit cards and other magnetized materials (including cell phones and computers) AWAY from magnets at all times! Also, magnets that are incredibly strong can cause pinching injuries (or worse if swallowed) and must be handled with caution.

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[1] It's important to get strong (often called "rare earth" or "neodymium") magnets, but it isn't critical to get the exact model shown in this activity. The model shown was purchased from K&J Magnetics: www.kjmagnetics.com (1" dia. x 1/4" thick, and axial magnetization direction [poles on flat ends]).

[2] A cow magnet is fed to a cow to collect metallic objects in the stomach that may have been accidentally consumed while grazing, and it protects the animal from hardware disease. Again, this magnet doesn't necessarily need to be a cow magnet, however, it should be stronger than a refrigerator magnet and weaker than the magnets used above. Ideally it should be about 2" to 3" long and relatively thin. Cow magnets can be purchased cheapest from pet/farm supply stores: www.valleyvet.com, www.americanlivestock.com, www.pet-vetsupply.com. Slaughter houses may also give away recovered magnets in rural areas.

[3] Iron filings can be found at Arbor Scientific: http://www.arborsci.com/iron-filings.

Primary misconception to avoid creating:

Misconception: "The ionosphere is made of iron particles and/or the charged particles behave the exact same way as the iron filings. I.e. charged particles are pushed or pulled towards the magnetic poles."

Correction to this misconception:

Charged particles do not get forced down (parallel to) magnetic field lines towards the poles. Instead they spin around the lines, but only when they are moving relative to (and perpendicular to) the field lines. The correct motions and forces are shown in the last slides of the accompanying PowerPoint. They involve concepts that are typically taught in college-level physics classes.

Prerequisite knowledge:

More background information can be found on slides 18-24 of the PowerPoint presentation.

- **Magnetic fields**: their basic shape; magnetic polarity; "seeing" fields using compasses and magnetic filings. **Recommended: *Magnetism* classroom session (found in *Exploring Magnetism*- http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/exploring_magnetism/)**
- **Basic "space weather" effects on Earth**: understanding that solar activity can affect Earth, that a solar storm involves large amounts of both high-energy radiation and charged particles, and that both affect Earth in different ways. Recommended: *Mystery Events* classroom activity (found in *Living With a Star GEMS Guide* - http://lhsgems.org/gemsLWAS.html, as well as *Space Science Sequence 6-8 Unit 1* - http://www.lhsgems.org/SpaceSciSeq.htm)
- **The Sun has a magnetic field that is related to the solar wind and extends past the planets**: the Sun's magnetic field extends throughout the solar system and can affect the planets. Recommended: *The Interplanetary Magnetic Field* classroom session (found in *Exploring Magnetism in the Solar Wind*- http://cse.ssl.berkeley.edu/SEGwayed/lessons/exploring_magnetism/in_the_Solar_Wind/)

- Optional:
    - **Basic electromagnetism**: the general understanding of the relationship between electricity (the flow of charged particles) and magnetism, and how one can affect the other. Recommended: *Electromagnetism* classroom session (found in *Exploring Magnetism*- http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/exploring_magnetism/)
    - **Earth's protection from the Sun's harmful effects**: Earth's atmosphere shields the surface from high-energy radiation from the Sun, and the magnetosphere shields it from most of the charged particles. Recommended: *Balloon-Rocket Mission* classroom activity (found in *Living With a Star GEMS Guide* - http://lhsgems.org/gemsLWAS.html, as well as *Space Science Sequence 6-8 Unit 1* - http://www.lhsgems.org/SpaceSciSeq.htm)
    - **Electromagnetic radiation (light), as well as charged particles, come from the Sun**: a very basic understanding that various wavelengths of light, as well as some particles with a positive or negative charge, are created and emitted by the Sun. Recommended: *EM Spectrum "Energy From the Sun"* classroom activity (found in *Living With a Star*

GEMS Guide - http://lhsgems.org/gemsLWAS.html, as well as *Space Science Sequence 6-8 Unit 1* - http://www.lhsgems.org/SpaceSciSeq.htm)

- **Ionization/ionized particle**: the process of an atom or molecule acquiring a positive or negative charge by gaining or losing electrons
- **The Sun's solar wind and its effect on Mars**: the stream of charged particles from the Sun that flows through the solar system affects any planet in its way, including Mars. Recommended: *MAVEN Studying the Solar Wind on Mars* video (found at http://youtu.be/k4WaxVVGzrg to watch or download from http://svs.gsfc.nasa.gov/vis/a010000/a011400/a011498/)

Getting Ready:

Setting up each group's model
(we recommend groups of 3, but it is variable based on available materials)

Figure 1. Gather the materials to make one group's model.

