National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-011-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Finding Worlds That Look Like Stars

Objective

To demonstrate methods developed by astronomers to discover asteroids, comets, and variable and exploding stars.

Time Required: 1 hour

Saturn System Analogy: Discovering new moons in the Saturn system

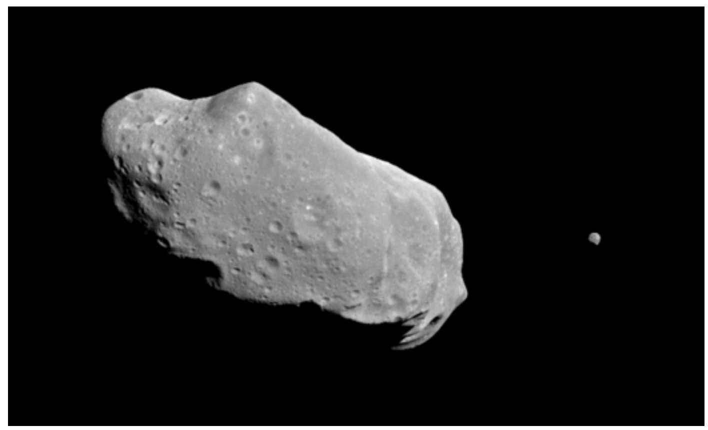
Keywords: Asteroid, Comet, Discovery, Positive/Negative Pair

MATERIALS

- Overhead projector
- Transparencies and paper copies of sample sky charts

Discussion

Discovering new objects or changes in the sky is a daunting process. Thousands of stars are visible to the unaided eye, and the numbers increase geometrically as counts continue to fainter and fainter telescopic limits. Astronomers searching the sky for discoveries take advantage of characteristics of the eye-brain combination to make changes and new objects in the sky apparent. Evolution has given humans stereo vision and great sensitivity to movement. Technology has made data recording and transformation possible. Utilizing these permits astronomers to discover new asteroids, comets, variable stars, and exploding stars.



Asteroids Ida and smaller Dactyl, as seen by the Galileo spacecraft.

The star charts included with this activity (see page 4) show Saturn in three positions as it approaches and moves by the star Regulus in the constellation Leo (the lion). The ancients were aware of Mercury, Venus, Mars, Jupiter, and Saturn by observing just such motions, and their observations can be easily repeated during the right times of year (winter and spring, 2002–2008). A well-built telescope and meticulous visual observing by William Herschel led to the discovery of Uranus. Mathematical studies of the motions of Uranus carried out independently by John C. Adams and Urbain Leverrier led to the prediction and subsequent discovery of Neptune. Pluto was discovered after a careful photographic search of the sky.

The first asteroid was discovered by accident, but the next several hundred asteroids orbiting the Sun between Mars and Jupiter were discovered by careful visual searches. Now more than 30,000 asteroids are known, the bulk of them discovered photographically or with electronic imagers.

Procedure

The star charts included with this activity are exact copies of each other. The ones showing white stars on a dark sky should be referred to as positives. The ones showing black stars on a white sky should be called negatives. By combining a positive and a negative, a subtraction of the images is made. This so-called "difference image" will show any changes or differences between the pair of originals being compared.

Make one transparency of the positive and negative sheets and cut each transparency to separate the three frames. This will be sufficient for a classroom demonstration with an overhead projector. If desired, a transparency and paper pair (one each positive and negative, either whole or in thirds) can be distributed to the students for their own experimentation individually or in groups.

For the classroom demonstration, use transparencies of both the positive and negative charts. Carefully overlay any one positive on any one negative. When the stars are accurately aligned, a uniform gray surface will be seen (though stars may not perfectly cancel out), with the exception of any waiting discoveries. The object to be discovered will be seen in two places. It will appear as a black spot in an area of gray sky or as a white spot where gray would be expected. The movement of the planet over the course of a few days causes the differences in positions.

Be prepared for poor alignment of the fixed stars. This can be caused by distortion introduced by the photocopier in making the transparencies and the paper copies. Make an initial pair of photocopies in advance to confirm that distortion isn't a problem. If distortion is a problem, try copying each individual frame separately, centered on the copier's copy surface. The distortion is likely more pronounced near the edges of the copies.

After illustrating the technique using the projector, distribute random positive/negative paper/transparency pairs for the students to make their own discoveries. Each student (or group of students) should have at least one transparent copy and one paper copy, one being positive and the other negative.

Extension

Image differencing is commonly found in image processing software. Scanned images of terrestrial or celestial scenes can be differenced and studied for changes.

Two of the most successful comet and asteroid hunters, Eleanor Helin and Carolyn Shoemaker, use a different technique for making their discoveries. Two photographic images taken in the same direction but at different times are aligned under a stereo microscope. The stereo microscope feeds one image to one eye and the other image to the other eye. The brain then melds the two images. Any changes will not meld properly and will be seen as an object above or below the plane of the rest of the image. This can be attempted in the classroom with inexpensive (or expensive!) stereoviewers, if available, or without magnification.

Place two different paper images, aligned and immediately next to each other, on a tabletop. Hold a card, roughly 12 centimeters high, vertically between the pictures. Lean down and place the middle of your nose on the card, forcing one eye to see one picture and the other eye to see only the other picture. Do additional alignment of the pictures if necessary and then merge the images (this takes practice!) and look for spots "floating" above or below the main image. The floating spots are differences between the two pictures. Note that the lighting has to be similar on both sides of the nose-card for this to work well.

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.

2. Understands Earth's composition and structure.

LEVEL 3 (GRADES 6–8)

Knows that fossils provide important evidence of how life and environmental conditions have changed on Earth over time (e.g., changes in atmospheric composition, movement of lithospheric plates, impact of an asteroid or comet).

3. Understands the composition and structure of the universe and Earth's place in it.

LEVEL 3 (GRADES 6–8)

Knows characteristics and movement patterns of asteroids, comets, and meteors.

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that the position of an object can be described by locating it relative to another object or the background.

LEVEL 2 (GRADES 3–5)

Knows that an object's motion can be described by tracing and measuring its position over time.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

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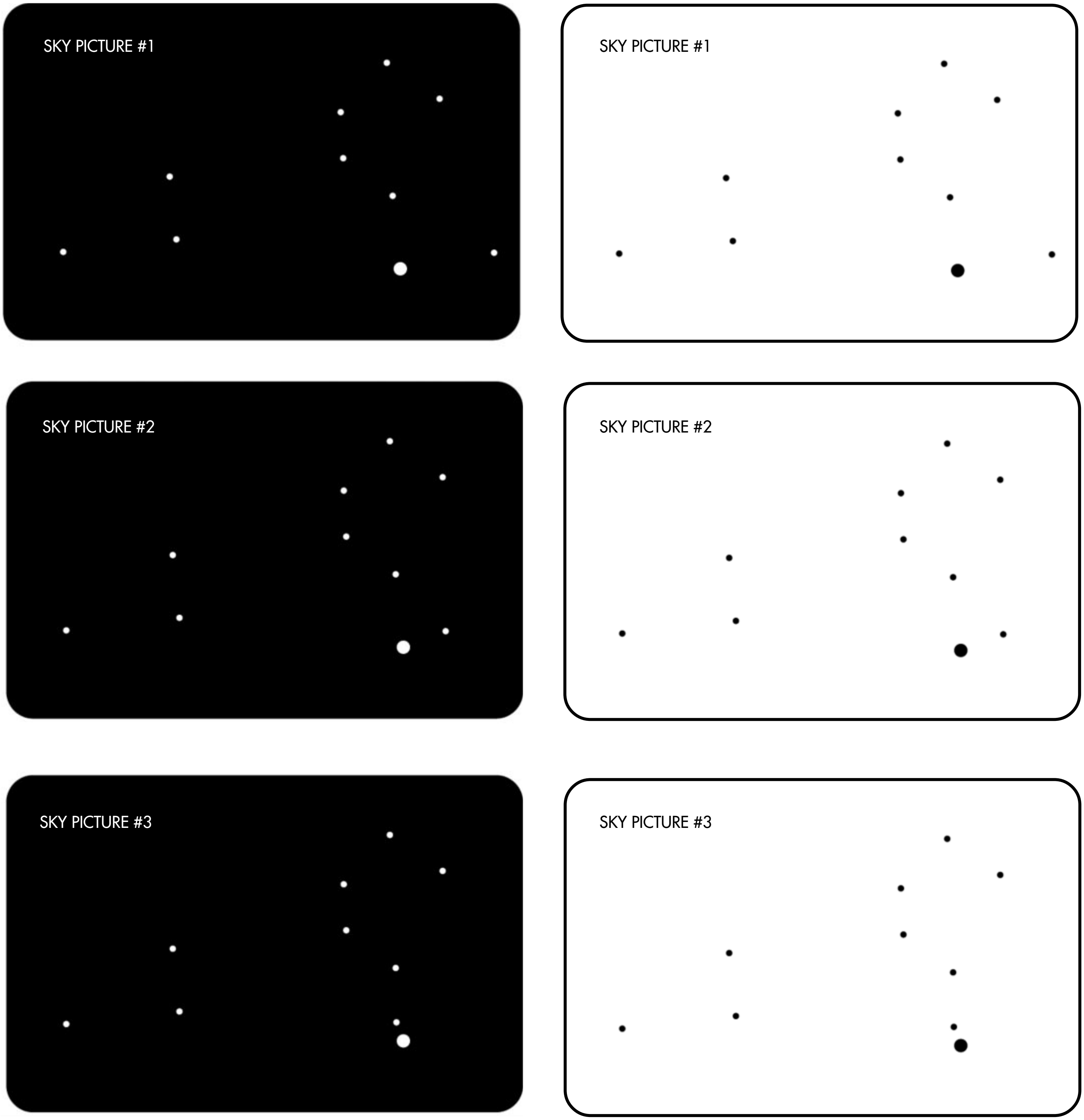


These "sky pictures" in positive (white stars on dark sky) and negative (black stars on white sky) show Saturn in three positions as it approaches and moves by the star Regulus in the constellation Leo. The pictures are separated in time by approximately one month. Astronomers frequently use negative images of star fields for detailed studies because black stars on a white background are easier to see.

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 1–4

EB-2001-12-012-JPL

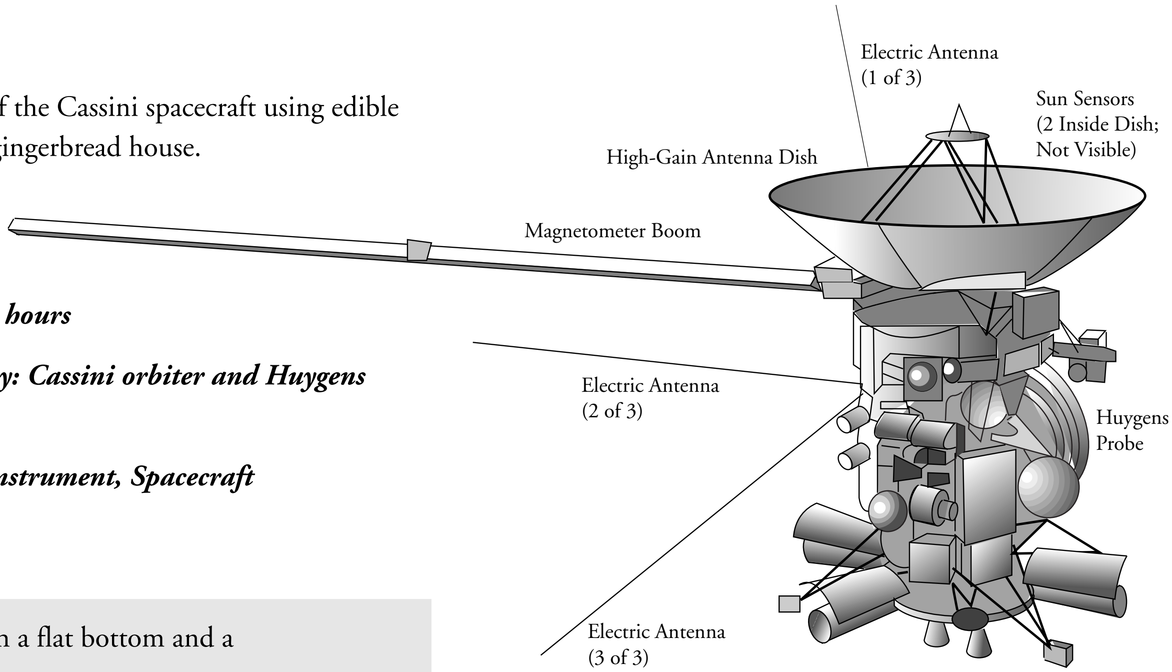
Educational Brief

CASSINI SCIENCE INVESTIGATION

Gingerbread Spacecraft

Objective

To construct a model of the Cassini spacecraft using edible products, much like a gingerbread house.



Time Required: 1 to 2 hours

Saturn System Analogy: Cassini orbiter and Huygens probe

Keywords: Antenna, Instrument, Spacecraft

MATERIALS

- Ice cream cone with a flat bottom and a cup-like top
- Cake mix (made according to box instructions)
- Cake frosting — or “ornamental” frosting (gingerbread house frosting), which adheres more effectively than standard cake frosting
- Chocolate wafer candy bar
- Candy mint still in its wrapping (preferably a metallic wrapping, or wrap it in aluminum foil)
- Small marshmallows
- Piece of licorice
- Small, disk-shaped candies (e.g., M&M’s®)

Discussion

Major portions of a spacecraft can be easily modeled using edible components. In this activity, students “construct” an edible “spacecraft” featuring some of the major components of the real thing. As illustrated, the Cassini spacecraft features a large dish antenna for communicating with Earth mounted on the main body of the spacecraft. A long boom out the side carries a magnetometer, an extremely sophisticated compass for measuring the direction and strength of a planetary magnetic field. It represents one of many scientific instruments aboard. Sun sensors near the main antenna represent one of the engineering subsystems on the spacecraft.

Procedure

1. Fill the ice cream cone 2/3 full of cake mix. Bake according to the cake mix instructions, just as for a cupcake.
2. Place a layer of frosting on top of the "cake."
3. Fold the licorice in half and poke the ends into the cake. The licorice should make an inverted V sticking out of the cake. This represents the support structure on the interior of Cassini's high-gain antenna dish.
4. Using frosting as glue, place two disk candies around the inside of the top of the ice cream cone. These represent the Sun sensors that tell the spacecraft where the Sun is.
5. Cut a hole in the ice cream cone right under the cake "antenna." Insert the chocolate wafer into the cone. Using frosting as glue, place a marshmallow on the end of the chocolate wafer. This represents the magnetometer boom.
6. Holding the cone with the chocolate wafer pointing to the right, take the candy mint and attach it to the side of the cone that is facing you. Use frosting as glue. This represents the Huygens probe.

Extension

Using a diagram of the spacecraft and some imagination, add additional instruments and engineering components onto your spacecraft. For a more detailed listing of Cassini's subsystems, visit *http://saturn.jpl.nasa.gov/cassini/english/spacecraft/* or order a copy of the "Ways of Seeing" CD-ROM at *http://saturn.jpl.nasa.gov/cassini/english/products/*. The "Saturn Educator Guide" (available for download at *http://saturn.jpl.nasa.gov/cassini/english/teachers/activities.shtml*) includes an activity associating Cassini's subsystems with analogs from everyday life.

Technology Standards

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

4. Understands the nature of technological design.

LEVEL 1 (GRADES K–2)

Knows that both objects and systems occur in nature (e.g., stars and the solar system), but people can also design and make objects and systems (e.g., telephones and communication systems) to solve a problem and to improve the quality of life.

5. Understands the nature and operation of systems.

LEVEL 2 (GRADES 3–5)

Knows that when things are made up of many parts, the parts usually affect one another.

Understands the relationships between elements (i.e., components, such as people or parts) in systems.

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National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-004-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Venus: A Global Greenhouse

Objective

To take temperature measurements in closed systems over time to demonstrate "greenhouse warming," which is observed in greenhouses and in planetary atmospheres like those of Venus, Saturn's moon Titan, and possibly Earth's.

