

Lab: Modeling Planetary Magnetism Teacher Guide

Description: This hands-on, guided-inquiry activity helps students to understand the features of Earth's and a Mars-like planet's planetary magnetic fields using a smartphone sensor and easily-constructed planetary models. Students will visualize the magnetic fields around a planet model with a planetary dipole field (representing Earth) and a Planet X with a disordered planetary field comprised of localized regions of magnetization in the crust (which is the situation on Mars). They will compare these magnetic fields and explain how field vectors vary based upon location on the surface of the planet. This resource is designed to supplement [*Physics by Inquiry*](#) for physics teacher preparation and includes elements similar to those found in [*Ranking Tasks for Introductory Astronomy*](#).

Purpose: This lesson was developed to promote understanding of:

1. Characteristics of planetary magnetic fields
2. Visualization of three-dimensional vectors, especially with respect to planetary geography

Prerequisite:

- Have a general conceptual understanding of magnetic field lines and magnetic field vectors.
- Basic understanding of magnetic dipole ("bar magnet") field

Materials Required:

- Opaque, hollow 2-3 inch diameter plastic balls (four per learning group)
- Button magnets (15-16 per learning group)
- Hot glue, sharp knife for cutting the plastic balls
- Mobile devices to run *Physics Toolbox* app

NGSS Connections: See Page 10 for detailed NGSS correlation statements

- High School Earth/Space Science: HS-ESS2.A.2 - Earth Materials and Systems
- High School Physical Science-Forces & Interactions: HS-PS2.B.2 - Magnetic and Electric Fields
- High School Physical Science-Waves: HS-PS4.B.2 - Electromagnetic Radiation
- Science and Engineering Practices: Developing and Using Models, Planning and Carrying Out Investigations
- Crosscutting Concepts: Systems and System Models

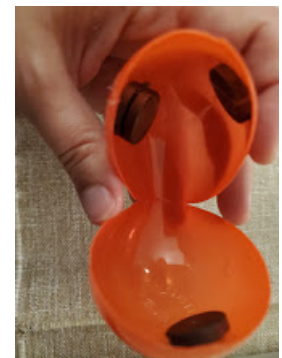
Advanced Preparation:

- Prepare planetary models in advance.

1. Cut open a small (ideally opaque) plastic ball with a knife along its seam.

Balls should be suitably small to ensure that the volume of the mapped field is primarily a result of the fields from the magnets that are placed inside of it, and not influenced significantly by the environmental field. (For ceramic button magnets, a ball of approximately 3-5 inches is suitable.)

2. Use hot glue to attach button magnets inside the ball, paying attention to which pole is facing outward.
3. The Earth has an approximate dipole magnetic field that is generated by convection currents in the liquid iron outer core of the planet. Earth's field may be modeled by placing two magnets opposite each other (blue). Make sure that the magnets are aligned so that one side of the Earth model has a north pole facing out and that the other side has a south pole facing out.
4. Planet X (similar to Mars) has an irregular field predominantly caused by remnant crustal magnetism, and does not have internal convection currents to generate a planetary dipole field. The second model will represent this situation. The field of Planet X may be modeled by placing magnets in various configurations. Different strengths of poles may be modeled by including more than one button magnet in each location.
5. Use hot glue to close up the ball representing Earth at its seam. Use a permanent marker to mark a North (N) and a South (S) geographic pole on each planetary model. For Earth, the N should be near to, but not exactly at the position of the magnet south pole (the point where the magnetic field points into the model). The S can then be at the exact opposite point of the model. The actual difference between Earth's geographic and magnetic pole changes with time, but



a difference of around 15° has been typical for the past 150 years. Currently, the magnetic pole in the Arctic (which is a south magnetic pole) has been moving rapidly (34 miles/year) from Canada toward Siberia.

6. Close the Planet X model and pick a point for the north geographic pole that is not very near a magnet. On Mars, the strongest fields are near the equator and in the southern geographic hemisphere.
- Prepare the mobile devices that will be used. This experience requires the use of one of two free apps:
 - **Physics Toolbox Sensor Suite** (AR mode, selected from the internal menu to the left of the screen)
 - **Physics Toolbox AR** (stand-alone)

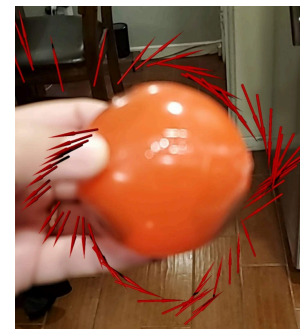


- Practice mapping field vectors. Mapping field vectors around the planetary models takes some time and patience. Review the tutorial within the app, or view it on YouTube: <https://www.youtube.com/watch?v=OEXWNcdImsc>. The exact look of the fields is dependent upon the location and strength of the magnets as well as the method for plotting the field. Sample fields for the Earth and Mars model are shown below. Be prepared to encourage students to use a combination of data collection methods, including uniform “sweeps” as well as detailed explorations of poles. Students will likely need to synthesize data from various data collection passes in order to get a good sense of the field around the whole model.

