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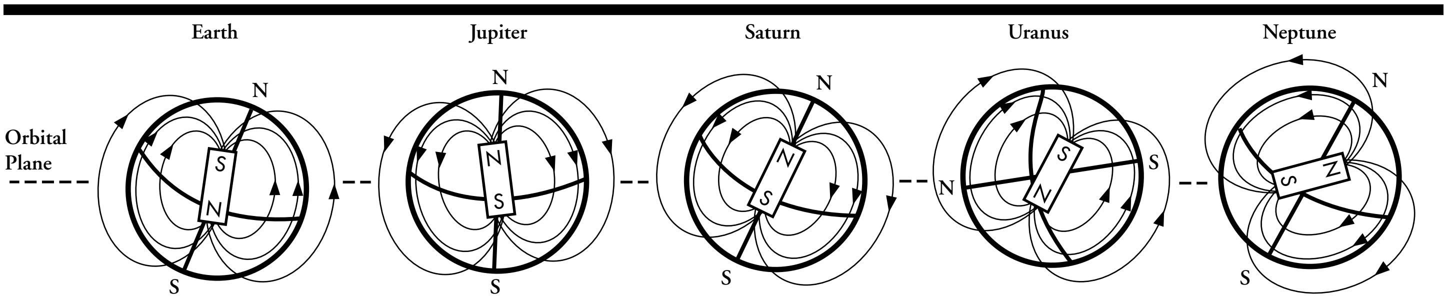
Educational Brief

CASSINI SCIENCE INVESTIGATION

Planetary Magnetic Fields



In this diagram of Earth, Jupiter, Saturn, Uranus, and Neptune (not to scale), the magnetic axes are shown by the bar magnets; the planet's orbital plane is the dotted line through the center of the diagram. This drawing also shows that a planet's rotational axis is not necessarily perpendicular to its orbital plane. Magnetic field lines extend into space and form a "cage" around the planet, trapping charged particles and sweeping them around in space as the planet rotates.

Objective

To demonstrate magnetism and its measurement and apply these concepts to understanding the structure of surrogate planets; to take three measurements with a magnetic compass and deduce the orientation of the magnetic fields in manufactured "planets."

Time Required: 1–2 hours over 1–2 days, depending on options exercised

Saturn System Analogy: Saturn's magnetosphere

Keywords: Compass, Dipole, Geomagnetic Field, Magnet, Magnetometer, Planet

MATERIALS

- Bar magnet(s) (available at toy, hardware, office supply or fabric store) or cow magnet(s) (available at veterinary or farm supply store); must be strong
- Rubber balls (approximately the size of a tennis ball)
- Pencil(s) or dowel(s)
- Magnetic compass(es), liquid-damped recommended

Discussion

The interiors of planets may forever remain out of the realm of direct observation and measurement. Yet, by means of laboratory experimentation, theoretical studies, and external observations, scientists can infer many details about the conditions found deep inside a planet. One external observation directly related to conditions in the core of a planet is that of the shape and orientation of the planetary magnetic field.

Spacecraft carry instruments called magnetometers to measure the field strength and direction of planetary magnetic fields. These instruments are so sensitive that they must be mounted on long booms extending from the main body of the spacecraft. Otherwise they would pick up magnetic fields generated by flowing electrical currents and permanent magnets aboard the spacecraft.

Earth, Jupiter, Saturn, Uranus, and Neptune all have magnetic fields that can be described as offset tilted dipoles. A dipole describes a system having two polarities such as the north and south of a bar magnet. "Tilted" refers to the alignment of the dipole with respect to the rotation axis of the planet, that is, how well the positions of the magnetic poles match the positions of the geographic poles. Offset describes the position of the dipole relative to the center of the planet. The center of the dipole may be shifted away from the planet's center both outward from the center and toward one of the geographic poles.

Planetologists believe that planetary magnetic fields are generated by a dynamo effect within the core of a planet. The dynamo effect occurs when moving electrical charges generate magnetic fields. Such processes are believed to occur deep inside some planets, based on the observation of their external magnetic fields. A spacecraft like Cassini can measure these magnetic fields, including their strength and direction, at a large number of places around Saturn, from the equator to near the poles and from nearby and far away. This allows detailed characterization of Saturn's magnetic field and permits the construction, within a computer, of good models of the generating source.

In this activity, students can observe the effects of a simulated planetary magnetic field and infer details about its source. The complexity of the planetary field can be specified by the instructor.

Procedure

Test "planets" made from bar magnets and balls can be made as either demonstrators or mysteries for students to solve. The length of the magnet, compared to the diameter of the ball, may be the determining factor. The simplest construction method is to bore a hole in each ball and place a magnet inside, held either by friction or with rubber cement. The holes or protruding magnet ends will give away the orientation of the magnet.

Alternatively, balls whose diameters exceed the lengths of the magnets can be cut in half. A section of one (for radial offset) or both hemispheres (for no or axial offset only) can be hollowed out. The magnet is placed in the hollow and the hemispheres are glued together again.

Make several "planets" and decide in advance on a prime meridian for each (draw a 0-degree longitude half-circle connecting the north and south geographic poles). Construct "planets" with no offset or tilt, and others with different amounts of offset, tilt, and both. More elaborate "planets" with more than one magnet can also be constructed (and have some similarity to the more complex magnetic fields of real planets). Use a pencil or dowel jammed into one pole of each "planet" to mark the rotation axis and as a handhold for experiments. Each "planet" can have more than one pole and prime meridian; color code and number them. Thus, each "planet" becomes several "planets" for experimentation.