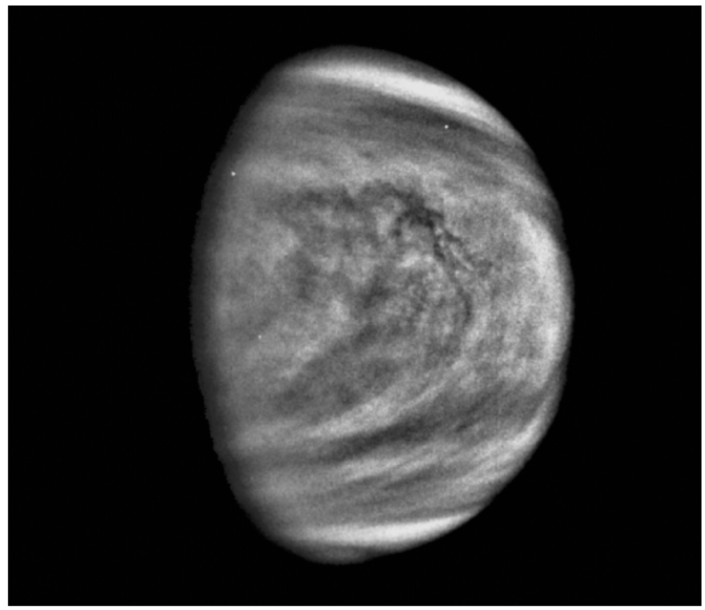
Time Required: 2–3 hours

Saturn System Analogy: Titan

Keywords: Equilibrium, Greenhouse, Titan, Venus

MATERIALS

- Bottles of different colors (similar size and shape) with labels attached. *Glass bottles are recommended to ensure the apparatus remains stable.*
- Bottle caps or corks to seal each bottle
- Thermometers (one per bottle, plus one extra)
- Notepaper for recording data
- Graph paper for plotting data
- Stiff cardboard (small pieces)

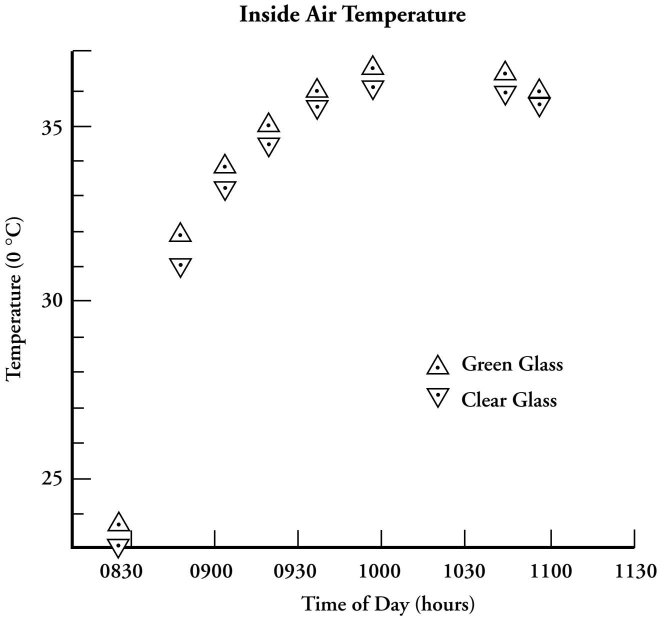


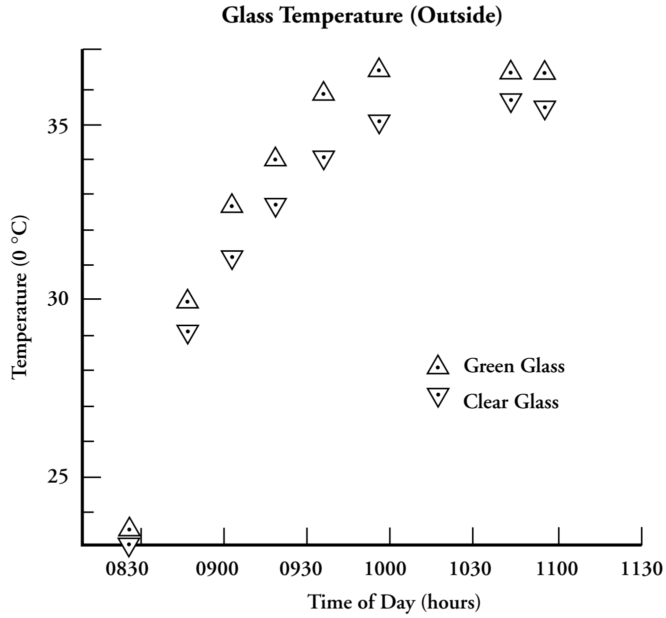
Venus as seen by the Galileo spacecraft. A special filter was applied to emphasize the contrasts in the clouds.

Discussion

Nearly everyone has heard about the "greenhouse effect," the natural process by which infrared energy (heat) is trapped in the atmosphere. The primary greenhouse gases are water (H_2O) vapor, carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). The heat trapped by atmospheric greenhouse gases can raise the average surface temperature of Earth by 35 kelvins (degrees Celsius).

Venus presents an extreme example of the greenhouse effect. The greenhouse gas carbon dioxide is the most abundant chemical (96 percent) in the Venusian atmosphere. The large





Examples of "greenhouse bottle" plots.

quantity of carbon dioxide helps boost the average surface temperature of Venus to more than 450 °C (over 900 °F). In contrast, the atmosphere of Titan, Saturn's largest moon, warms the surface just a few degrees higher than if there were no atmosphere at all.

A simulated greenhouse effect can be demonstrated using common household materials.

Procedure

Prior to the experiment, drill the bottle caps (or corks) to snugly hold the thermometers; there should be some freedom to change the thermometer depth in the bottle. The extra thermometer should be suspended, out of contact with anything but air, and shaded with the cardboard.

Insert the thermometers into the bottle caps (or corks), and then cap each bottle. Place the bottles together in sunlight, either upright or on their sides (prevent them from rolling), and determine that they will not cast shadows on one another over the course of the experiment. Also, ensure the labels will shade the thermometer bulbs for several hours. (If a bulb is exposed to direct sunlight, a false reading may result.) Place the open air thermometer alongside the bottles, also ensuring the bulb remains in the shade. Record the temperatures of each thermometer at regular intervals every 10–15 minutes for at least 2 hours. After collecting the data, plot the temperatures versus the recorded times and interpret the results.

You could do this experiment over a couple of class periods with the first class setting up and starting the experiment and the second class continuing to record the data. After combining the data, both classes can plot the temperature versus the time and interpret these data.

Scientific Note

"Greenhouse effect" is really a misnomer for atmospheric heating by gases. A greenhouse for growing flowers or vegetables on Earth is heated by sunlight falling on the vegetation, which warms up and heats the air trapped in the enclosure. This same process warms the air in the demonstration bottles. A planetary atmosphere is warmed by the absorption of infrared photons by molecules of the atmospheric gases.

Additional Experiments and Questions

1. Why do some bottles warm the air inside faster than other bottles? Do they reach the same equilibrium temperatures?
2. Do the internal temperatures behave differently if the bottles are open to the outside air?
3. What happens if a few drops of water are placed in the bottles?
4. What happens if dry ice sublimates and displaces the air in a bottle? (Don't seal until the dry ice is gone!)

Extension

Several vendors offer temperature 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.

9. Understands the sources and properties of energy.

LEVEL 1 (GRADES K–2)

Knows that the Sun supplies heat and light to Earth.

Knows that heat can be produced in many ways (e.g., burning, rubbing, mixing substances together).

LEVEL 2 (GRADES 3–5)

Knows that heat is often produced as a by-product when one form of energy is converted to another form (e.g., when machines and living organisms convert stored energy to motion).

LEVEL 3 (GRADES 6–8)

Knows that heat energy flows from warmer objects to cooler ones through conduction, convection, and radiation.

Knows how the Sun acts as a major source of energy for changes on Earth's surface (i.e., the Sun loses energy by emitting light; some of this light is transferred to Earth in a range of wavelengths, including visible light, infrared radiation, and ultraviolet radiation).

LEVEL 4 (GRADES 9–12)

Knows how the energy associated with individual atoms and molecules can be used to identify the substances they comprise; each kind of atom or molecule can gain or lose energy only in particular discrete amounts, and thus can absorb and emit light only at wavelengths corresponding to these amounts.

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)

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.

LEVEL 3 (GRADES 6–8)

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

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Student Worksheet — Venus: A Global Greenhouse

Procedure

1. Insert thermometers into bottle caps.
2. Place bottle caps with thermometers on bottles.
3. Place bottles together in sunlight (be sure that no bottles are shaded and that they are spaced far enough apart so that they won't shade each other over a 2-hour period).
4. Be sure that the thermometer bulbs (inside the bottles) are shaded by the bottle labels.
5. Place the open air thermometer in a shaded location (use cardboard) next to the bottles.
6. Record the temperature of each bottle as well as the shaded thermometer every 10–15 minutes for at least 2 hours.
7. After collecting data, plot temperature versus time for your "greenhouse bottles."

Describe your bottles (color and volume):

Bottle #1: ____________________

Bottle #2: ____________________

Bottle #3: ____________________

Time at start of experiment: ____________________

Time	Temperature – Open Air	Temperature – Bottle #1	Temperature – Bottle #2	Temperature – Bottle #3

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-005-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Lightning in a Planetary Atmosphere

Objective

To reproduce and study in the classroom phenomena analogous to the "flash-bang" of lightning and thunder. The observation of lightning in a planetary atmosphere indicates that active meteorology is occurring.

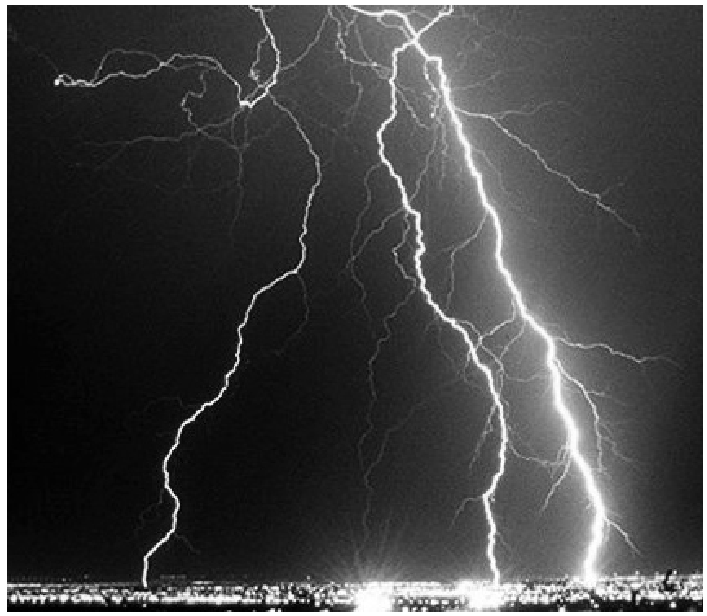
Time Required: Less than 1 hour

Saturn System Analogy: The search for lightning on Saturn and Titan

Keywords: AM Radio, Lightning, Thunderstorm, Whistler

MATERIALS

- AM radio with extending antenna (available at most variety, department, and consumer electronics stores for $5.00 and up)
- Electric barbecue lighter (available at many variety, grocery, or picnic or camping-supply stores for about $5.00). *Cigarette lighters will work but do not have as strong a spark as barbecue lighters.*
- Optional: Tesla coil, Van de Graaf generator, Wimshurst generator, or even an automobile coil. *Be careful as these can make large sparks for this demonstration!*
- Optional: oscilloscope

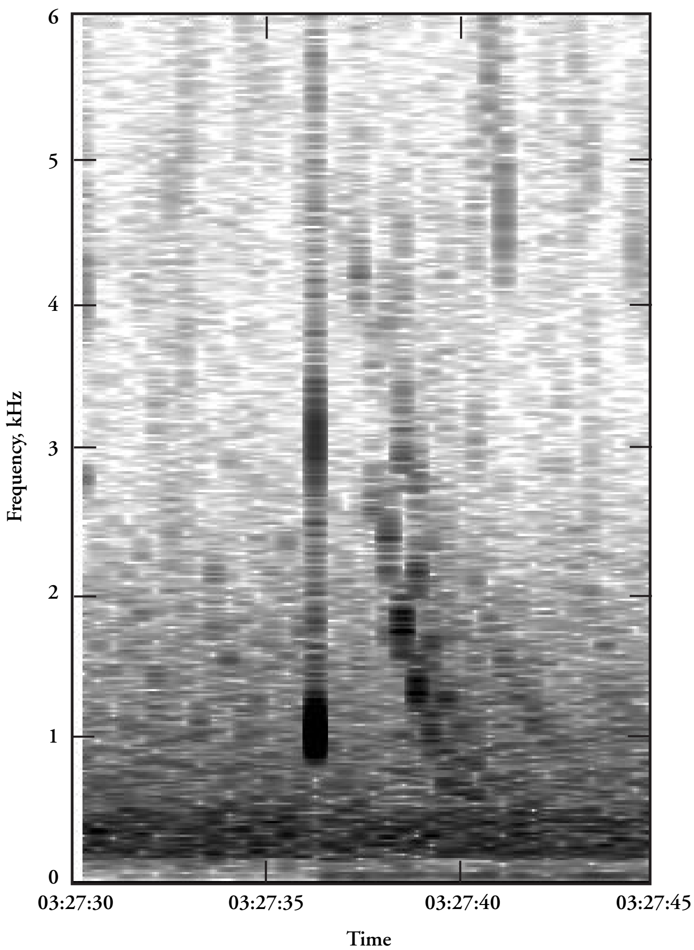


Inside a thundercloud on Earth, an enormous electrical charge builds up. When it discharges, there is a blinding flash as lightning zigzags between the ground and the cloud.

Discussion

Lightning is a phenomenon most people have experienced. The glaring flash of light is followed by booming thunder rolling across the landscape. Sometimes the bolt of lightning is seen and followed by thunder, while at other times the lightning is so distant that flashes are the only evidence of storm activity. On a smaller scale, anyone walking across a carpet on a dry (low humidity) day can produce miniature lightning. These static discharges, usually felt, are sometimes seen (in the dark), and often heard.

The phenomenon, whether spanning kilometers of atmosphere from cloud to ground or millimeters from fingertip to doorknob, has the same origin: moving electrons. Negatively charged electrons moving across a spark gap, large or small, excite atoms in the air, making them glow briefly and heating the air. The hot air expands rapidly to generate thunderclaps and static discharge snaps.



This is a picture of radio noise generated by lightning in Earth's atmosphere, as observed by Cassini's Radio and Plasma Wave Science instrument. The vertical stripe shown here just after 03:27:36 is the radio emission of a lightning discharge and is called a 'spheric (or atmospheric). Notice that the discharge generated radio noise at many frequencies from about 0.8 kHz to beyond 6 kHz, with signal strength especially strong near 1 kHz and 3 kHz. A lightning discharge also generated the curved signal, called a whistler, in the frequencies between 0.5 kHz to about 2.5 kHz that spans 03:27:38 to 03:27:41.

The acceleration of electrons during the discharge also produces radio frequency emissions. Just as lightning appears white because it generates (roughly) equivalent portions of all colors, radio emission from lightning likewise covers a broad radio frequency range.

The mechanism that separates electric charge in an atmosphere, leading to lightning, tells meteorologists about conditions in that atmosphere. Simply finding lightning alerts meteorologists that there are strong vertical movements in an atmosphere.

The Cassini spacecraft carries its Radio and Plasma Wave Science (RPWS) instrument to study, among other things, radio emissions from planets and plasma interactions. Lightning is among the emissions it can study. Lightning has distinctive radio emissions, called 'spherics (or atmospherics) and, because of their distinctive sound when the radio emission is converted to sound, "whistlers." A 'spheric is a brief burst of static across many frequencies.

A whistler presents the curved signal in the illustration and is the result of a 'spheric that has been modified during its journey to the receiver. The curvature indicates that higher frequencies of the whistler reach the receiver before the lower frequencies. This is a property of the propagation of low-frequency radio signals in a magnetized plasma (a gas of charged particles with an imbedded magnetic field — in this case, the magnetic field is that of Earth). The whistler waves propagate more or less along the magnetic field, and the longer they propagate, the larger will be the difference in arrival times between the high and low frequencies.

An analog to the RPWS receiver is the common AM radio receiver found in cars, boom boxes, stereo systems, and personal sound systems. Whereas an AM receiver is intended to select a single frequency (station) for listening, the RPWS receiver is designed to detect and record many frequencies at once.

This demonstration uses an everyday AM radio and a barbecue lighter to illustrate the broadband radio emission of lightning 'spherics.

Procedure

Turn on the AM radio and adjust the dial to the extreme low frequency end of the receiver (near 530 kHz). The volume can be set fairly high; most likely static will be heard. (If a station broadcasts at this frequency, adjust the tuner to the lowest frequency on which only static can be heard.) Place the igniter end of the barbecue lighter next to the antenna to hear the signal more easily. Trigger the lighter. Note the spark discharge inside the igniter, the snap of its miniature thunder, and the click from the radio speaker. The click is a radio emission from the discharge. (The sound of the trigger sometimes makes the snap and click hard to distinguish.)