1. Begin by gathering your materials:
   a. Two sheets of clear acrylic (about ¼" thick, enough to be rigid, and 8.5"x11")
   b. One red sheet of cardboard or heavy paper
   c. One translucent plastic sheet (like the kind used for laminating, or a sheet protector)
   d. Heavy duty tape or masking tape
   e. 2 x very-strong circular magnets
   f. 1 x cow magnet
   g. Golf pencil (or any pencil that is small and without metal)
   h. 4 x DVD cases, or something of similar depth to use as spacers e.g. books
   i. Iron filings
   j. Optional: base board (e.g. cutting board, card board. Should be at least letter-sized)

Warning: keep all electronics, credit cards and other magnetized materials (including cell phones and computers) AWAY from magnets at all times! Also, magnets that are incredibly strong can cause pinching injuries (or worse if swallowed) and must be handled with caution.

Figure 2. One circular magnet with a golf pencil to show scale.

2. Next, place one circular magnet on your baseboard (or directly on your desk).

3. Tape the magnet in place, ensuring it is secure around all sides. More than one piece of tape should be used. Scotch tape is generally not strong enough!

4. Place the other circular magnet approximately 1/2 inch from the first. Using a cow magnet, make sure that the *opposite* polarity from the first magnet is pointing upwards. This can be done by touching the tip of the cow magnet to the secured circular magnet and noting whether there is an attractive or repulsive force. Then, using the same end of the cow magnet, and holding the second circular magnet securely, repeat the attraction/repulsion test. The second magnet should do the *opposite* of the first magnet (i.e. if the cow magnet was attracted to the first circular magnet, the second magnet should be oriented to repel the cow magnet. The second magnet should be flipped over if needs be.

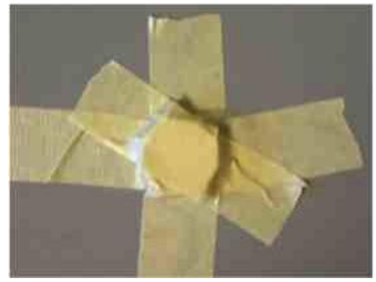

Figure 3. A circular magnet securely taped into place.

5. Secure the second magnet using heavy duty tape.

6. Place a small pencil or other non-magnetic object between the magnets to prevent them from moving towards each other.

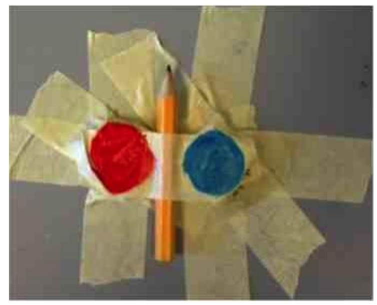

Figure 4. Both circular magnets securely taped down and color coded.

7. At this point, you can color the magnets red and blue using felt tip pens to color the tape. This can be done by testing them using a standard red/blue bar magnet (though it isn't critical to know the proper polarity). Remember opposites attract so the side that is repelled by each circular magnet is the color that magnet should be.

Adding atmosphere

Figure 5. Two DVD cases flanking the taped down magnets.

8. Next, place a DVD/book on each side of the magnets, about 8-10 inches apart.

9. Add the Martian "surface" by laying the red paper over the DVD boxes, creating a gap between the magnet and the "surface".

10. Now, add the regular atmosphere by placing one of the acrylic sheets on top of the red card. This represents the lower, more dense, and non-ionized atmosphere.

11. The third layer of the atmosphere is represented by the translucent sheet, or sheet protector, which is laid on top of the acrylic sheet.

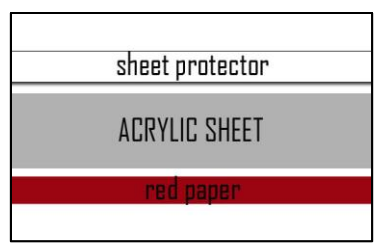

Figure 6. Close-up of steps 10 & 11.

Adding "charged particles" (only needed to choose proper spacing)

12. Since ionized particles have a charge associated with them (generally a positive charge since electrons are stripped away), we will use iron filings as an analogy for ions. Charged particles (e.g. ions) and magnetized materials behave in similar ways under certain conditions. However it is important to note that *they are not the same in every situation*. We are using iron filings for simplicity.

13. Scatter about a teaspoon's worth of iron filings evenly over the translucent sheet. Use a pencil to distribute them evenly if necessary. You should notice that some iron filings are immediately attracted to the region above the magnets, forming a loop-like orientation.

