Studying Simulated Planetary Magnetic Fields

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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 precision magnetometers to measure the field strength and direction of planetary magnetic fields. Earth, Jupiter, Saturn, Uranus, and Neptune all have magnetic fields that can be described as offset, tilted dipoles. Dipole describes 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.

Spacecraft like Galileo, Cassini, Mars orbiters, and numerous Earth orbiters measure planetary magnetic fields, including their strength and direction, at a large number of places around the planet being studied, from the equator to near the poles and from nearby and far away. This allows detailed characterization of the 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 determined by the instructor.

Materials
- bar magnets or cow magnets; must be strong (sources: bar magnets - toy store, office supply store, or fabric store; cow magnet - veterinary or farm supply)
- Rubber balls or clay for making “planets” (approximately the size of a tennis ball)
- Pencil(s)
- Vernier magnetic field sensor(s), interface, and computer+monitor

Procedure
Test "planets" made from bar magnets and solid rubber balls or clay can be made as either demonstrators or mysteries for students to solve.

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 its rotation axis and as a handhold for experiments. Each "planet" can have more than one geographic pole and prime meridian; color code them. Thus, each "planet" becomes several "planets" for experimentation.

The magnetic field sensor 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, and preferably three, positions. One position should be in the plane of the equator. The other(s) should be near the pole(s).

Example

In the Figure 1, Planet “Alamo” (the source of the ball) was slowly rotated while the computer collected data from three Vernier magnetic field sensors situated near Alamo’s poles and equator. All three sensors show the field strength changing in phase so we infer that the dipole source is offset radially from the center but not tilted. Additional measurements would help us decide if there is an offset towards the “green” pole or if the sensor was simply closer to it than the other sensors were to the dipole. Note how noisy the green sensor is compared to red and blue, but the shapes of the curves are all similar.

In Figure 2, a model of Earth was measured. The red and green signals are out of phase, measuring the opposite polarities of the dipole. The red sensor might be closer to the pole or more sensitive based on the larger signal it is generating. Measurements at different distances would resolve this ambiguity. The modulation displayed by the blue, equatorial sensor, in phase with the red signal, tells us that the dipole is offset from the rotation axis such that the pole measured by the red sensor is closer to the equator. So this model demonstrates an offset, tilted dipole in its magnetic signature.

A lower “tech”, but more detailed discussion of this activity may be found at http://eis.jpl.nasa.gov/cassini_epo/education/pdfs/Planetary_Magnetics.pdf .

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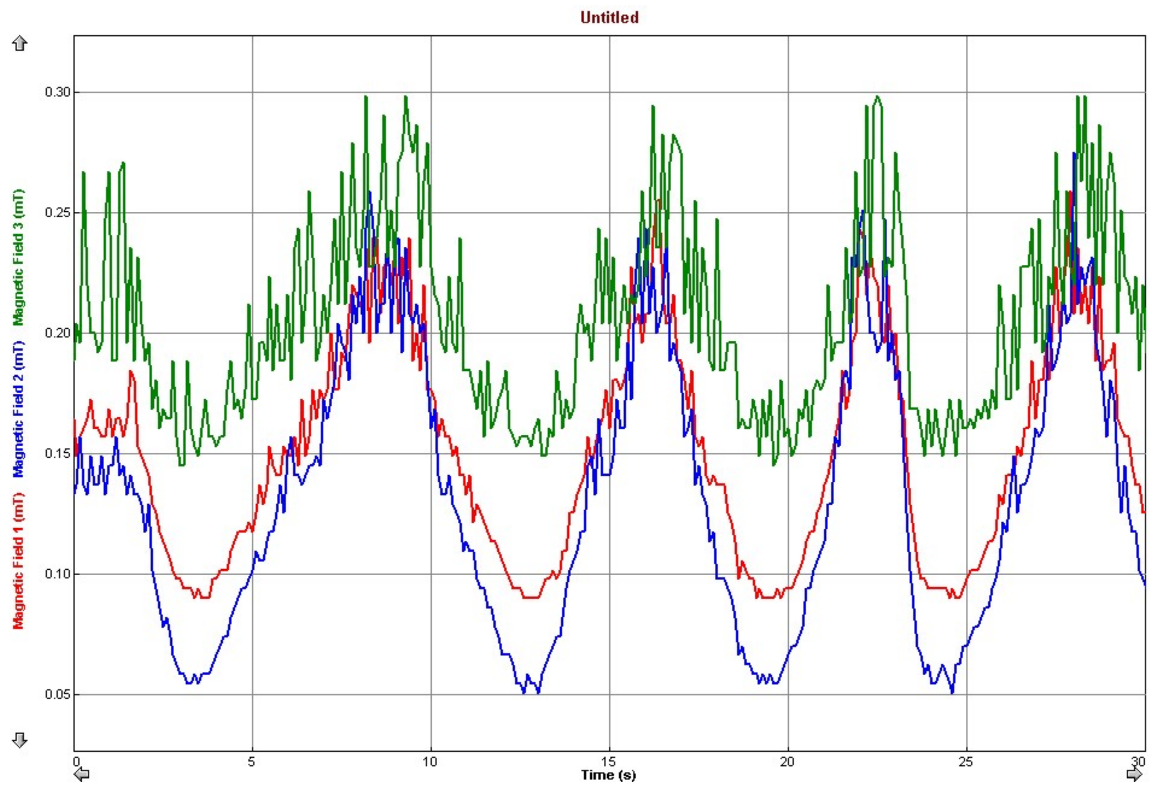