Follow the same procedure at additional frequencies (where there is static, not a broadcasting station signal) up the radio spectrum to its maximum at about 1600 kHz. Does the click from the speaker sound different at different radio frequencies? If so, how does the sound change as you proceed up the AM dial (to higher frequencies)?

An oscilloscope attached to the radio receiver, a microphone, and/or a light sensor and set for a single sweep can record the characteristics of the barbecue lighter/thunderstorm. Some creative thinking will allow the sound of the trigger and the snap of the "thunder" to be separated in the recording. There are several possibilities.

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 4 (GRADES 9–12)

Knows that materials that contain equal proportions of positive and negative charges are electrically neutral, but a very small excess or deficit of negative charges in a material produces noticeable electric forces.

Knows that the strength of the electric force between two charged objects is proportional to the charges (opposite charges attract whereas like charges repel), and, as with gravitation, inversely proportional to the square of the distance between them.

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).

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Student Worksheet — Lightning in a Planetary Atmosphere

Procedure

1. Turn on the AM radio and adjust the dial to the extreme low frequency end (530 kHz). If there is a station transmitting at that frequency, set the radio to the lowest frequency at which no station broadcasts.

2. Set the volume at a high level so that static is heard.

3. Place the igniter end of the barbecue lighter close to the antenna.

3. Trigger the lighter.

5. Repeat the procedure for various frequencies up and down the AM dial.

Questions

Can you hear the click at the low frequency end?

Can you hear the click at higher frequencies?

How close to the antenna must the lighter be held so that the experimenter can hear the “snaps” on the radio?

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-015-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Mapping Worlds That Look Like Stars

Objective

To demonstrate methods developed by astronomers to map objects too distant to show detail when viewed with a telescope.

Time Required: 1 hour

Saturn System Analogy: The small, distant moons in the Saturn system

Keywords: Asteroid, Color, Mapping, Photometry, Reflected Light, Rotation

Asteroid Gaspra, as seen by the Galileo spacecraft.

MATERIALS

- Peanuts in their shells: 3 or 4 for classroom demonstration (or per group of students), with different sizes and shapes (small colored clay forms may also be used as alternatives) that will become “asteroids”
- Black paper, cardboard, or cloth for sky background
- Colored marking pens
- Construction paper with colors matching the artificial asteroids and/or the colors of the marking pens
- Pencils with good, flexible erasers (one per peanut-asteroid) or lightweight monofilament fishing line
- Paper clips (one per peanut-asteroid)
- Optional: large (approximately 12"×12"×18") box, one per group of students

Discussion

Most individual objects in the universe are too distant for us to discern details on their outer layers, whether they are solid planets or gaseous planets or stars. With a handful of exceptions, the surface geographies of asteroids remain a mystery. Yet, astronomers have developed many techniques that yield a wide variety of information about these objects. In particular, measurements of the light intensity and color from objects can reveal parameters like rotation rate, shape, and geographic features.

To make these measurements, astronomers measure the sunlight reflected by an asteroid over the course of hours to days. In “integrated” (white) light, the strongest signal can be measured. Over the course of time, changes will be due to the rotation of the asteroid. If the asteroid is spherical, changes in the light reflected by the surface indicate differences in the reflectivity of surface materials. If the asteroid has a more complex shape, changes in reflected light can indicate both differences in surface materials and the effects of the different illuminated cross-section presented to observers on Earth.

Astronomers usually use filters to measure brightness in a variety of colors to better discriminate between geographic features and a changing cross-section. The variation in color even provides hints to the composition of the surface. All such astronomical measurements rely on comparison with constant-brightness background stars.

Procedure

Prepare your peanut-asteroids in advance, by mounting each one in a pencil-handle: bend a paper clip around the waist of the peanut or create a cradle or clasp for the peanut, sticking one end of the paper clip into the pencil's eraser so the peanut is separated from the eraser. The pencil will be much less distracting if it is dark-colored. Alternatively, monofilament strings can be tied around the peanuts so they can be suspended. Controlling their rotation will be more difficult, however, if string is used. Set up some peanut-asteroids so that they present different cross-sections to an observer as they rotate and at least one that does not change its apparent shape as it rotates.

The background sky and comparison stars should also be prepared in advance. Use black construction paper or black cloth (black velvet is especially effective) to make the background sky, large enough (about 1 meter square) for the classroom demonstration.

Cut out at least four circles of various sizes, one whose diameter is smaller than the smallest peanut and one whose diameter is larger than the longest peanut, from the construction paper that comes closest to matching the peanuts' color. Attach (with tape or glue) these "stars" to the black background. It is convenient to also have unique numbers or letters attached near the stars so students can discuss their comparisons of the asteroid with the stars.

Set up the classroom so that the overhead projector will shine its "sun" light on the sky background that has been mounted to the wall.

Stand near the background, being careful not to obscure any stars with your body as seen by students around the room. Holding a sample peanut-asteroid, ask the students to make a judgment about how bright the asteroid appears in comparison with the stars. Realize that students looking from different angles around the room will record different brightnesses. Rotate the asteroid 90 degrees and ask them to note the brightness, repeating this three more times (to confirm that the results "close" on themselves, i.e., that they return to the starting value). Repeat these observations with other peanut-asteroids.

Compare results around the room. The students will see that as tiny as the peanut appears from their seats, they can still tell that it is rotating and they can even get a feel for its relative dimensions. They may also note that because of the different viewing angle at the far ends of the room, there is a phase shift in when maximum/minimum apparent brightness occurs.

Variation and Extension

More "stars" for comparison allow more precise estimates of brightness and that can generate smoother light curves (a plot of brightness vs. time [in this case, asteroid orientation with respect to the viewer]). The light curve will also be smoother if brightness measurements are made at intervals spaced more closely than 90 degrees of rotation. Actual brightness measurements may be possible with a photographic spot meter.

Obtain two small balls (or marbles). One should be uniform in color, and the other should be painted black on one hemisphere. Mount them in the same manner as the peanuts and have the students observe their light curves. The uniform sphere will have no variations. The two-faced sphere will demonstrate that reflectivity (albedo) variations can mimic the effects of complex shapes.

Small groups of students can make their own observations by constructing a sky box. The box should have a viewing hole in one end and a starry sky background affixed to the inside of the other end. A hole in the side or top, near the sky background, should be large enough to allow insertion of a peanut-asteroid and allow it to be rotated.

Room light through the open box top provides illumination. It should be uniform on the comparison stars and the asteroid. Problems with illumination will illustrate experimental error.

Color some significant portions of the peanuts with the colored pens. Three possibilities can be pursued for the star background: (1) Create sets of similarly colored stars (from construction paper or white paper colored with the same pens). Your background, comparison star constellations will, of necessity, have many more stars since size-sets are needed in each color. (2) Use colored filters on the sun-analog (overhead projector). (3) For a sky box, filters can be interchanged at the eye-hole, in a manner similar to the way real astronomical observations are made. Colored gift wrapping film is an easily available and inexpensive source of color filter material. Have the students perform the same observations of the asteroids, but now they have to interpret the variations they see as being due to both shape and color reflectivity. Asteroids can also be constructed from clays of different colors and tested the same way.

Several vendors offer light measuring photometry systems that acquire data and plot it under computer control. Such systems can be adapted for quantitative measurements of the "asteroids" in this activity. Computerized data acquisition is common in many laboratories and is used almost exclusively in observatories.

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.

3. Understands the composition and structure of the universe and Earth's place in it.

LEVEL 3 (GRADES 6–8)

Knows characteristics and movement patterns of the nine planets in our solar system (e.g., planets differ in size, composition, and surface features; planets move around the Sun in elliptical orbits; some planets have moons, rings of particles, and other satellites orbiting them.

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that the position of an object can be described by locating it relative to another object or the background.

LEVEL 2 (GRADES 3–5)

Knows that an object's motion can be described by tracing and measuring its position over time.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

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 — Mapping Worlds That Look Like Stars

Procedure

For each peanut-asteroid, write down the number of the "star" that has the closest brightness to the asteroid each time you are asked to make an estimate. You will do this five times for each asteroid.

Do the first and last estimates match each other? Why or why not?

What does the variation in brightness tell you about the asteroid?

Make a similar set of estimates for the colored "asteroids." Do the first and last estimates match each other? Why or why not?

Compare your lists of estimates with the lists made by other students across the room. How well do they compare? Why is there a difference?

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-021-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Observing Outer Planets

Objective

To allow students to practice making regular observations of a natural phenomenon and record appropriate data; and to understand the effect of Earth's orbital motion on objects in the sky and the apparent motion of outer planets.

Time Required: 10–20 minutes weekly for several months

Saturn System Analogy: Deep Space Network antenna tracking of Cassini during its orbital mission at Saturn

Keywords: Constellation, Planet, Prograde, Retrograde, Retrograde Loop, Rise, Set, Star

MATERIALS

- Simple Planet Orbit Chart, Star-Rise Chart, and Simulated-Motion Chart (attached to this Educational Brief — see Student Worksheet section)
- Pencil
- Straightedge
- Clipboard (or other portable writing surface)
- Freeware and shareware planetarium programs and numerous pages on the World Wide Web can provide star charts and planet positions for instructor preparation for this activity. The planets Saturn, Jupiter, and Mars are especially suitable for this activity, though Venus (and with much more difficulty, Mercury) can also be used.

Procedure

Over the course of several months, students should make weekly (or more frequent) observations of the rise time of available planets and bright stars in the night sky. Eventually, the initially observed objects will be rising in daylight; other objects can be chosen for additional work or conclusions can be drawn based on the observation set already completed.

In addition to noting rise times, students should carefully sketch on a star chart the position of the planet(s) being observed. These positions will be connected and eventually compared to the classroom planetary motion activities described below, using the simple *Planet Orbit Chart* (see Student Worksheet section in this Educational Brief).

Some variations on the observation procedure should be mentioned here. If it is more convenient to observe setting times for planets and stars, the results will be the same, in that rise and set times occur 4 minutes earlier (for stars) each day. Observations will have to be made with a precision of about 1 second for the effect of a planet's motion on its rise/set time to be determined (and that amount will be variable over the course of the planet's period of visibility in the night sky). The Moon can be used as a surrogate planet instead, with some loss of apparent phenomena. Its daily change in rise time is on the order of tens of minutes (variable, depending on time of "moonth" and season); time-measurement precision, as for star measurements, should be 1 minute or less. Newspapers often give moon rise/set times for a fixed, nearby geographical point (that will almost certainly be different from where students will observe).

A distant horizon is not a requirement for the observations. The roof of a house, the top of a skyscraper, or the highest branch of a tree can be used as a comparison point. The selected "horizon" can be well above horizontal, as long as the observer's position and the "horizon" are fixed at the same place for each observation.

Students can plot the star's time of rise/set collected daily over a few weeks' time. The slope of the line will approximate 4 minutes per day. Careful measurements of different stars made over a few weeks during each season will show small variations from the 4 minute/day value. These variations are due to the ellipticity of Earth's orbit around the Sun.

The changing time of a star's rise or set can be illustrated in the classroom with the *Star-Rise Chart* (attached; see Student Worksheet section). Each student can pick any background star on the sheet. Starting on the right end of the diameter crossing Earth's orbit (actually, any of the radii can be used), students should draw a line from the orbit at that point to the selected star. Then the student should draw a line parallel to this original line of sight (by measurement or by geometric construction) such that the new line passes through the intersection of the next radius and the orbit circle, counterclockwise. Next, students should draw a –line from the second intersection point to the original star. They should immediately note that from the new orbital position, the angle between the star and the old line of sight changes. This change in angle is reflected in a change in the time of star-rise.

Observing and timing the passage of the Sun, as well as stars, can generate a more elaborate classroom and home set of observations. See Edberg, S. J., "Length of the Day," *Practical Uses of Math and Science*, an on-line refereed journal at *http://pumas.jpl.nasa.gov*, accepted October 30, 1997. The specific URL is: *http://pumas.jpl.nasa.gov/cgi-bin/layout.pl?examples:EX00000011-W:inv/examples/07_31_97_1.lbl*

The simplified Planet Orbit Chart is used to illustrate the motions of the planet that have been (or will be) observed in the sky. The Sun is at the center of the circle. The large circle represents Earth's orbit. An outer planet, without its orbital motion, is represented by the dot.

Starting on the right end of the diameter crossing Earth's orbit, students should draw a line from the orbit at that point through the planet to the background stars. Students should then continue drawing lines, one step at a time, moving around Earth's orbit in a counterclockwise direction (as if an observer were looking down on the solar system from high above the north pole). Each time step is approximately 22.5 days; this is not a magic number, just convenient.

Students should notice how the planet appears to slow down and then go backwards (retrograde) against the background stars, and then slow down and resume its "forward" (prograde) motion. Ask them how this result would be different if the planet itself were moving. (Answer: The extent of the backward motion (the retrograde loop) would be decreased.)

Students can even demonstrate the effect of simple planetary motion by repeating this lesson, adding a planet dot on each side of the original dot (about 1 centimeter left and right: see *Simulated-Motion Chart* attached). Draw a set of lines from the first three positions on the orbit through the right dot, a set of lines from the next three orbital positions through the middle dot, and the set of lines through the left dot.

The planets work the same way, but of course their motions are smooth and continuous. A continuous set of observations over several months will show the forward–backward–forward motion of the planet against the background stars. This prograde–retrograde–prograde motion is often manifested as a loop or Z among the background stars since the planes of Earth's orbit and other planets' orbits differ slightly.

Extension

The motions of an outer planet get much more interesting if one assumes that the outer planet orbits differently from what is observed in the solar system. Use the Simulated-Motion Chart again, but to simulate a planet in an orbit moving opposite Earth's direction (a retrograde orbit), connect Earth's position to the dots in the order opposite that described above (i.e., from left to right instead of right to left). Draw a strongly elliptical orbit for an Earth-like planet and observe the effects different portions of the orbit have on the apparent motion of the (stationary or moving) outer planet. Think in three dimensions and determine the apparent motion of a moving outer planet with an orbital plane that is steeply inclined compared to Earth's. Such motions are common among comets and some asteroids. As you can see, predicting the apparent motions of such objects can get challenging fast.

An observer on Earth with binoculars can see Jupiter's four large satellites. Their orbital minuets can be tracked over the course of one or more nights. On some nights, as few as two moons may be visible. Their order outward from Jupiter is: Io, Europa, Ganymede, Callisto. Their orbital periods range from less than two days to more than 16 days.

Observers with small telescopes can see the movements of Jupiter's moons and will also be able to see some of the dark belts and bright zones marking Jupiter's cloud tops. With small telescopes, observers can also discern a dark band across Saturn, Saturn's rings, and its largest moon, Titan. Titan is comparable in size to Jupiter's largest moon, Ganymede, but it is almost twice as far away from Earth and much more mysterious owing to its opaque atmosphere.

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:

3. Understands the composition and structure of the universe and Earth's place in it.

LEVEL 1 (GRADES K–2)

Knows basic patterns of the Sun and Moon (e.g., the Sun appears every day and the Moon appears sometimes at night and sometimes during the day; the Sun and Moon appear to move from east to west across the sky; the Moon appears to change shape over the course of a month; the Sun's position in the sky changes through the seasons).

LEVEL 2 (GRADES 3–5)

Knows that the patterns of stars in the sky stay the same, although they appear to slowly move from east to west across the sky nightly and different stars can be seen in different seasons.

Knows that planets look like stars, but over time they appear to wander among the constellations.

LEVEL 3 (GRADES 6–8)

Knows characteristics and movement patterns of the nine planets in our solar system (e.g., planets differ in size, composition, and surface features; planets move around the Sun in elliptical orbits; some planets have moons, rings of particles, and other satellites orbiting them).

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that the position of an object can be described by locating it relative to another object or the background.