Model Earth



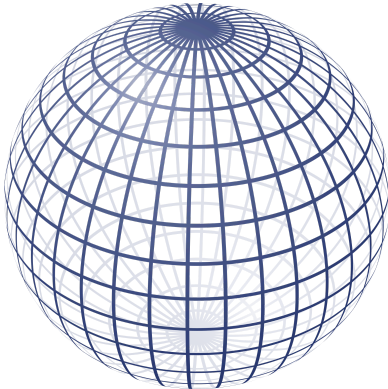
Model Planet X (example)



Learning Sequence: Note to teacher: *Italicized commentary* are notes for teachers. **Red statements** show sample correct student responses.

Part 1. Modeling Earth's Magnetic Field

- A. Using the app and the Earth model provided to you by your teacher, perform enough explorations with the smartphone app to determine what the field looks like around the globe. Using vectors (with attention to magnitude and direction), sketch the approximate field, and provide a narrative description of it. Assume that the seam of the ball represents the equator, and note the location of the north geographic pole.

Sketch	Description
North Geographic Pole 	The Earth's magnetic field looks similar to that of a bar magnet. Field lines go into the planet near the north geographic pole (which is actually a south magnetic pole, because field lines point north to south), and come out of the planet near the south geographic pole (which is actually a north magnetic pole). Near the equator, field lines are almost perpendicular to the surface of the Earth. Near the geographic poles, field lines are almost vertical. Regardless of how the data are collected, the field lines totally surround the globe. (We assume that field lines are present even where they are not measured).

- B. Consider Earth from various perspectives. Draw arrows that show Earth's approximate magnetic field direction on each map below.



Source: Sean Baker



Source: CIA



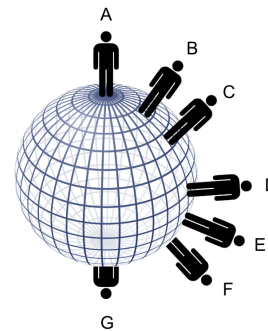
Source: CIA

- C. Imagine you were visualizing Earth's magnetic field standing on the surface of the planet while looking East and West off the coast of California. Which way would the magnetic field point? Draw in at least five arrows on the screen, and provide an explanation.

Visualization	Explanation
Looking East  Image by picapp.net	Because California is roughly half-way between the equator (where the field is horizontal) and the north pole (where the field points almost directly downward), the field lines point downward at an angle to the north (to the left-hand side of the screen).
Looking West  Image by picapp.net	Using the same reasoning as above, and considering that the person has just rotated 180 degrees, the field lines point downward at an angle to the north (to the right-hand side of the screen).

- D. Two individuals at different points of the globe took screenshots of visualized magnetic fields around them. Consider the locations on Earth represented on the globe as you answer the questions in the table below.

North Geographic Pole



1. At which point (A-G) must the viewer have taken the picture?
2. Which direction (N, S, E, W) must the viewer have been facing?
3. Provide a rationale for your answers.

Visualization



Image by [picapp.net](#)
Source: Arturo Marti

This photograph must have been taken in the southern hemisphere because the field lines point “upward” with respect to the ground. The picture could have been taken at point E or F.

Because the arrows point toward the northern hemisphere, the person must have been looking toward the east.

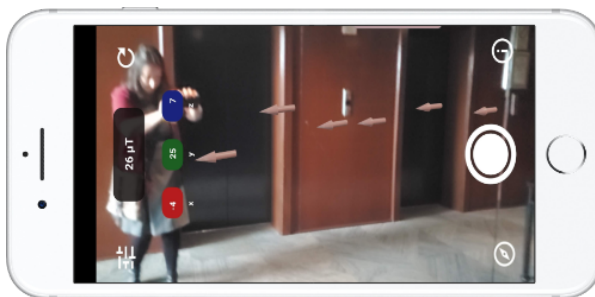


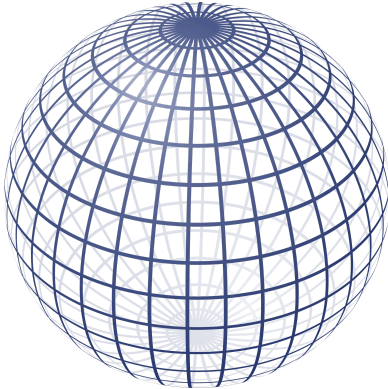
Image by [picapp.net](#)
Source: Rebecca Vieyra

This photograph must have been taken near the equator, where the field lines are horizontal. The picture could have been taken at point D.