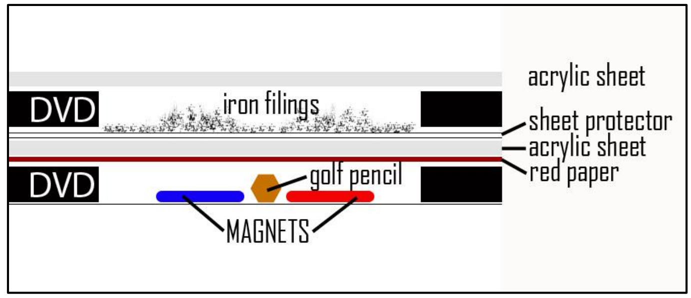

Figure 7. Profile diagram of a completed model after step 15.

14. Place another set of DVDs/books on top of the translucent sheet, in the same position as the original two boxes to create a stacked effect.

15. On top of the second set of DVD boxes, place the other acrylic sheet. This represents the topmost layer of the atmosphere.

Adjusting the spacing to create the desired effect

16. Next, take a cow magnet and place it on top of the topmost acrylic sheet, away from the underlying magnets. The iron filings should be attracted to the cow magnet and should jump to the underside of the acrylic sheet. If you do not see the iron filings rise up, then most likely the space between the cow magnet/filings is too large. Use something thinner than what you used in step 14 to make a smaller space.

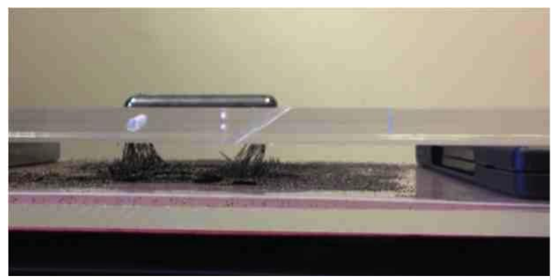
Figure 8. Iron filings attracted to the cow magnet and jumping up to the underside of the acrylic sheet.

17. Now move the cow magnet along the topmost sheet until it is over the underlying magnets. You should see the iron filings being pulled between the various magnets. Move the cow magnet around in slow circles, and then slide it away from the underlying magnets. Most of the filings should not move away with the cow magnet, instead they should mostly stay stuck to the underlying magnets. If not, then adjust the space between the underlying magnets and the surface that the filings rest on, or replace the underlying magnets with stronger ones (this is why it is important to use strong magnets).

18. Make sure you have the spacing correct in the previous two steps, then try out the instructions in the accompanying Student Guide to ensure that the model achieves the desired effect (i.e. the filings are attracted to the cow magnet, but cannot be pulled away from the stronger underlying hidden magnets. However the filings that are far from the hidden magnets can easily be moved around by the cow magnet and, if so desired, removed from the altogether by pulling the cow magnet away from the model).

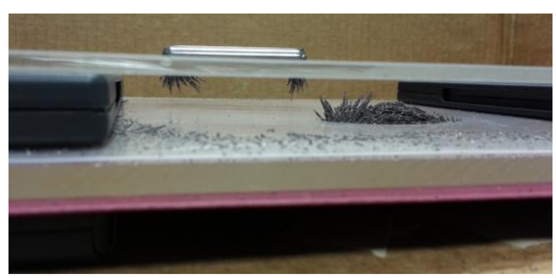
Figure 9. Cow magnet pulling away iron filings from the underlying magnets.

Also, become very familiar with the model's analogy to Mars, which is described at the bottom of page 2 of the Student Guide.

19. Once you are confident that the model is set up correctly, remove the top two layers (acrylic sheet and whatever you used as spacers in step 14) and all of the iron filings. Return the model to the condition it was in after step 11. Give each group of a students a model, the top acrylic sheet, the DVDs/spacers, and iron filings just before beginning the activity.

Doing the Activity:

Engage

Show students the magnetic compass (or several if you have them), hold it up, and pass it around the class. Ask them the following questions and wait for them to respond:

- **"What direction does the needle point?"**
  - North
- **"Why?"**
  - Due to magnetism it's pointing towards one of Earth's magnetic poles
- **"What is a magnetic field?"**
  - The region around a magnetic material or a moving electric charge within which the force of magnetism acts. Or, the lines of force surrounding a permanent magnet or a moving charged particle
- **"Does the Earth have a magnetic field?"**
  - Yes
- **"Does the Sun have a magnetic field?"**
  - Yes
- **"How far out does the Sun's magnetic field extend?"**
  - Very far. Past all of the planets. More than twice as far as Pluto.