LEVEL 2 (GRADES 3–5)

Knows that an object's motion can be described by tracing and measuring its position over time.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

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 — Observing Outer Planets

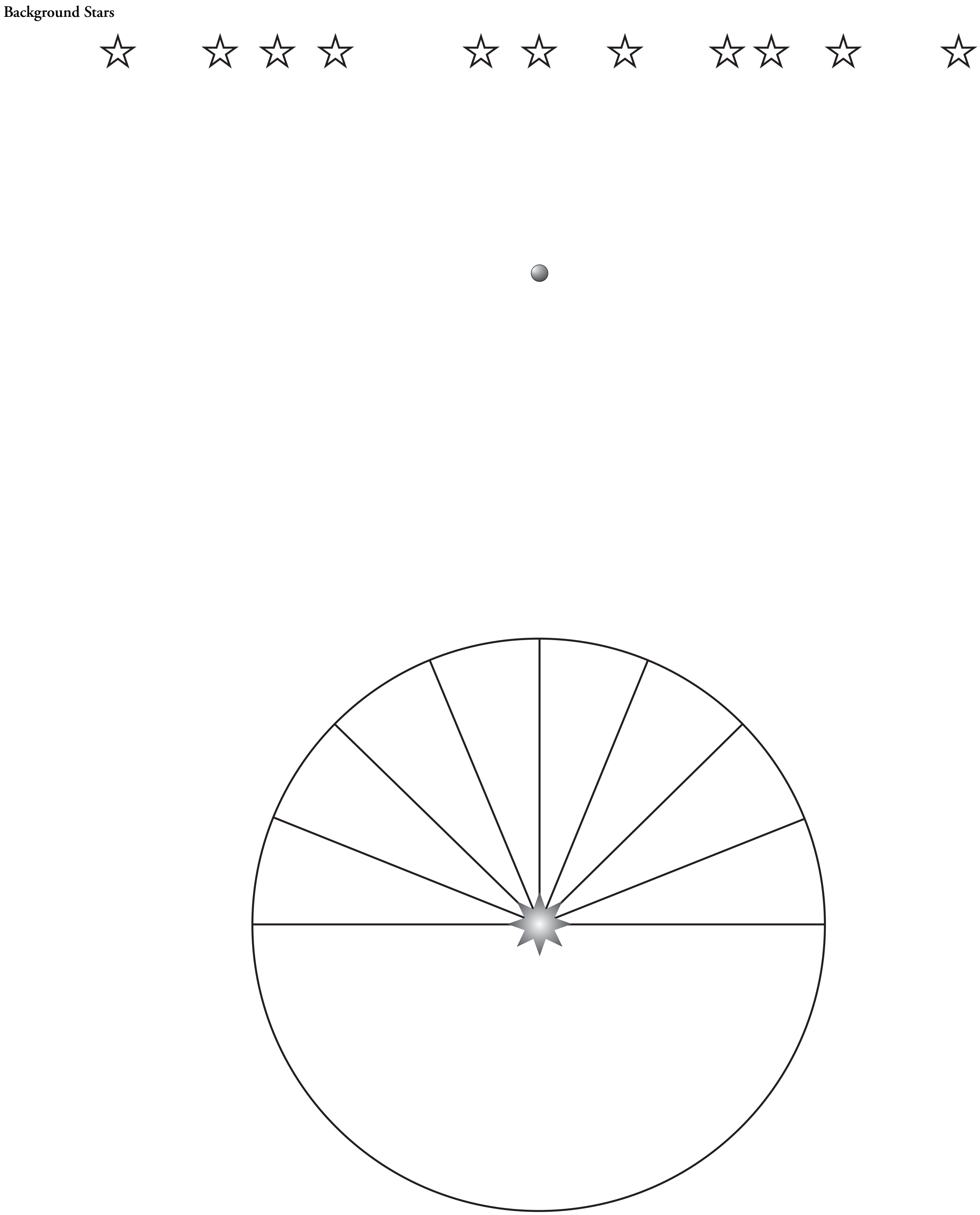
Procedure

The teacher will describe the observing activities and how to use the charts.

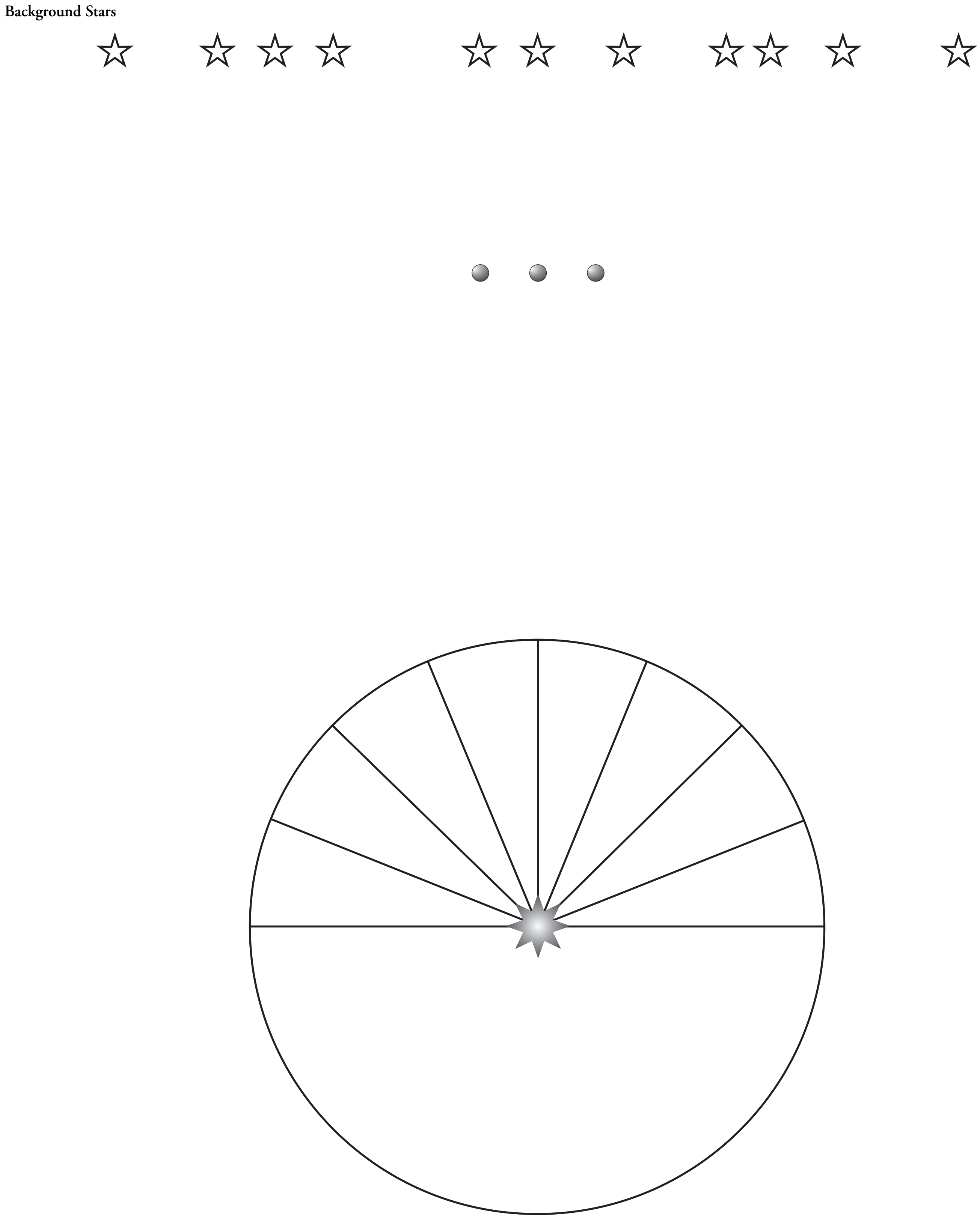
List the date and the rise or set time for your selected star. Describe the weather if it prevented a time observation.

Compare the colors of Jupiter and Saturn to the colors of the brightest stars. Reddish stars (actually salmon-colored) have temperatures of 3000–4000 degrees Celsius and bluish stars have temperatures exceeding 10,000 degrees Celsius. Jupiter's naked-eye color matches the Sun's. What would you conclude the temperature of the Sun to be?

Sketch the positions of the moons relative to Jupiter. By making nightly drawings over a period of a few weeks it is possible to sort out which moons are which, based on how frequently they circle Jupiter and their maximum apparent distance from the planet. Imagine yourself as Galileo in 1610 seeing the moons for the first time. How far from the planet does each moon get? How fast does each go from side to side and back? Are there any color differences between them? Use a telescope and sketch Titan's motion around Saturn. How long does it take to make a revolution around Saturn?

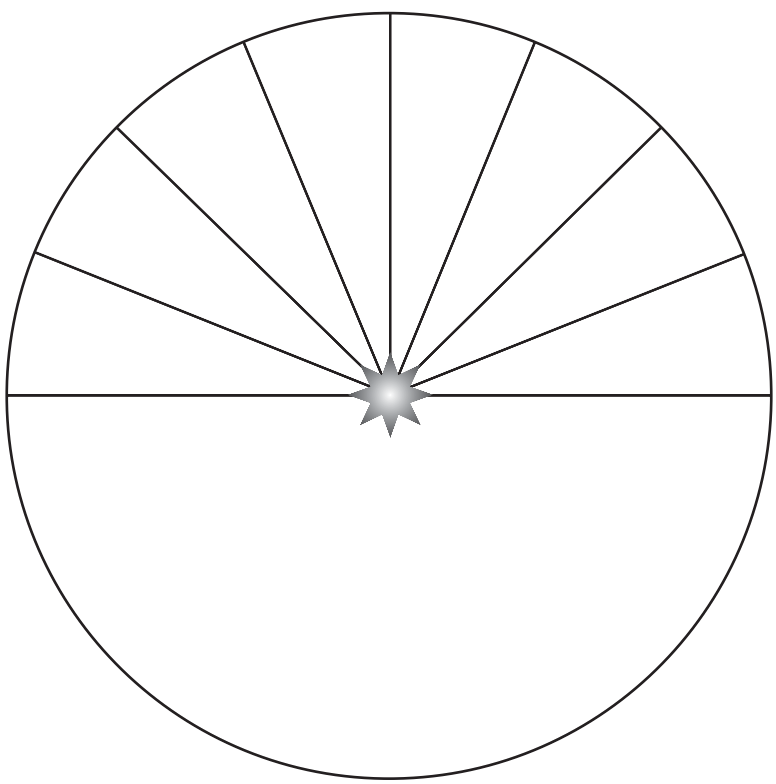


Planet Orbit Chart



Simulated-Motion Chart

Background Stars



Star-Rise Chart

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 6–12

EB-2001-12-018-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Can Photosynthesis Occur at Saturn?

Objective

Students will learn the basic principle of photosynthesis and how light intensity diminishes as a function of distance from the light source.

Time Required: Several hours

Saturn System Analogy: Titan and Saturn

Keywords: Chlorophyll, Displacement, Glucose, Inverse-Square Law, Photosynthesis, Proportional

MATERIALS

- 2 plastic funnels of the same size and shape. *The maximum diameter of the funnels needs to be just enough smaller than the internal diameter of the cups listed below) so that the funnels will rest just inside the cup's rim*
- 2 plastic or glass cups that have a slightly larger inner diameter than the funnels' outer diameter
- 2 rubber bands
- 2 clear drinking straws (a bubble in water in the straw must be visible)
- Plastic cling food wrap
- Salt (1/4 teaspoon for each setup)
- Baking soda (1/4 teaspoon for each setup)
- Water
- 2 bunches of fresh spinach leaves from the produce aisle of the local grocery store
- 2 butterfly clips to pinch straw ends
- Metric ruler
- Graph paper to display results
- Light meter (separate instrument or built into a camera)

Discussion

Photosynthesis is the transformation of light energy into chemical energy. Green leafy plants contain a light-absorbing pigment called chlorophyll. This pigment provides the biological mechanism that drives photosynthesis in plants. Chlorophyll uses the energy from sunlight to convert carbon dioxide into glucose, with the production of oxygen as a by-product. The glucose is used by the plant to produce leaves, flowers, fruits, and seeds. Glucose is also converted into cellulose, which is the structural material used in cell walls.

Photosynthesis occurs not only in green leafy plants, but in seaweed, algae, and certain bacteria as well. Light is absorbed by ocean water and can penetrate to tens of meters in depth. The volume of the ocean where sunlight can penetrate is called the "photic zone." The photic zone extends to a depth where the intensity of light is approximately 1% of the intensity of sunlight on the surface. The boundary of the photic zone marks the ocean depth below which photosynthesis cannot occur.

The actual depth of sunlight penetration varies depending on water clarity. In clear tropical water, the photic zone can extend to a depth of 150 meters. The photic zone is drastically reduced in water containing lots of suspended solids.

The "inverse-square law" of physics states that as energy radiates equally in all directions from a source, the intensity (brightness) of the energy decreases at a rate that is proportional to the square of the distance that the energy has traveled. The illumination of a light bulb 4 meters away is only a fourth as intense as the illumination from a light bulb 2 meters away. Since the inverse-square law says that illumination goes as the reciprocal of the distance squared, a light source twice as far away appears only one-fourth as bright. If it were three times further (6 meters, compared to 2 meters), it would be one-ninth as bright. The inverse-square law is applicable to all forms of electromagnetic radiation as well as to the force of gravity.

Saturn is more than 9 times farther away from the Sun as Earth is from the Sun. As a result, Saturn receives less than approximately 1/81 or 1.2 % of the sunlight that Earth receives. Is this enough sunlight to drive photosynthesis?

Oxygen is used by nearly all multicellular organisms in chemical reactions that break down glucose to "retrieve" the chemically stored Sun's energy. The energy is used for growth and other living functions. Using oxygen is much more efficient than using reactions that break down glucose without oxygen. When Earth first formed about 4.5 billion years ago, there was no oxygen in the atmosphere. The evolution of photosynthesis was necessary for the buildup of atmospheric oxygen that made complex life possible.

Procedure

Using the metric ruler, mark centimeter lines along the length of each straw.

Make two identical apparatus setups. One setup is to be placed in direct sunlight to measure the rate of photosynthesis occurring on Earth. The second setup is to be placed in a location in the classroom that simulates the light intensity at Saturn. As mentioned in the discussion, the light intensity at Saturn is approximately 1.2% of the light intensity on Earth.

For each experiment setup, follow this procedure:

1. Wrap the rubber band several times around one end of the straw.
2. Draw the straw up into the funnel so that the rubber-band end is inside the conical portion of the funnel.
3. Wrap the straw and funnel stem tightly with cling-wrap. This will provide a watertight seal.
4. Weigh the spinach leaves that are going to be placed in each glass. Record the weights of each sample on the student worksheet (provided).
5. Place the spinach leaves, stem end down, in the glass.
6. Fill the glass nearly to the top with water. Add the salt and baking soda.
7. Invert the funnel over the glass containing the spinach and water. The spinach leaves should be immediately under the inverted cup end of the funnel.
8. Gently suck water up into the funnel until it fills nearly to the top of the straw. Then pinch the top of the straw with a butterfly clip. This will result in an airtight column of water in the glass. If the water column falls, the seals are not tight.
9. Use a simple light meter to determine the light intensity of the sunlight coming through the window onto a plain white sheet of paper. Record that reading on the student worksheet.

Once both apparatuses are assembled, place one in a window exposed to bright sunlight. Be sure that the area in which the apparatus is placed is well ventilated. Failure to do so will result in a buildup of heat. This experiment is focused on learning about light-energy and not heat, so avoid having temperature enter into the experiment.

Using a light meter, find a corner of the classroom where light intensity falling on a plain white sheet of paper is a little more than 1% (6.5 photographic "stops") of the reading taken in the window. This might be a corner under a desk, a closet, or other dark area. Record the location chosen and the light intensity reading on the student worksheet. Place the second apparatus in the chosen location.

Use the millimeter ruler to measure from the clip to the end of the bubble in the straw. This is a measure of the oxygen level. Measure each bubble every 30 minutes for 4 hours. Students should note the appearance of small bubbles on the surface of the leaves, as photosynthesis begins to generate oxygen. These bubbles of oxygen will rise into the straw, and displace an amount of water directly proportional to the volume of oxygen produced. As the experiment proceeds, the water columns will continue to descend. The rate at which the water column descends is directly proportional to the rate of photosynthesis occurring in the plant. Record the measurements in the table provided in the student worksheet.

Upon completion of data collection, use the graph paper to plot the results for each bottle. Compare the results between the two environments.

Extensions

Baking soda provides carbon dioxide (after dissociation from sodium bicarbonate) to drive the light-independent chemical reactions of photosynthesis forward. The addition of salt provides osmotic balance for the water. More advanced students can research the distinction between the light dependent reaction and the light independent reaction of photosynthesis and write the chemical equation for each reaction.

Education Standards

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

Science Standards

1. Understands atmospheric processes and the water cycle.

LEVEL 3 (GRADES 6–8)

Knows that the Sun is the principal energy source for phenomena on Earth's surface (e.g., winds, ocean currents, the water cycle, plant growth).

5. Understands the structure and function of cells and organisms.

LEVEL 3 (GRADES 6–8)

Knows that all organisms are composed of cells, which are the fundamental units of life; most organisms are single cells, but other organisms (including humans) are multicellular.