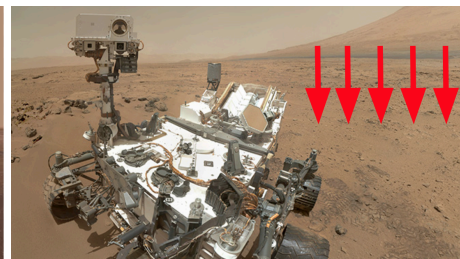
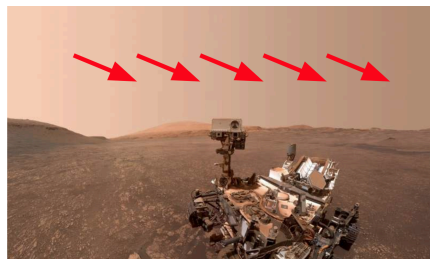
Because the arrows point toward the northern hemisphere, the person must have been looking toward the east.

Part 2. Modeling Planet X's Magnetic Field

- A. Using the app and the Planet X model provided to you by your teacher, perform enough explorations with the smartphone app to determine what the field looks like around the globe. Using vectors (with attention to magnitude and direction), sketch the approximate field, and provide a narrative description of it. Assume that the seam of the ball represents the equator, and note the location of the north geographic pole.

Sketch	Description
North Geographic Pole 	Student responses will vary. <i>Teachers should ensure that students note the location of poles and their relative strengths.</i>

- B. Compare Planet X's field with Earth's magnetic field. How are they similar/different?
Earth's field is much more uniform compared to Planet X. Earth also has only two poles, while Planet X has multiple poles.
- C. Imagine that NASA sent a rover to two locations on Planet X. Based on the magnetic field vectors within the images, mark the possible locations of Rover #1 and Rover #2 on your sketch in question A, above.



Credit: NASA

Part 3. Understanding the Source and Impact of Planetary Magnetic Fields

Planet X's magnetic field is similar to that of Mars. Unlike Earth, Mars does not have an organized dipole field. Magnetism on Mars is restricted to regions of the crust where there are magnetic minerals. Scientists speculate Earth's magnetic field might arise from convection currents of fluid metal under the crust. In contrast, Mars has no such active fluid flow. Mars' field is caused by magnetic minerals, somewhat akin to having randomly-organized permanent magnets buried in the crust.

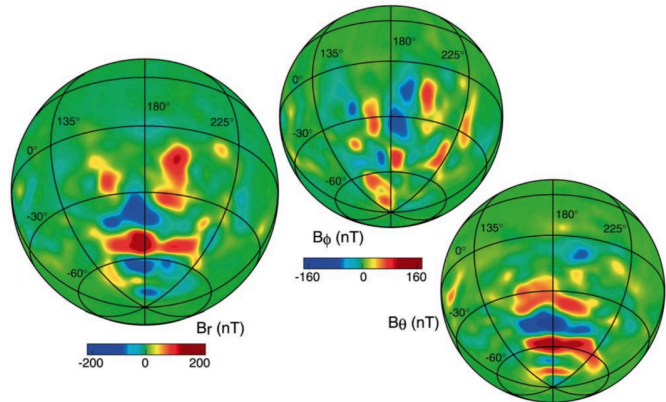
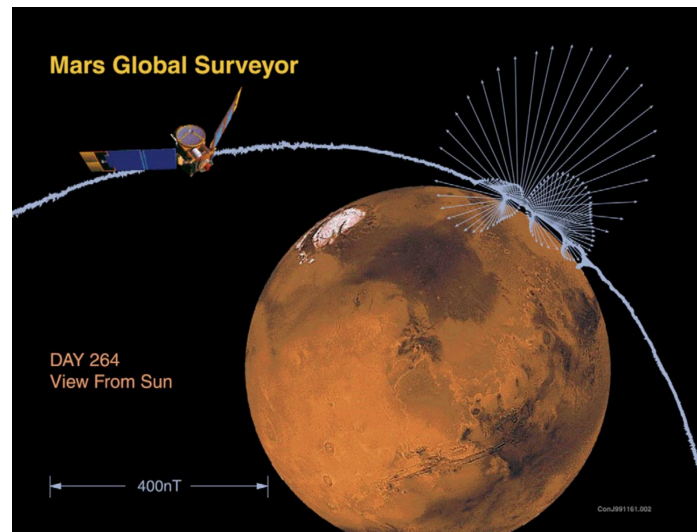


Figure 2. Orthographic projections of the three components of the magnetic field (B_r , B_θ , B_ϕ) at a nominal 400 km mapping orbit altitude, viewed from 30 deg S and 180 deg East longitude (after Connerney *et al.*, 2001).