For demonstrations to the whole class, a large, transparent compass (available from sporting goods stores) can be placed on an overhead projector. The class can observe the projected motions of the compass needle as various "planets" are slowly rotated nearby.

Alternatively, each student or group of students can make their own measurements. The compass should be placed on the edge of a nonmagnetic surface (ideally, each student's desk). Students should observe the effect of slowly rotating the "planet" about its axis from at least two positions of the compass. One position should be in the plane of the equator. The other should be near one pole. One can predict the idealized effect of the "planet" on the compass as follows:

No offset, no tilt — From both positions, the compass points towards the "planet," with no effects visible due to rotation.

Radial offset, no tilt — From both positions, the compass points towards the "planet," but rotation will cause the compass needle to be displaced a small amount in either direction from some zero-point.

Axial offset, no tilt — Three measurements, at the equator and near both poles, may distinguish a geographic offset. Otherwise, the compass will point towards the "planet," with no effects visible due to rotation. Additional measurements made at a different distance may help to indicate this offset.

No offset with small tilt — With an equatorial measurement, the compass will point towards the "planet," with no effects visible due to rotation. Polar measurements will show oscillating displacements with rotation. A different end of the needle will point towards either pole.

No offset with tilt near 90 degrees — The equatorial measurement shows the needle reversing direction; i.e., rotating in step with the rotation of the "planet." Polar measurements show little difference from the equator measurement.

Offset and tilt — Measurements at the equator and both poles and at two distances should allow the observer to distinguish the degrees of offset and tilt of the internal dipole. Similar measurements of "planets" with multiple dipoles can sort out their more complex magnetic fields.

Extension

Let students build their own "planets" by embedding a magnet and pencil in clay. They can then exchange "planets" and determine the orientation of the hidden magnet.

Locate Earth's geomagnetic poles on a globe or world map. There is clearly a tilt; is there an offset?

Several vendors offer directional magnetic field sensors and software that allow data to be acquired, recorded, and plotted under computer control. Many spacecraft acquire all their data via computer control, and computerized data acquisition is common in many laboratories on Earth.

Science Standards

A visit to the URL http://www.mcrel.org yielded the following standards and included benchmarks that may be applicable to this activity.

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that magnets can be used to make some things move without being touched.

LEVEL 2 (GRADES 3–5)

Knows that magnets attract and repel each other and attract certain kinds of other materials (e.g., iron, steel).

Knows that when a force is applied to an object, the object either speeds up, slows down, or goes in a different direction.

Knows the relationship between the strength of a force and its effect on an object (e.g., the greater the force, the greater the change in motion; the more massive the object, the smaller the effect of a given force).

11. Understands the nature of scientific knowledge.

LEVEL 2 (GRADES 3–5)

Knows that good scientific explanations are based on evidence (observations) and scientific knowledge.

Knows that scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations.

Knows that scientists review and ask questions about the results of other scientists' work.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

Knows that learning can come from careful observations and simple experiments.

Knows that tools (e.g., thermometers, magnifiers, rulers, balances) can be used to gather information and extend the senses.

LEVEL 2 (GRADES 3–5)

Knows that scientific investigations involve asking and answering a question and comparing the answer to what scientists already know about the world.

Knows that scientists use different kinds of investigations (e.g., naturalistic observation of things or events, data collection, controlled experiments), depending on the questions they are trying to answer.

Plans and conducts simple investigations (e.g., formulates a testable question, makes systematic observations, develops logical conclusions).

Uses appropriate tools and simple equipment (e.g., thermometers, magnifiers, microscopes, calculators, graduated cylinders) to gather scientific data and extend the senses.

Knows that different people may interpret the same set of observations differently.

LEVEL 3 (GRADES 6–8)

Designs and conducts a scientific investigation (e.g., formulates hypotheses, designs and executes investigations, interprets data, synthesizes evidence into explanations, proposes alternative explanations for observations, critiques explanations and procedures).

Uses appropriate tools (including computer hardware and software) and techniques to gather, analyze, and interpret scientific data.

Establishes relationships based on evidence and logical argument (e.g., provides causes for effects).

LEVEL 4 (GRADES 9–12)

Understands the use of hypotheses in science (e.g., selecting and narrowing the focus of data, determining additional data to be gathered; guiding the interpretation of data).

Designs and conducts scientific investigations (e.g., formulates testable hypotheses; identifies and clarifies the method, controls, and variables; organizes, displays, and analyzes data; revises methods and explanations; presents results; receives critical response from others).

Knows that, when conditions of an investigation cannot be controlled, it may be necessary to discern patterns by observing a wide range of natural occurrences.

***Teachers** — Please take a moment to evaluate this product at* http://ehb2.gsfc.nasa.gov/edcats/educational_brief.
Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.

Student Worksheet — Planetary Magnetic Fields

Procedure

The teacher will construct some different "planets" for the experiment.

1. Place the compass on the edge of a horizontal nonmagnetic surface.
2. Hold the "planet" near the compass. The compass should be at the "planet's" equator.
3. Rotate the "planet" slowly. Observe the effect on the compass of the "planet" slowly rotating about its axis.
4. Move the "planet" above the compass and repeat.
5. Repeat the experiment by placing the "planet" below the compass.
6. Repeat with different "planets."

Observe how the compass behaves in each position.

Questions

How did the different "planets" affect the compass differently?

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How was the compass affected differently when the "planet" was placed above, below, and at the compass' level?

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If you assume a simple bar magnet is hidden in each "planet," figure out how the magnet is oriented in each "planet."

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