Knows that cells convert energy obtained from food to carry on the many functions needed to sustain life (e.g., cell growth and division, production of materials that the cell or organism needs).

LEVEL 4 (GRADES 9–12)

Knows the structures of different types of cell parts (e.g., cell wall; cell membrane; cytoplasm; cell organelles such as the nucleus, chloroplast, mitochondrion, Golgi apparatus, vacuole) and the functions they perform (e.g., transport of materials, storage of genetic information, photosynthesis and respiration, synthesis of new molecules, waste disposal).

Understands the processes of photosynthesis and respiration in plants (e.g., chloroplasts in plant cells use energy from sunlight to combine molecules of carbon dioxide and water into complex, energy-rich organic compounds and release oxygen to the environment).

6. Understands relationships among organisms and their physical environment.

LEVEL 3 (GRADES 6–8)

Knows how energy is transferred through food webs in an ecosystem (e.g., energy enters ecosystems as sunlight, and green plants transfer this energy into chemical energy through photosynthesis; this chemical energy is passed from organism to organism; animals get energy from oxidizing their food, releasing some of this energy as heat).

LEVEL 4 (GRADES 9–12)

Knows how the amount of life an environment can support is limited by the availability of matter and energy and the ability of the ecosystem to recycle materials.

Knows that as matter and energy flow through different levels of organization in living systems and between living systems and the physical environment, chemical elements (e.g., carbon, nitrogen) are recombined in different ways.

9. Understands the sources and properties of energy.

LEVEL 3 (GRADES 6–8)

Knows how the Sun acts as a major source of energy for changes on Earth's surface (i.e., the Sun loses energy by emitting light; some of this light is transferred to Earth in a range of wavelengths including visible light, infrared radiation, and ultraviolet radiation).

Knows ways in which light interacts with matter (e.g., transmission, including refraction; absorption; scattering, including reflection).

11. Understands the nature of scientific knowledge.

LEVEL 3 (GRADES 6–8)

Knows that an experiment must be repeated many times and yield consistent results before the results are accepted as correct.

12. Understands the nature of scientific inquiry.

LEVEL 3 (GRADES 6–8)

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

LEVEL 4 (GRADES 9–12)

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).

Mathematics Standards

6. Understands and applies basic and advanced concepts of statistics and data analysis.

LEVEL 2 (GRADES 3–5)

Understands that data represent specific pieces of information about real-world objects or activities.

Organizes and displays data in simple bar graphs, pie charts, and line graphs.

Reads and interprets simple bar graphs, pie charts, and line graphs.

LEVEL 3 (GRADES 6–8)

Reads and interprets data in charts, tables, plots (e.g., stem-and-leaf, box-and-whiskers, scatter), and graphs (e.g., bar, circle, line).

Organizes and displays data using tables, graphs (e.g., line, circle, bar), frequency distributions, and plots (e.g., stem-and-leaf, box-and-whiskers, scatter).

LEVEL 4 (GRADES 9–12)

Selects and uses the best method of representing and describing a set of data (e.g., scatter plot, line graph, two-way table).

9. Understands the general nature and uses of mathematics.

LEVEL 2 (GRADES 3–5)

Understands that numbers and the operations performed on them can be used to describe things in the real world and predict what might occur.

Understands that mathematical ideas and concepts can be represented concretely, graphically, and symbolically.

LEVEL 3 (GRADES 6–8)

Understands that mathematicians often represent real things using abstract ideas like numbers or lines; they then work with these abstractions to learn about the things they represent.

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 — Does Photosynthesis Occur at Saturn?

Procedure

Your teacher will set up the experiment.

The setup for Earth's sunlight is Setup #__________

The setup for Saturn light intensity is Setup # __________

My Saturn simulation location is: __________

Setup Parameters	**Setup #1**	**Setup #2**
Weight of Spinach		
Light Meter Reading		

Water Displacement Measurements

Time of Measurement	**Setup #1** Amount of Water Displacement	**Setup #1** Amount of Water Displacement

Questions

1. Based on the data collected, is the amount of sunlight available at Saturn enough to drive photosynthesis?

2. What is the purpose of adding salt to the water?

3. What is the purpose of adding baking soda to the water?

4. What other environmental factors influence photosynthesis? Temperature? Other chemicals present in Earth's atmosphere?

5. Saturn and its satellites are far enough away from the Sun that sunlight reaching the system is greatly reduced. Gravitational flexing, internal radioactive decay, and chemicals like methane and ammonia may yield more energy at Saturn than sunlight. Could plant life adapt to any of these energy sources? (Note that this is a VERY open-ended question.)

6. Where on Earth does photosynthesis occur at a light intensity greatly reduced from the light intensity on the surface?

7. How would you change the experiment to test the possibility of photosynthesis on Mars, which is about 1.5 times as far from the Sun as is Earth?

8. Based on your experimental results and the background material, what do you think the chances are for the existence of large, complex living organisms in the outer solar system (Saturn and beyond)

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 3–12

EB-2001-12-017-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Planetary Billiards

Objective

To illustrate how the force of gravity is used to modify the trajectory of a spacecraft.

Time Required: 1-3 hours, depending on activities selected

Saturn System Analogy: Cassini's tour of the Saturn system using Titan for gravity-assist trajectory modifications.

Keywords: Angle, Asymptote, Eccentricity, Flyby, Gravity Assist, Hyperbola, Inclination, Vector

MATERIALS

1. Trajectory Modification Demonstration

- Strong magnet (available at hardware stores)
- Steel bearing balls (available at hardware stores, an auto parts store, bicycle shop, or surplus house). *Get several different sizes (1/8" and larger) of magnetic balls and spares (the balls are easy to lose!).*
- A piece of transparent Plexiglas (available at hardware stores) for a baseboard (approximately 10" square). *Size and shape are not important as long as there is room for the balls to roll; the Plexiglas should be flat and not bend easily. Any thin, nonmagnetic material will work as a base board, but targeting the balls is easier if the magnet is visible. The thickness of the material must be such that a magnet will have a noticeable affect on the balls rolling on top of the baseboard above it.*
- 6"–12" piece of angle aluminum—a right-angle V cross-section (available at hardware stores)

2. Effect on Trajectory Demonstration

- Laser pointer (available at camera stores and department stores). *A flashlight could be used, but the spread in the beam makes the effect more difficult to observe and measure and a larger mirror (see next item) is necessary.*
- Make-up mirror (or other small mirror)
- Alternative materials: rubber "super" balls (available at a toy store) and a solid wall in the classroom; plain white wrapping paper for recording data.

Discussion

Sending spacecraft to the planets is a complicated process. It requires careful study of such factors as:

- Payload — Science investigations that will be carried out; science instruments, plus their supporting hardware, electronics, and power supplies; and rocket engines and their propellants necessary to accomplish the goals of the program.
- Booster rocket lift capability — How much a rocket can carry into space beyond Earth's gravitational influence.
- Flight time — How long the mission will take, with factors such as hardware lifetime affecting the choices.

The Cassini–Huygens spacecraft embarked on October 15, 1997, on a mission to Saturn that will continue through

June 2008. The first 6-3/4 years are called the cruise phase (Figure 1).

The last four years involve a "tour" of the Saturn system (Figure 2), including detailed studies of the planet, rings, the large satellite Titan and the numerous smaller satellites, and Saturn's extensive magnetosphere (the volume of space that is filled with atoms and electrically charged particles and controlled by the magnetic field generated by the planet). Close flybys of Titan provide good opportunities to study that satellite. Flybys use the satellite's gravity to change the eccentricity (shape), inclination with respect to Saturn's equator, and solar orientation of the spacecraft's orbit so it can travel widely throughout Saturn's environment.

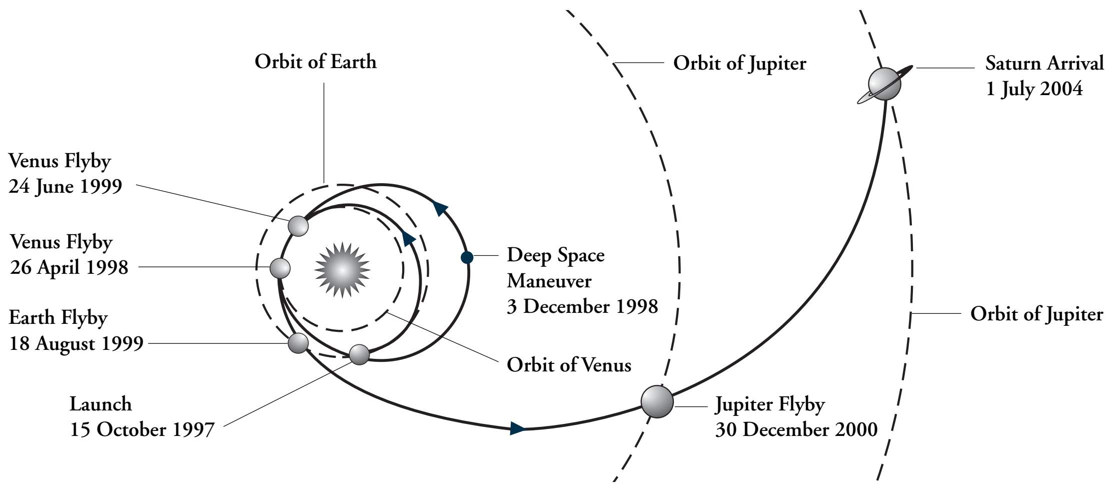
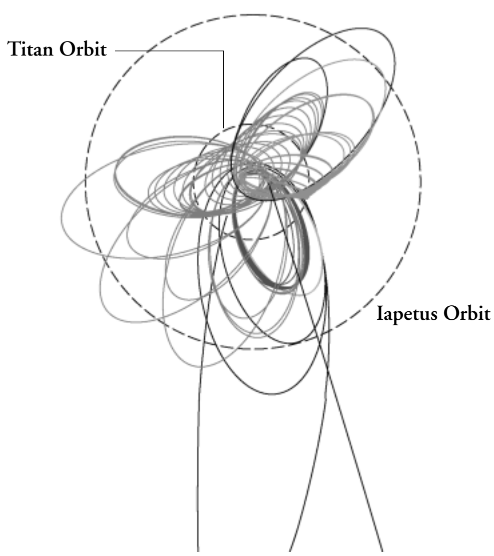


Figure 1. The cruise phase: Cassini–Huygens' route to Saturn is shown, with major milestones indicated by their dates. The Deep Space Maneuver uses the spacecraft's large rocket engine to adjust its path. The planetary flybys also adjust the path, but don't require the engine to be used. On the scale of this diagram, the change in direction due to the flybys cannot be seen.



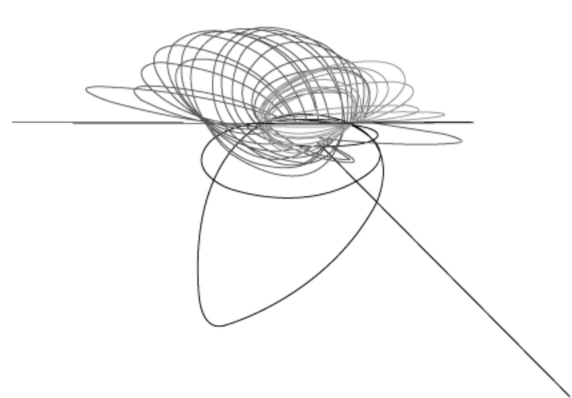


Figure 2. The Cassini orbiter's "tour" of Saturn's system is traced with orbital tracks around Saturn. The left diagram is a "petal plot" with the view looking down on Saturn's north pole. The right diagram shows orbit tracks as seen from the plane of Saturn's equator and rings. Note that the orbiter ranges widely around Saturn and above and below the planet's poles.

Because exploration requirements demanded a very capable spacecraft — one with a wide variety of advanced instrumentation and therefore very massive — the largest expendable rocket in the U.S. fleet, the Titan IVB Centaur SRMU, was chosen to launch the spacecraft. The Titan IV is the fourth generation in a family of launchers first designed in the 1950s. The B refers to an upgrade from the A model of this generation of Titans. SRMU stands for Solid Rocket Motor Upgrade — advanced, lighter weight, and more powerful solid-fuel rocket motors that strap onto the liquid-fueled Titan core. This portion of the launcher lifted the spacecraft into Earth orbit with the help of the Centaur rocket.

The Centaur is a liquid-fueled rocket that finished the Titan's job of boosting Cassini–Huygens into Earth orbit. It then ignited again after "coasting" 1/3 of the way around the world and propelled Cassini–Huygens out of Earth orbit and into a solar orbit through interplanetary space.

As large as the Titan IVB Centaur SRMU is, it could not send Cassini–Huygens directly to Saturn. Instead, the spacecraft was directed onto a trajectory involving a series of orbits around the Sun. These orbits include flybys of three planets: Venus (twice), Earth, and Jupiter. Using the gravity of the planets to change the speed and direction of the spacecraft, the combination of these flybys supplies the equivalent of the rocket power of the Titan launcher, while using a minimal amount of Cassini's onboard propellants.

The exercises described here will give students an understanding of the mechanics of planetary flybys through first-hand observations and measurement. In addition, students can use vectors to understand how planetary flybys can shorten interplanetary cruise durations.

The force of gravity from a body actually extends to infinity. But practically speaking for interplanetary flight, the gravitational force affecting a spacecraft is limited in extent. Around the time of a planetary flyby, a spacecraft can be characterized as following a curve called a hyperbola (Figure 3). When it is far from the planet, the spacecraft's path parallels the asymptote, a straight line that is very close to the actual hyperbolic path far from the focus (planet).

(Note: This is not true, strictly speaking. A spacecraft on the way to a planetary flyby is actually on an elliptical, heliocentric orbit. Over short distances [on an astronomical scale], a portion of the ellipse can look like a straight line, specifically outside the range where a planet affects the spacecraft's trajectory — less than a few hundred thousand kilometers in the case of a planet with approximately Earth's mass.)

As it gets closer to the planet, the path of the spacecraft deviates more and more from the asymptote, following the hyperbolic trajectory, and the spacecraft speeds up. After the flyby the spacecraft slows down to the same speed (relative to the planet) that it had inbound, and joins the outbound asymptote.

The amount of "bending" is a function of the spacecraft's flyby speed and mass, the planet's mass, and the distance of the close approach from the planet's center. Figure 3 shows two hyperbolas to indicate the variation in bending depending on the distance from the planet.

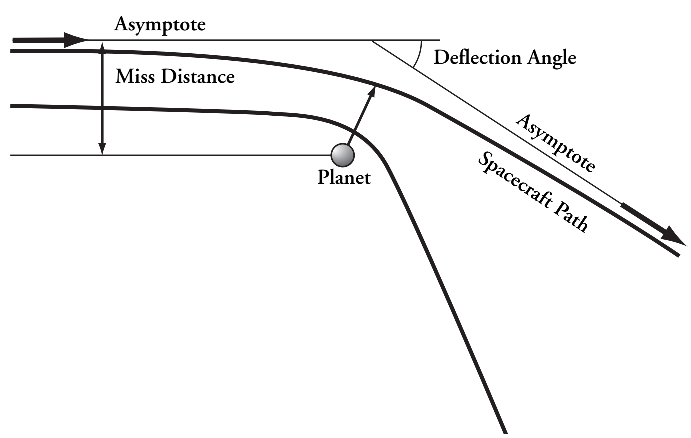


Figure 3. The deflection of a spacecraft going by a planet differs depending on its miss distance, its speed, and the mass of the planet. These same parameters apply when demonstrating the effect of a magnet on steel balls rolling by (the strength of the magnet is analogous to the mass of the planet). Two hyperbolas are shown here, for near and more distant flybys. The miss distance is illustrated for the more distant flyby and is the separation of the asymptote from the planet's center.

The speed of the spacecraft on the asymptote before the flyby is "v-infinity" (the speed when not influenced by the gravity of the flyby planet, typically 35 to 41 kilometers/second at Venus and Earth, 12 kilometers/second at Jupiter, and 6 kilometers/second at Saturn's moon Titan), and the speed is v-infinity afterwards (Figure 4). The inbound speed increase caused by the planet's gravity is exactly decreased during the outbound leg. However, the spacecraft's direction of motion is altered — the spacecraft's velocity (combined speed and direction) relative to the Sun changes. At the completion of a flyby the spacecraft's direction has changed, but not its speed. It is the change in velocity relative to the Sun that makes flybys useful in shortening interplanetary flights.