The diagram to the upper right shows the components of Mars' magnetic field, with red showing an outward magnetic field (a north pole near the surface) and blue showing inward magnetic field (a south pole near the surface). The diagram to the right shows the complex arrangement of magnetic vectors measured by Mars Global Surveyor as it passed close to the Martian surface during its mission.



What does the lack of a substantial planetary magnetic field mean for humans on Mars?

The lack of a substantial planetary magnetic field means that the Martian surface has essentially no shield from particles in space. The Martian atmosphere is quite thin as well, so Mars is essentially exposed to all of the cosmic rays—high-energy particles—flying around in interplanetary space. While the magnetic field in the solar wind protects the inner solar system to some degree by pushing cosmic rays away, cosmic radiation in space is still at a level that is

quite dangerous for human life. In addition, the Sun produces occasional blasts of material and magnetic field called coronal mass ejections (CMEs). These fast-moving clouds pile up the solar wind in front of them and produce shock waves, which in turn produce high energy particles called Solar Energetic Particles (SEPs), some of which are travelling almost the speed of light. Even when there are no blasts of CMEs from the Sun, the solar wind from different parts of the Sun can have different speeds. Fast wind catches up to slow wind, compressing it, eventually producing a shock wave, which yields more SEPs. All of this means that interplanetary space is full of high energy particles that are dangerous for humans. On Earth we are protected by our atmosphere and magnetic field. Mars provides no such protection.

Astronauts on the way to Mars will have to be shielded, probably by living inside the center of the water tank or other dense material since only a thick blanket of matter can stop the high energy particles. Once on Mars, humans will have to dig a shelter or find a cave, and do it quickly before they get a lethal dose of radiation. Once they have shelter, they will still need to limit the time they spend on the surface. Space weather prediction will provide critical information about when the Martians can expect a radiation storm. They will want to stay sheltered at all costs during those times. In the distant future, if we terraform Mars to provide it with a thick, breathable atmosphere, that atmosphere will be an effective shield against space radiation, but Martians will still get a significantly bigger dose of cosmic rays compared to Earthlings because of the lack of a magnetic field.

- A. Envision that NASA is one day able to collect and transmit data about magnetic fields for various planets outside of the solar system to look for inhabited or inhabitable planets. Using the information above, what kind of information might scientists be able to glean about the planet in general, as well as the planet's inhabitability from magnetic field readings?

Assuming that the planet in question is near a star not unlike our own (which would probably need to be the case, if it was an inhabitable planet), planets with a very weak field would likely be uninhabitable and not worth exploring. Although they might have been inhabited at one time, any living organisms would have likely been destroyed.

Next Generation Science Standards (NGSS)

Disciplinary Core Ideas (DCI's): Grades 9-12

High School Earth Science

1. **HS-ESS2.A.2 Earth and Space Science - Earth's Systems:** *Evidence from deep probes and seismic waves, reconstructions of changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle, and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior. NOTE: Partial alignment only to the first sentence of the DCI.)*

High School Physical Science

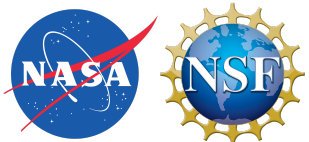
1. **HS-PS2.B.2 Physical Science-Forces and Interactions:** *Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. Strong, explicit correlation*
2. **HS-PS4.B.2 Physical Science-Electromagnetic Radiation:** *Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. Implicit correlation: can be easily introduced with class discussion of how Earth's magnetic field deflects ionizing radiation away from our planet's surface.*

Science and Engineering Practices: Grades 9-12

1. **Developing and Using Models:** *Develop and/or revise a model to predict and/or describe phenomena.*
2. **Planning and Carrying Out Investigations:** *Plan and conduct an investigation to produce data to serve as the basis for evidence.*

Crosscutting Concepts: Grades 9-12

1. **Systems and System Models:** *Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.*



Find more teaching resources at aapt.org/Resources/SSEC

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