Figure 1. Simulated Planet Alamo's magnetic field displayed over several rotations.

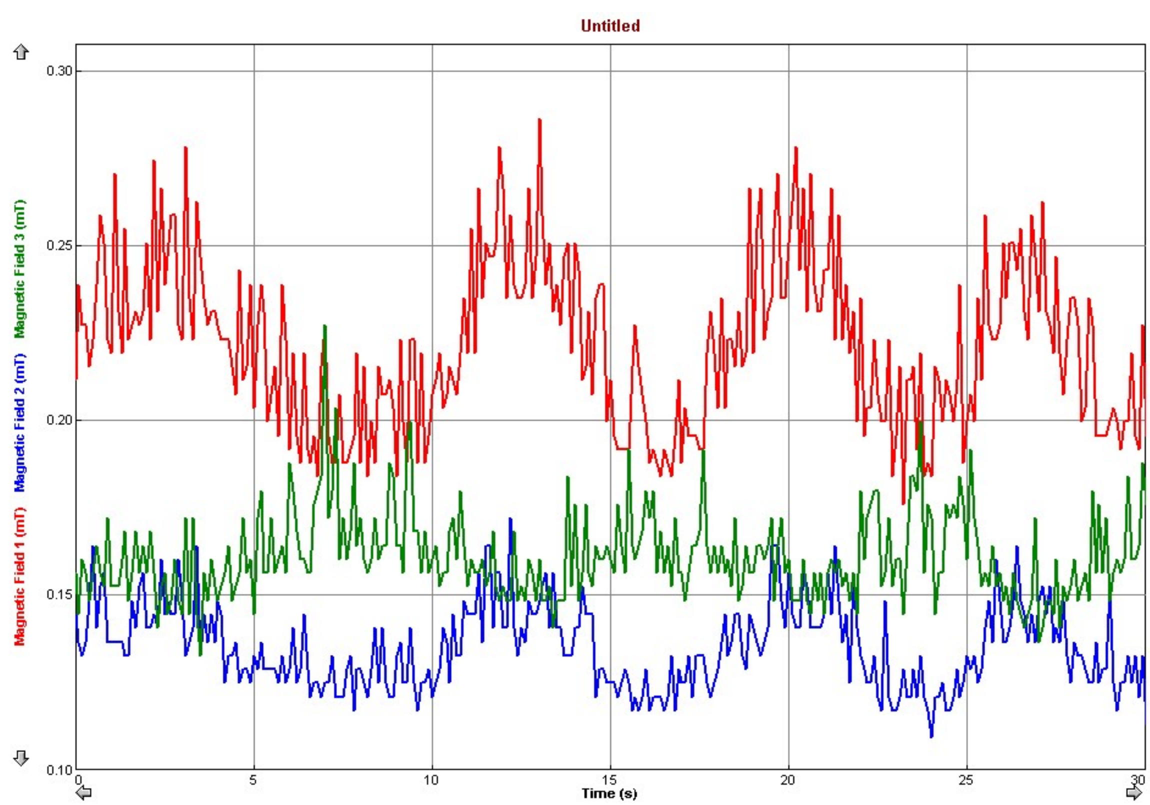

Figure 2. Simulated Planet Earth's magnetic field displayed over several rotations.