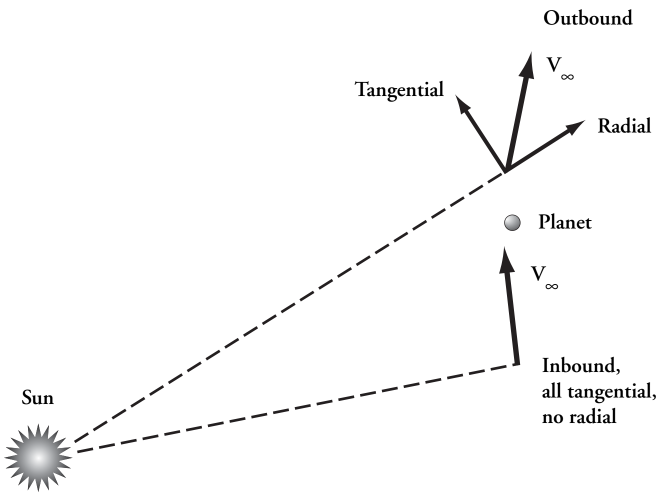


Figure 4. This diagram exaggerates the effect of a planetary flyby. In this example, inbound (before the planetary flyby), the spacecraft's velocity is perpendicular to a line from the Sun (called a radius vector). It is only moving around the Sun (with tangential velocity, but no radial velocity), not approaching or receding from it. After the flyby, the spacecraft's overall speed is the same (note that the bold vectors have the same length before and after) but the outbound vector can be resolved into tangential and radial components: the tangential component is smaller after the flyby and the radial component is large, when it had been zero before. In reality, the radial component typically changes only a few kilometers/second compared to a v-infinity of a few tens of kilometers/second.

Procedure

1. Trajectory Modification Demonstration

Rest the baseboard on the magnet, approximately centered. Use any convenient spacers to prop up the corners of the baseboard so it stays flat and level (Figure 5). The launch ramp can be mounted on the side of a small box so the angle remains consistent. Incline the launcher at a very shallow

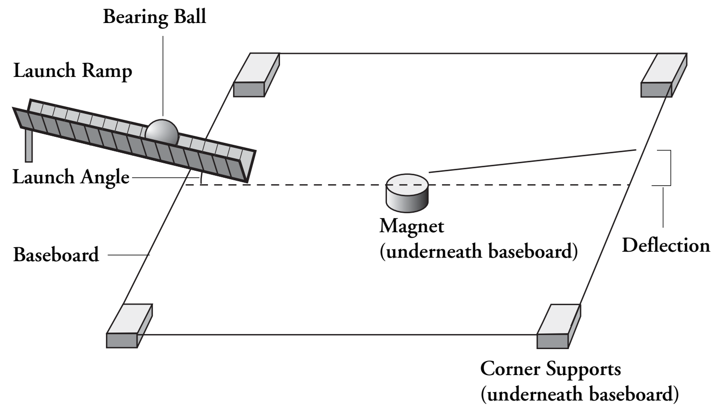


Figure 5. The experiment setup for magnetism-governed flybys of steel balls. An inclined launch ramp is used to guide a steel ball towards a magnet.

angle. Minimize the distance that the ball might drop (instead of rolling smoothly) from the ramp onto the baseboard.

Starting from the middle of the ramp, roll a bearing ball down the launcher. Experiment with the aiming of the launcher, watching the effect of close roll-bys of the balls. Close to the magnet the balls will be pulled off their straight-line paths. Far from the magnet, and going directly over the magnet's center, there will be no noticeable deviation of the path. (The lack of deviation directly over the magnet's center is the result of forces from all parts of the magnet acting equally on the ball. Similarly, there would be no deviation for an object falling through the center of a planet, if that were possible.)

The speed of the ball can be increased by steepening the ramp angle and/or by allowing more rolling distance on the ramp. The deviation will decrease for a faster "flyby" of the magnet. A larger ball with the same launch angle and position and range from the magnet will have less deviation than a small ball. The deviation is a function of the momentum (mass × velocity) of the ball, just as it is for a spacecraft.

Set up the launch ramp so that the magnet deviates a larger ball's path by a noticeable amount. Fix the launch ramp's position and angle and roll balls of varying size down the ramp from the same starting point. Note the amount of bending as a function of ball size or weight (mass). Ideally, a larger ball with the same launch angle and position and range from the magnet will have less deviation than a small ball. The momentum of a larger ball is greater than for a smaller ball by the ratio of the masses. Note that the difference in deviation for large and small spacecraft is too small to measure. Planets are so much more massive than any spacecraft that the difference in behavior of the spacecraft is undetectable.

Set up the launch ramp so that a ball's path deviates by some convenient, measurable amount. Fix the launch ramp's position and angle and roll balls down the ramp from different, marked starting points (see Figure 5). If the speed is changed by changing the length of the roll down the launcher, the ratio of the speeds is proportional to the ratio of the square root of the ratio of the roll lengths:

(new speed)/(old speed) = sqrt[(new length)/(old length)]

The launcher angle, with fixed launch point, can be varied for the same effect. The effect on the ball's rolling speed by changing the launcher angle is seen in the ratio of the sines of the old angle and the new angle:

(new speed)/(old speed) = [sin(new angle)]/[sin(old angle)]

This has assumed the magnet is a simple, short bar magnet, ideally with one pole projecting normal to the baseboard. The basic effect of deviating the motion of the balls is true for any common magnet (i.e., a dipole or a horseshoe) for paths staying outside the cross-section of the magnet. The motions get considerably more complex for balls, especially slow-rollers, that cross over a horseshoe magnet. In essence, two magnets are now affecting the motion, and that motion can demonstrate some extreme effects.

In Vol. 1, Chapter 9–7 of *The Feynman Lectures on Physics* (Addison-Wesley Publishing Co., Reading, MA, 1963), Feynman, Leighton, and Sands present a calculation of the motion of a planet around the Sun. Such a step-by-step calculation can be modified to illustrate a gravity-assist flyby of a planet.

2. Effect on Trajectory Demonstration

The path of a spacecraft before and after a planetary flyby closely follows straight lines at angles to each other (the asymptotes in Figure 3). The path can be mimicked with a beam from a laser pointer. Because spacecraft motion is along an asymptote before and after the flyby, it can be modeled with a reflection of the laser beam off a mirror (Figure 6). A flashlight could be used, but the spread in the beam makes the effect more difficult to observe and measure and a larger mirror is necessary.)

Put a large piece of wrapping paper on the experimental surface (table or floor). Place a mark on the paper to show the position of the laser and its beam direction. The position of the mirror should be fixed, and a line should be drawn on the paper at the mirror's position showing its orientation. Aim the laser from its position mark towards the mirror and mark on the paper the position of the beam's interception of the mirror. Using a piece of cardboard as a screen, note the position on the base paper of the reflected beam's "end" point on the screen.

CAUTION: BE CAREFUL NOT TO SHINE THE LASER BEAM INTO ANYONE'S EYES. EYE DAMAGE CAN RESULT.

Draw lines from the laser source point to the mirror intersection point, and from the mirror point to the end point indicated by the cardboard screen. Use a protractor to measure the angles of the inbound and outbound light with respect to a perpendicular from the mirror — they should be equal. Try several different angles to confirm that (angle in) = (angle out); i.e., the (angle of incidence) = (angle of reflection).

Rubber "super" balls can be horizontally bounced (reflected) off a hard vertical surface. Students can mark the launch

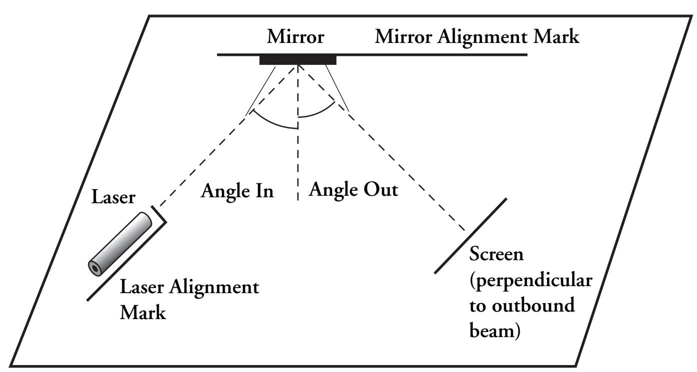


Figure 6. The experimental setup for the before/after effect of a planetary flyby. The laser beam reflects off the mirror to the screen. Measurement will show that (angle in) = (angle out) for all angles. To use rubber balls, the laser can be replaced with a v-shaped launch ramp and the mirror must be replaced with a solid, immovable wall.

point on the wrapping paper, the impact point on the surface, and the point where the ball is stopped. A launch ramp made of angle aluminum will allow better control and repeatability of the ball launches. Again, by connecting the points the angles can be measured.

To demonstrate the change in velocity relative to the Sun, place an X anywhere on the wrapping paper. Mark off some convenient length of line segment on the inbound leg and the outbound leg; both segments should be equal in length. Now draw a line from the symbolic Sun at X to the beginning of each line segment ("beginning" means the end closer to the starting point on the inbound leg). Resolve the two segments into vector components parallel to and perpendicular to the line (called a radius vector) from the Sun symbol (see Figure 4). Measurements of the lengths of the components parallel to the radius vector will be different for the inbound and outbound legs, establishing a change in velocity relative to the Sun, just as happens during a flyby maneuver. This shows why planetary flybys are used: the speed of the spacecraft relative to the Sun is increased, which decreases the travel time to the planet. In the case of gravity assist using Titan, the speed relative to Saturn is changed, with the goal of modifying Cassini's orbit around the planet.

Students can demonstrate the Pythagorean theorem by squaring the lengths of the radial and tangential components, summing them, and taking the square root of the sum. The result should equal the length of the original line segments.

Extensions

1. Make a small change in the angle and observe its effect on the end point. While the inbound and outbound angles are the same, the end point moves by a calculable amount. If the inbound angle is changed less than about 8 degrees, the shift in the position of the end point can be calculated with this formula:

shift in mm = [({1st angle in} - {2nd angle in})/57.3] × [mirror to screen distance in mm]

2. Use the same pair of incidence angles with the screen moved farther from the mirror. The ratio of the new and old shifts is directly proportional to the ratio of the new and old screen distances, an example of similar triangles (Figure 7). This demonstrates that precise pointing is necessary, as in billiards, to assure that a target will be hit.

With both laser+mirror and bouncing balls, the straight line paths before and after are like those of a spacecraft before and after its planetary flyby. The bending due to gravity is a sweeping curve and not the instantaneous reflection demonstrated here.

3. A better analogy to Cassini's interplanetary trajectory would use four small mirrors mounted on the sides of a box or the walls of a room. (**Reminder: Be very careful to avoid shining the laser into anyone's eyes.**) Precise aiming is necessary to reach the final end point. Even a small offset at the first mirror will make it difficult to reach the desired endpoint. To set up this demonstration, it is best to fix the beam's direction, place the first mirror, place the second mirror where the beam's first reflection intersects the wall, place the third mirror where the beam's second reflection intersects the wall, and place the fourth mirror where the beam's third reflection intersects the wall. A target can be placed where the beam's fourth reflection strikes the wall. Placing the mirrors at random and then trying to aim the laser so the beam strikes them all will be much more challenging.

Carefully offsetting the laser's aim at the first mirror will immediately affect the beam's position on the target, and will

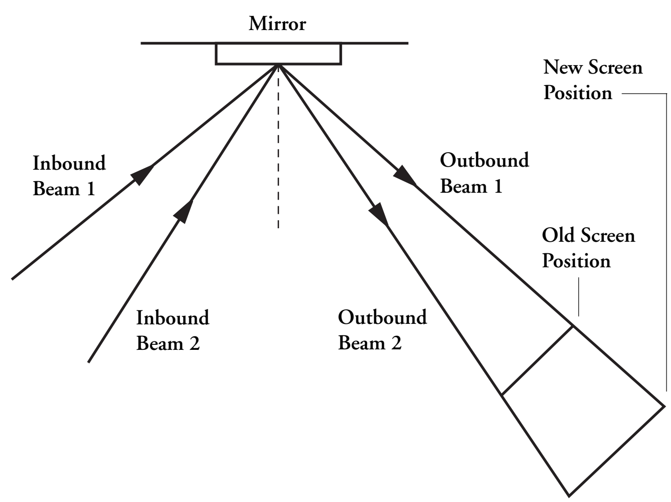


Figure 7. The separation of laser beam endpoints grows if the screen is moved farther from the mirror. By analogy, a small change in a planetary flyby can produce large effects later.

likely remove it completely since the beam will probably be missing one or more of mirrors 2, 3, or 4. Note that the room will have to be dark for both the setup and demonstration. Figure 8 shows an experiment setup.

A billiards table is a small and easily controlled environment, though any player will tell you that getting the desired ball into a desired pocket takes careful aiming and hitting. Interplanetary space flight in the solar system takes careful aiming and precise launch power. But different from billiards, we can correct the spacecraft's motion along the way. The gravitational field of the Sun and planets are all well known and their effects are easily calculated. Small imperfections in direction and speed during the launch of the rocket can be measured.

Just as a car must be steered to stay in a lane on the road, so can the motion of a spacecraft be corrected along its trajectory, but the corrections necessary are much smaller and are needed much less frequently than maintaining a car in a lane. These corrections are made to make sure that desired aim points — necessary for a successful planetary flyby — are passed. Trajectory correction maneuvers are scheduled throughout the course of an interplanetary trip and during Cassini's Saturn tour as well to make sure the spacecraft stays precisely in the middle of the "lane."

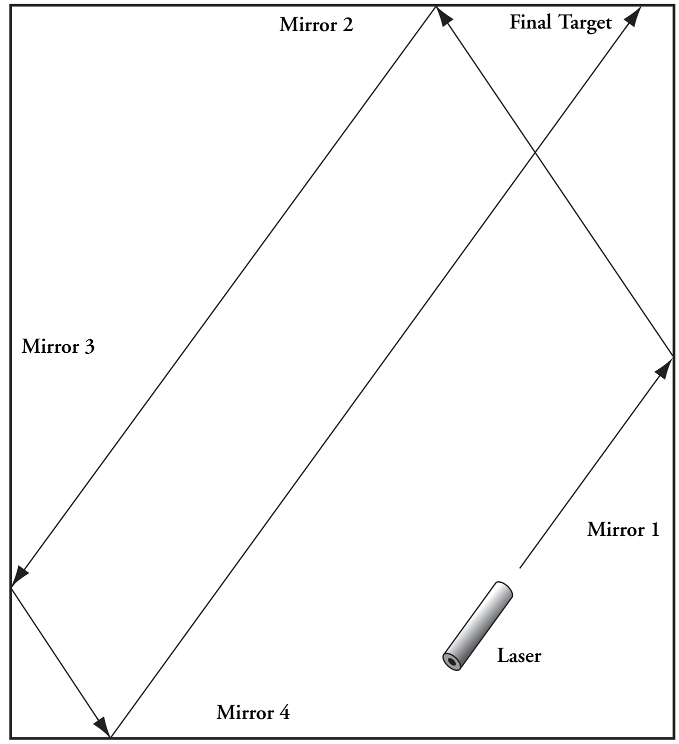


Figure 8. Mirrors placed on walls (or the sides of a box) throw a laser beam around the room to a final target. A small offset of the laser's pointing will affect the final position of the beam at the end of the string of reflections. Each individual reflection is like a planetary flyby. Any set of four reflections (around the room as illustrated, zigzag, etc.) will demonstrate the effect of changing the laser's pointing. Be very careful to avoid shining the laser into anyone's eyes. The laser can be set up so its beam is high above students' eye levels, or the whole demonstration can be performed inside a large cardboard box.

Education Standards

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

Mathematics Standards

1. Uses a variety of strategies in the problem-solving process.

LEVEL 1 (GRADES K–2)

Draws pictures to represent problems.

Uses discussions with teachers and other students to understand problems.

Makes organized lists or tables of information necessary for solving a problem.

4. Understands and applies basic and advanced properties of the concepts of measurement.

LEVEL 2 (GRADES 3–5)

Understands the basic measures perimeter, area, volume, capacity, mass, angle, and circumference.

Selects and uses appropriate tools for given measurement situations (e.g., rulers for length, measuring cups for capacity, protractors for angle).

Understands that measurement is not exact (i.e., measurements may give slightly different numbers when measured multiple times).

LEVEL 3 (GRADES 6–8)

Understands the concepts of precision and significant digits as they relate to measurement (e.g., how units indicate precision).

Selects and uses appropriate units and tools, depending on degree of accuracy required, to find measurements units indicate precision for real-world problems.

5. Understands and applies basic and advanced properties of the concepts of geometry.

LEVEL 1 (GRADES K–2)

Understands that geometric shapes are useful for representing and describing real world situations.