Use their answers to gauge their preconceptions and prior understanding of the topics listed above in the *Prerequisite Knowledge* section. Fill in any gaps as necessary. Then tell them the following:

- **"If you were on Mars, your compass would not always point north. It would seem to point in very random directions depending on where you were. And sometimes it wouldn't seem to want to point in any particular direction at all. Your compass wouldn't be able to tell north, south, east, or west. Unlike Earth's strong global magnetic field, Mars has a lot of very weak and small magnetic fields that are scattered around the planet. We're going to be learning more about how this might affect Mars' atmosphere."**

Explore, Explain, and Elaborate

Distribute the Student Guides and instruct the students to begin with the instructions and stop at the bottom of page 5.

- Remind them to keep magnets away from all electronics.
- They should be writing down their observations and answers in the boxes provided.

Elaborate (continued)

Show the accompanying PowerPoint to the students, 18 slides (15-30 minutes).

Note: the optional PowerPoint presentation "Detailed Science of the MAVEN mission" (25 slides) provides relevant information and useful background materials for anyone who wants to know more. They are not a required part of the activity (30 min). The topics include:

- *The MAVEN mission (Slides 1-7)*
- *Atoms, Ions, and the Ionosphere (Slides 8-15)*
- *Solar wind interactions with the atmosphere (Slides 16-17)*
- *The movement of charged particles in a moving magnetic field (Slides 18-25)*

Evaluate

Optional: Have the students complete the last 3 pages of the Student Guide (*Going Further* & *Going Even Further*).

- The *Going Even Further* section requires some advanced math skills, so it may be skipped depending on your students' abilities (Algebra is a pre-requisite, so this section is recommended for grades 8-12).

Once the students are finished, have them turn in their Student Guides.

Grading Rubric: Student Guide Pages 1-5

Engagement (Do It) = 30%

The student was present and participated in the activity.

Completion (Explain & Explore) = 20%

Pages 1-2: The student answered the questions with their observations.

Understanding Concepts (Elaborate) = 25%

Pages 3-4: Make sure the student answered every single question thoughtfully. There are no right or wrong answers but students should have reasonable explanations.

Demonstrating Knowledge (Final Reflection) = 25%

Page 5: Students hopefully come to the conclusion that an underlying magnetic field can "shield" a planet's atmosphere from the Sun's magnetic field, and that a stronger gravitational pull from the planet can do the same.

Fair – 3 or less concepts/ vocabulary/relationships included, little or no final reflection

Good – 5 concepts/vocabulary/relationships included, reasonable attempt at final reflection

Excellent – 7 concepts/vocabulary/relationships included, a well-thought and in-depth final reflection

Extra Credit: *Going Further* and *Going Even Further* Pages 6-8

Fair – Hypothesis and attempt one math problem

Good – Hypothesis and attempt 2-3 math problems

Excellent – Hypothesis and attempt 4 math problems

Page 6 (*Going Further*):

The student's hypothesis should include 2 of the 3 following arguments:

1) The stronger gravitational pull of Venus helps it to retain its atmosphere.
2) Venus' atmosphere is always being replenished by active volcanoes.
3) Venus used to have a strong magnetic field, but it disappeared relatively recently (astronomically speaking) and there hasn't been enough time since then for the atmosphere to be stripped away.

Page 7-8 (*Going Even Further*):

First answer: **Magnetism**

(Gravity = 8.76×10^{-26} Newtons; Magnetism = 1.92×10^{-22} Newtons)

Second answer: **Magnetism**

(Gravity = 2.09×10^{-25} Newtons; Magnetism = 1.92×10^{-22} Newtons)

Third answer: *note, there may be rounding uncertainties*

On Mars = **182.5 m/s** (which is about 408 miles per hour)

On Venus = **435.4 m/s** (which is about 973 miles per hour)

Next Generation Science Standards covered in this activity:

3-PS2-3. Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other. [Clarification Statement: Examples of an electric force could include the force on hair from an electrically charged balloon and the electrical forces between a charged rod and pieces of paper; examples of a magnetic force could include the force between two permanent magnets, the force between an electromagnet and steel paperclips, and the force exerted by one magnet versus the force exerted by two magnets. Examples of cause and effect relationships could include how the distance between objects affects strength of the force and how the orientation of magnets affects the direction of the magnetic force.] [Assessment Boundary: Assessment is limited to forces produced by objects that can be manipulated by students, and electrical interactions are limited to static electricity.]

3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. [Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.] [Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.]

MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame, and to change in one variable at a time. Assessment does not include the use of trigonometry.]

MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. [Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.] [Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.]

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. [Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.] [Assessment Boundary: Assessment is limited to electric and magnetic fields. Assessment is limited to qualitative evidence for the existence of fields.]

Acknowledgements:

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