LEVEL 2 (GRADES 3–5)

Understands characteristics of lines (e.g., parallel, perpendicular, intersecting) and angles (e.g., right, acute).

9. Understands the general nature and uses of mathematics.

LEVEL 2 (GRADES 3–5)

Understands that numbers and the operations performed on them can be used to describe things in the real world and predict what might occur.

Understands that mathematical ideas and concepts can be represented concretely, graphically, and symbolically.

LEVEL 4 (GRADES 9–12)

Understands that mathematics provides a precise system to describe objects, events, and relationships and to construct logical arguments.

Science Standards

3. Understands the composition and structure of the universe and Earth's place in it.

LEVEL 3 (GRADES 6–8)

Knows that gravitational force keeps planets in orbit around the Sun and moons in orbit around the planets.

9. Understands the sources and properties of energy.

LEVEL 2 (GRADES 3–5)

Knows that light can be reflected, refracted, or absorbed.

LEVEL 3 (GRADES 6–8)

Knows ways in which light interacts with matter (e.g., transmission, including refraction; absorption; scattering, including reflection).

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

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

Knows that things near Earth fall to the ground unless something holds them up.

Knows that the position of an object can be described by locating it relative to another object or the background.

Knows that the position and motion of an object can be changed by pushing or pulling.

Knows that things move in many different ways (e.g., straight line, zigzag, vibration, circular motion).

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 Earth's gravity pulls any object toward it without touching it.

Knows that an object's motion can be described by tracing and measuring its position over time.

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).

LEVEL 3 (GRADES 6–8)

Understands general concepts related to gravitational force (e.g., every object exerts gravitational force on every other object; this force depends on the mass of the objects and their distance from one another; gravitational force is hard to detect unless at least one of the objects, such as Earth, has a lot of mass).

Knows that an object's motion can be described and represented graphically according to its position, direction of motion, and speed.

Understands effects of balanced and unbalanced forces on an object's motion (e.g., if more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude; unbalanced forces such as friction will cause changes in the speed or direction on an object's motion).

Knows that an object that is not being subjected to a force will continue to move at a constant speed and in a straight line.

LEVEL 4 (GRADES 9–12)

Knows that the strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

Knows that laws of motion can be used to determine the effects of forces on the motion of objects (e.g., objects change their motion only when a net force is applied; whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object; the magnitude of the change in motion can be calculated using the relationship $F = ma$, which is independent of the nature of the force).

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 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.

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)

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).

Uses technology (e.g., hand tools, measuring instruments, calculators, computers) and mathematics (e.g., measurement, formulas, charts, graphs) to perform accurate scientific investigations and communications.

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 Billiards

Procedure

Trajectory Modification Demonstration

Observe the motion of the bearing balls as they roll over the magnet.

- Is the deflection greater for larger or smaller bearing balls?
- What parameter of the rolling ball changes when the ball is released from the top of the ramp or from the middle of the ramp? How does this affect the deflection caused by the magnet?
- What parameter of the rolling ball changes when the ramp is made steeper? How does this affect the deflection caused by the magnet?
- If a bearing ball rolls directly over the center of the magnet, is it deflected? Why or why not?
- If a bearing ball is rolled very slowly across the magnet it may gyrate around and finally come to rest directly over the magnet instead of continuing on as faster-moving bearing balls or a spacecraft going by a planet would. Why is the behavior different?

Effect on Trajectory Demonstration

Put a large piece of wrapping paper on the experimental surface (table or floor). Place a mark on the paper to show the position of the laser and its beam direction. The position of the mirror should be fixed, and a line should be drawn on the paper at the mirror's position showing its orientation. Aim the laser from its position mark towards the mirror and mark on the paper the position of the beam's interception of the mirror. Using a piece of cardboard as a screen, note the position on the base paper of the reflected beam's "end" point on the screen.

CAUTION: BE CAREFUL NOT TO SHINE THE LASER BEAM INTO ANYONE'S EYES. EYE DAMAGE CAN RESULT.

Draw lines from the source point to the mirror intersection point, and from the mirror point to the end point. Use a protractor to measure the angles of the inbound and outbound light with respect to a perpendicular from the mirror. Change the position of the laser and repeat the measurements. Try this for several different angles.

- Do your measurements confirm that (angle in) = (angle out) — i.e., the (angle of incidence) = (angle of reflection)?
- Demonstrate the change in velocity relative to the Sun for one (or more) reflection experiments. Place an X anywhere on the wrapping paper. Mark off some convenient length of line segment on the inbound leg and the outbound leg; the segments should be equal in length. Now draw a line from the symbolic Sun at X to the beginning of each line segment (beginning means the end closer to the starting point on the inbound leg). Resolve the two segments into vector components parallel to and perpendicular to the line (called a radius vector) from the Sun symbol. Measurements of the lengths of the components parallel to the radius vector will be different for the inbound and outbound legs, establishing a change in velocity relative to the Sun, just as happens during a flyby maneuver. This shows why planetary flybys are used: the speed of the spacecraft relative to the Sun is increased, which decreases the travel time to the planet. In the case of gravity assist using Titan, the speed relative to Saturn is changed, with the goal of modifying Cassini's orbit around the planet.
- Measure the lengths of the vector components and the line segments for the inbound and outbound legs. Test whether the values match the Pythagorean theorem ($x^2 + y^2 = z^2$). If the results don't match, what could be causing the error(s)?

National Aeronautics and
Space Administration

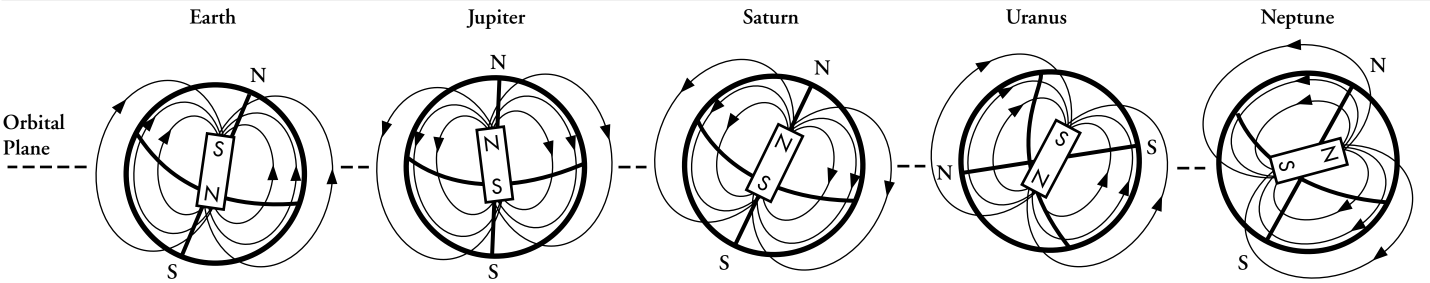
Educational Product	
Educators & Students	Grades 3–12

EB-2001-12-008-JPL

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?

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

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

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-009-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Sand or Rock: Finding Out From 1000 km

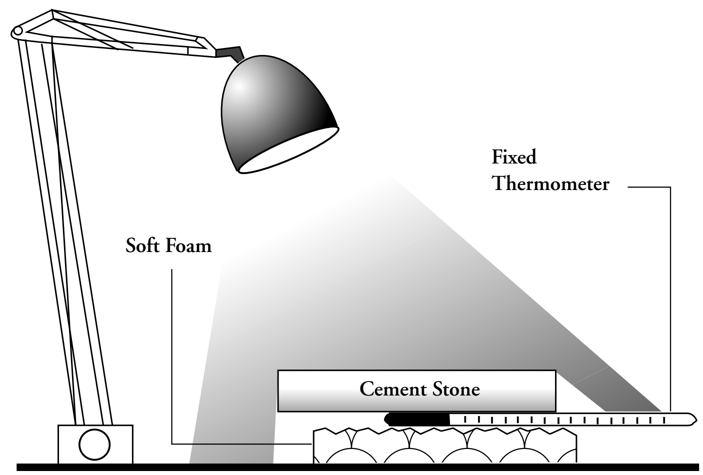
Objective

To observe the differences in thermal behavior between similar materials having different physical properties by making a series of temperature measurements and plotting the results.

Time Required: 3–6 hours

Saturn System Analogy: Remote sensing of thermal properties in the Saturn system

Keywords: Rock, Sand, Thermal Inertia, Thermal Infrared, Thermal Mass, Thermometer



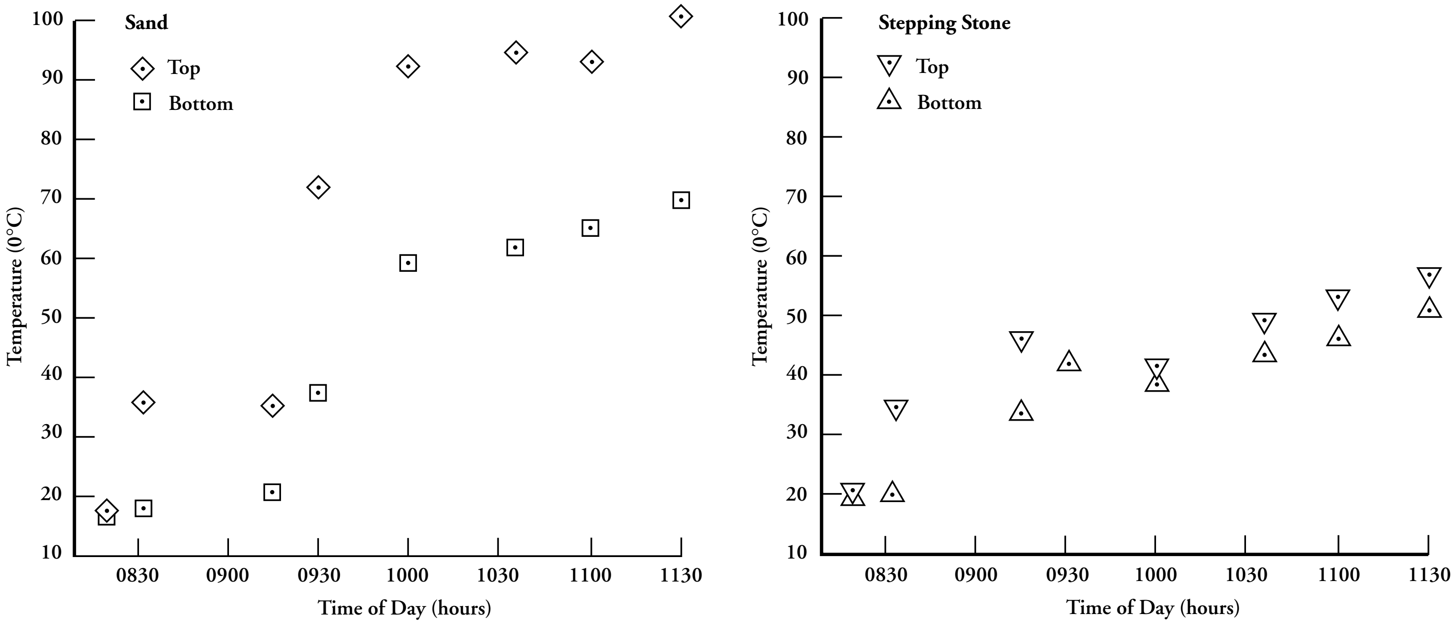
MATERIALS

- Cement stepping stone
- Loose sand with weight and color similar to that of the cement stone
- Cardboard to hold the sand in the same shape/size as the block (take-out pizza cartons may be particularly suitable)
- Four laboratory thermometers (that can be read to 1 °C)
- Scraps of foam rubber
- Optional: plastic bag
- Several hours of direct sunlight or two desk lamps (bulbs need to be of equal wattage)
- Notebook paper
- Graph paper

Discussion

Determining the physical characteristics of a surface from a long distance is not as difficult as it seems, given the right instrumentation. Spacecraft carrying instruments that operate in the thermal infrared (the portion of the electromagnetic spectrum sensed as heat that lies between visible light and radio waves) collect data that can provide strong evidence of the surface material type in the measured area.

Anyone who has visited a beach around sunset knows how fast the sand surface cools, but how it remains warmer underneath. Similarly, an unused fire ring that has been baking in the Sun during the day stays warm long after sundown. In this activity, students make measurements that illustrate the heating and cooling behavior of different materials.



Examples of thermal data recorded by a student. Some inconsistencies are apparent but the difference in thermal behaviors of the two materials is obvious.

Procedure

Start by constructing a cardboard tray with approximately the same shape and size as the stepping stone. The tray can be lined with a plastic bag to prevent leakage, if desired. Pour the sand into the tray, and place one thermometer bulb beneath the sand. The sand depth should equal the stone's thickness.

On the morning of the experiment, take the tray of sand and the stone and place both in an area that will receive direct sunlight through early afternoon. Place the thermometer bulb on top of a piece of foam rubber (so the thermometer won't be crushed), and then place the cement stone gently, in direct contact, on top of the thermometer. (On cloudy days, a pair of desk lamps, one for the sand and one for the stone can be used. Place the lamps equidistant from the centers of the tray of sand and the stepping stone.)

Next, place a thermometer on top of the cement stone and another on top of the sand. Hold the bulbs gently in contact with the surfaces using some foam rubber, and wait for the temperatures to stabilize. (For consistency, a book or some other weight can be used to hold the foam and thermometers in contact with the surfaces with the same force for each measurement.)

Make temperature readings of all four thermometers every 15 to 30 minutes, and record them for later plotting. (Read more or less frequently depending on the observed rate of surface temperature change.) Be sure to remove the surface thermometers between measurements so that insolation can continue, and remember that they need time to match the surface temperatures before those measurements are recorded.

In the afternoon, remove the sand and stone from the sunlight and record their temperatures as they cool down. Data recording can be shared among classes over the course of the day and combined later.

Thermal infrared recording instruments aboard spacecraft make similar measurements using remote sensing. By determining the wavelength (or frequency) of the peak of the black body curve of a surface, the temperature of that surface can be measured. It is more diagnostic to study the temperature behavior of a surface as it warms up from the cold of night, but measurements made after sunset are also informative. The placement of the stone and sand in the morning sunlight mimics the sunrise on a planetary surface, and removing the samples from sunlight to let them cool down mimics sunset.

The shapes of the warming and cooling curves will be quite different for the two samples. The sand will warm and cool quickly on the surface. The cement stepping stone will warm slowly and not as much as sand, and it will retain its warmth much longer after sunlight is removed. We can draw the same conclusion when looking at planetary surfaces: slowly cooling surfaces are solid and rapidly cooling surfaces may be fragments or loose, sandy material.

Extension

Experiment with different sizes of material, including fine and coarse-grained sand and various grades of gravel. Also compare wet and dry materials. Examine the effect of the color and reflectivity (albedo) of different samples of sand, gravel, and stone too. Try good insulators, like styrofoam or foam rubber, and good conductors (large scraps of metal), like iron and aluminum.

Several vendors offer temperature 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.

Noncontact infrared thermometers are available from several manufacturers at prices starting around $100. These sensors detect thermal infrared radiation (wavelength range of about 8 to 14 micrometers) and compute the temperature that would produce the amount of received infrared. Such a thermometer can be used instead of the surface-measuring laboratory thermometers described in this lesson, closely mimicking actual spaceflight measurements.

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.

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.

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.

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).

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

LEVEL 4 (GRADES 9–12)

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).

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http://ehb2.gsfc.nasa.gov/edcats/educational_brief.
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Student Worksheet — Sand or Rock: Finding Out From 1000 km

Procedure

1. Pour sand into the box. Place one thermometer into the sand so it touches the box bottom.

2. Place the stepping stone and the box of sand in direct sunlight.

3. Place a thermometer on top of a piece of foam rubber. Lift the cement stone and gently lower it onto the thermometer that is on top of the foam rubber.

4. Place a thermometer on top of the stone and another on top of the sand. Hold them in contact by placing a piece of foam rubber on top, and then a book on top of the foam rubber.

5. Wait for the thermometer temperatures to stabilize and record all four temperatures.

6. Remove the top thermometers.

7. Repeat all four temperature readings every 30 minutes (or at a time interval specified by your teacher) and record the data.

8. Later in the day, remove the sand and stepping stone from the sunlight.

9. Continue to take temperature readings as they cool down.

10. Plot your temperature results on graph paper to see how the two materials respond to the thermal environment.

Time	Sand Top	Sand Bottom	Stone Top	Stone Bottom

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-007-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Scattering: Seeing the Microscopic Among the Giants

Objective

To demonstrate how light waves passing through a medium can be used to determine the sizes of particles within the medium.

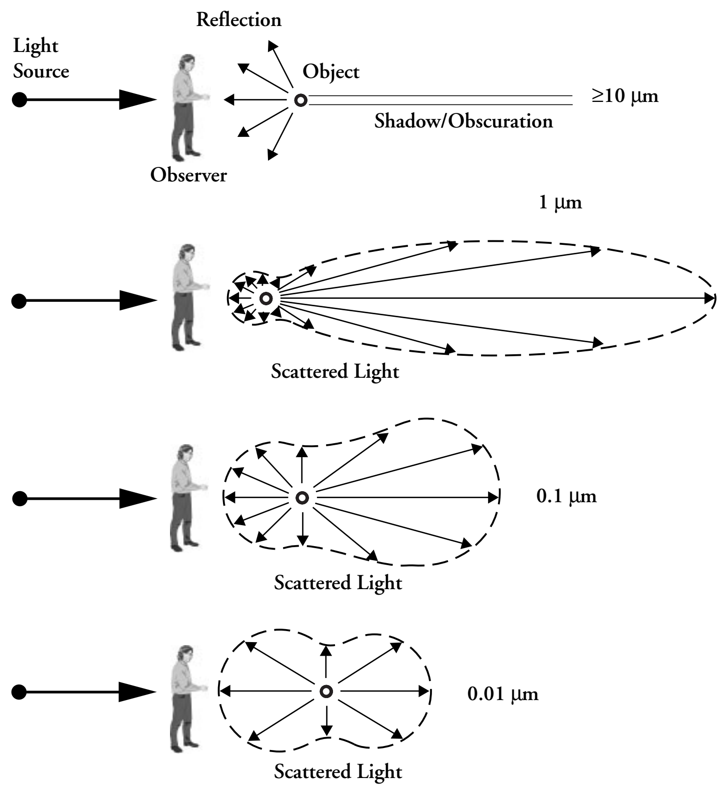
Time Required: 1 hour

Saturn System Analogy: Rings and Atmospheres of Saturn and Titan

Keywords: Aerosols, Obscuration, Particles, Reflection, Ring Spokes, Scattering, Shadow

MATERIALS

- Laser pointer (preferred; small focusable flashlight will work if laser is not available)
- Two large binder clips
- Two clear plastic or glass water bottles or cups (walls should be vertical), 50–100 millimeters in diameter (bottled-water or soft drink bottles are good as long as they have some noncorrugated surface)
- Tap water
- Milk (1/20 teaspoon per 12 ounces of water)
- Eye dropper
- Flour (less than or equal to 1/4 teaspoon – a “pinch” – per 12 ounces of water)
- Lazy Susan turntable (optional but helpful)
- Masking, duct, or electrical tape



Light striking an object is reflected or scattered depending on the object’s size. In each example, the amount of light sent in each direction is indicated by the length of the arrow. Objects larger than about 10 micrometers reflect light and create shadows. Objects about 1/100 micrometer in size scatter equal amounts of light back toward the source and away from the source, and lesser amounts in other directions. Objects about 1 micrometer in size exhibit strong forward scattering and weak backscattering.

Discussion

Our everyday view of the world relies on the reflection of light from the objects around us. This reflection is called “backscatter” when it is coming from small objects, and especially when the light source is *behind* the observer. Very tiny objects, approximately the size of the light source's wavelength, also send light *forward*, that is, *continuing from the source and away from* the observer. This effect, called "forward scattering," is useful to scientists in determining the sizes of particles in planetary atmospheres and ring systems.

Procedure

Adhere a piece of tape to one side of each container. Fill one container with water and place it on a Lazy Susan. In the other container, prepare a highly dilute solution of milk, thoroughly mixed so the water is just slightly whitened. (Start with 1/20 teaspoon of milk per 12 ounces of water; find the right proportions by experimentation in advance.) Use the binder clips as legs for the laser pointer, with one of them holding the laser's switch in the "on" position. Place the laser and sample bottle on the Lazy Susan.

CAUTION: BE CAREFUL NOT TO PROJECT THE LASER BEAM INTO ANYONE'S EYES. EYE DAMAGE CAN RESULT!

Align the laser pointer so that the beam passes through the water bottle and projects onto the piece of tape on the far side of the container. (The tape will ensure that the laser beam is not projected farther into the room and perhaps into someone's eyes.)

Darken the room, if possible. Project the laser beam through the container of plain water. Observe the brightness of the beam in the water as the Lazy Susan is rotated. The beam should pass straight through and be invisible or nearly so from all directions except directly along the beam.

Next, project the beam through the dilute milk solution. Laser light scattering from tiny particles of milk will delineate the laser beam. The intensity of the beam is stronger or weaker according to the scattering properties of the milk particles (primarily their size) as the assembly is turned in front of fixed observers. Observers should note how the beam reaches maximum brightness when they are looking in nearly the direction it is coming from.

Mix flour with the plain water (less than or equal to 1/4 teaspoon flour per 12 ounces of water) in the first container. Project the laser beam through the dilute flour solution. The scattering properties of the milk and flour solutions are different because there is greater variation in flour particle size than in milk particle size. Store-bought milk is homogenized (its particles are reduced to the same size) so the cream stays in solution. With either mixture, notice how the beam intensity diminishes with distance (looking from the side).

As an everyday terrestrial example, recall that bright headlights in fog may or may not help drivers, depending on particle size. Reflections from large fog droplets make night visibility with bright headlights poorer than with dimmed headlights.

Additional Experiments and Questions

Try other materials that will remain suspended in liquid for useful amounts of time. Corn meal, corn starch, oat bran, silt from a local stream bed, glitter, salt, and sugar will provide varying results. Try transparent carbonated beverages, including their foams, and smoke trapped in a jar. Which work? Which don't? Why? Estimate particle sizes in gelatin based on its scattering properties. Can you detect different particle shapes based on scattering?

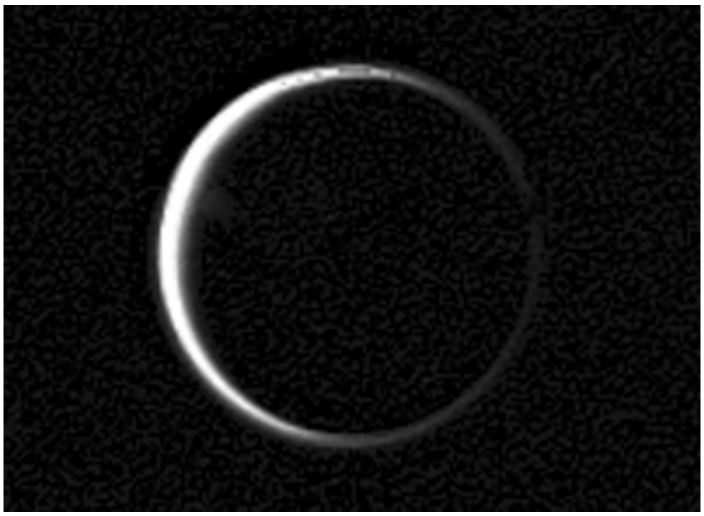
A simple photometer can be used to compare the brightness of the beam as a function of the viewing angle. Mount a solar cell on one end of an empty toilet paper tube so the tube shades the light-sensitive surface from ambient light. Attach the leads to a millivolt meter (or multimeter). With the sample bottle centered on the Lazy Susan, align the laser on the Lazy Susan so it shines through the center of the bottle and onto the solar cell.

Record voltage measurements every 30 degrees around the full circle for each sample bottle. Plot the voltage as a proportioned line segment every 30 degrees around a point. Diluted milk will produce a pattern like the 1-micrometer pattern illustrated on the front of this Educational Brief.

Several vendors offer light-measuring photometry systems that acquire data and plot it under computer control. Such systems can be adapted for quantitative measurements of the sample bottles in this activity. Computerized data acquisition is common in many laboratories.

Is the color of the daylight sky related to sunset colors and scattering?

Because scattering is a phenomenon dependent on both the wavelength of the wave being scattered and on the size of the scatterer, much can be learned by working in well-separated parts of the electromagnetic spectrum. Where light waves tell us about the sizes of small particles, radio waves can tell us about the sizes of objects ranging in size from golf balls to houses.



This picture of Titan taken by Voyager 2 shows sunlight scattered by aerosols in Titan's atmosphere all around the satellite. If there were no atmosphere to scatter light, only a thin crescent, like the Moon just past new, would be visible. A fuzzy tennis ball shows a similar effect when viewed with a single, compact bright light in the background.

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.

8. Understands the structure and properties of matter.

LEVEL 1 (GRADES K–2)

Knows that different objects are made up of many different types of materials (e.g., cloth, paper, wood, metal) and have many different observable properties (e.g., color, size, shape, weight).

Knows that things can be done to materials to change some of their properties (e.g., heating, freezing, mixing, cutting, dissolving, bending), but not all materials respond the same way to what is done to them.

LEVEL 2 (GRADES 3–5)

Knows that substances can be classified by their physical and chemical properties (e.g., magnetism, conductivity, density, solubility, boiling and melting points).

Knows that materials may be composed of parts that are too small to be seen without magnification.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

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).

LEVEL 3 (GRADES 6–8)

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

LEVEL 4 (GRADES 9–12)

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.

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Student Worksheet — Scattering: Seeing the Microscopic Among the Giants

Procedure

Your teacher will set up the experiment.

The teacher will shine the laser through a glass of water. What do you see as the glass is rotated?

The teacher will then add milk, flour, or some other substance. How does the laser beam change as it passes through the water mixture?

The teacher will experiment with different substances in the water. Observe how the beam changes as each different material is used.

Questions

What are some examples of light scattering in everyday life?

Which substances demonstrate scattering? Which don't?

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-014-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

When the Sky Is Falling

Objective

Impact cratering has shaped planetary surfaces and life on Earth. Students will explore the cratering process and understand the relationship between the projectile, the energy it delivers, and the landform it creates.

Time Required: 1–2 hours

Saturn System Analogy: Cratered satellite surfaces

Keywords: Asteroid, Collision, Crater, Impact, Kinetic Energy, Mass, Meteorite, Meteoroid, Volume

The Barringer Meteor Crater in Arizona.

MATERIALS

- Baking pan or cardboard box at least 7 centimeters deep, to make a portable sandbox (the depth is necessary to avoid bouncing the projectiles off the bottom)
- Projectiles: BBs, marbles, and bearing balls (various sizes)
- Sand (to fill the pan)
- Optional: flour, cocoa, or colored sand to provide a thin layer on top of the sand that will better show the effects of the impact; colored sand is available from craft stores
- Ruler or tape measure
- 3 meters of string (may need to be longer depending on your laboratory situation); heavy washer (tied to end of string to make a plumb bob)
- Piece of cardboard (to smooth sand surface)
- Magnet (to help retrieve bearing balls that get buried)
- Optional: one serving of cooked oatmeal and spoon (for experiment extension)

Discussion

Craters are found on nearly every solid body in the solar system. The exceptions are Jupiter's moon Io, which continually resurfaces itself with lava flows that cover any craters formed there, and perhaps Titan (a moon of Saturn), whose surface we haven't yet seen in detail. Tiny craters are found on Moon rocks, they have been seen on asteroids, and they are found on the largest solid planet in the solar system, Earth.

The process of crater formation on planets involves the transformation of the energy of motion of a projectile (a meteoroid or small asteroid) into heat. This heat, in turn, causes an explosion that creates the crater. Crater diameters typically range from 10 to 20 times greater than the size of the projectile. Large projectiles, on the order of 1 to 15 kilometers in size, can be very destructive. The devastation resulting from the impact, earthquakes, tsunamis, and atmospheric effects can cover state-size territories or even larger and can lead to mass extinctions, such as that of the dinosaurs 65 million years ago.

Cosmic velocities exceeding 11 kilometers per second cannot be reproduced in the school laboratory. Still, cratering by excavation rather than explosion will demonstrate the principles involved.

Procedure

In the simplest experiment, projectiles are dropped one at a time from a fixed height into the sandbox. The diameter of the excavated crater is measured and the data are recorded for further analysis. With a little more effort, additional data can be acquired that will significantly add to the scientific investigation.

Gravity provides a constant, repeatable impact velocity for the different-sized projectiles. For all the projectiles recommended for experimentation here, air resistance should be neglected. The projectiles can be dropped from desk height, some shelf or ladder, and if available, from the upper stories of a building. Use the plumb bob to center the sandbox directly under the projectile release point. Smooth the sand before each drop. After impact, gently remove the projectile so as not to damage the crater. Measure the diameter of the crater. (These measurements are more challenging than might first be thought. Deciding where the crater rim peaks is not always easy and individuals will make different choices. Expect experimental variability in these measurements.) Repeat the smooth-drop-measure-record process for each projectile at each of several different heights.

Before the drop tests are made, students should prepare a table of characteristics for the projectiles. Each projectile should be weighed and its diameter measured, and the volume and density of each projectile should be computed. The kinetic energy at impact can be calculated from $KE = 1/2(mv^2)$, where m is the measured ("weighed") mass and v is the velocity just before impact. The velocity can be computed from $v = (2gL)^{1/2}$ where g is the gravitational acceleration 9.8 m/s^2 and L is the drop distance.

Once these parameters and crater sizes are known, have students compare various parameters with crater diameter. While diameter and volume will show little relationship to crater size, mass and kinetic energy will show a strong relationship.

Extensions

An impact has more effects than the excavation of a crater. The initial contact with the surface generates a far-ranging spray of material that can cover an area much larger than the sandbox. This is one good reason to do this activity outdoors.

As the projectile impacts, the excavation process not only sprays surface material out, but subsurface material may be thrown short distances or overturned to help create the crater rim. These effects can be studied in more detail by using two or more layers of colored sand/flour/cocoa (so that the layers are distinctive). New layers will have to be added after each smoothing if additional drop tests are conducted.

This analogy to impact cratering in the solar system suffers from a serious deficiency: the projectiles remain whole after impact, something that is uncommon except for small meteoroids striking Earth. Most large cosmic projectiles explode on impact with the surface. To observe this effect in these classroom scale experiments, drop individual spoonfuls of cooked oatmeal from various heights. The oatmeal has enough tensile strength to hold together as it falls (large water droplets will break up and gelatin holds together on impact) but will "shatter" on impact with the sandbox, splattering oatmeal and sand over a fairly wide area. Use food coloring in the oatmeal to help distinguish it from sand after the impact. Note that experiments with oatmeal are messy enough that they should be conducted outdoors.

Real-world craters often have central peaks caused by the rebound of subsurface material at the end of the collision process. Do classroom craters develop central peaks? Why or why not?

Numerous challenges to the students can be made for measuring the drop distance. While a tape measure is the obvious solution and measuring the length of the plumb line is easy, other physics can be used. For example, a precision barometer can be used as an altimeter.

The height can be measured by timing the duration of the fall: $s = 1/2(gt^2)$. A stopwatch is a necessity, and experimental error due to reaction time will be notable and variable among students.

A stopwatch can also be used to measure the period of a pendulum extending from the drop point to the top of the sand (move the sandbox out of the way so the pendulum can swing freely). The length L = drop height can be determined by timing the period of the pendulum, $T = \pi(L/g)^{1/2}$. Experimental error will creep in with the timing; compare the period measured for a single swing back and forth with the period determined by measuring the duration of 5 and 10 swings and computing the average period.

Compare the potential energy of the projectiles, $PE = mgL$, with the projectiles' kinetic energy.

Sporting goods stores sell special baseballs that use time of flight to determine the speed of a pitch. These can be used to measure the average speed of your projectiles (make sure someone catches the baseball, rather than letting it hit the sandbox hard).

What is the effect of air resistance on the speed of the projectiles? How does it vary with size?

Do projectiles with different shapes generate different crater shapes?

Use a slingshot to create craters with angles of impact different from 90 degrees (or tilt the sandbox at various angles to the maximum angle of repose (at which a landslide starts). Do the craters have different shapes? Why or why not?

Several vendors offer accelerometers and speed-measuring sonar systems that acquire data and plot it under computer control. Such systems can be adapted for quantitative measurements of the projectiles in this activity. Computerized data acquisition is common in many laboratories.

Have the students watch the movies *Deep Impact* and *Armageddon*. Are the asteroids and comets in the films realistic? (This might take a bit of background research.) Are the effects of the impactors portrayed realistically? Consider whether small projectiles "burn" all the way to Earth's surface and if they are moving so fast that a nearby observer, as presented by the movies, would be able to follow their motion as they came down. Are the effects of the large impact realistic? Are there other effects that might occur?

Education Standards

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

Science Standards

3. Understands essential ideas about the composition and structure of the universe and Earth's place in it.

LEVEL 3 (GRADES 6–8)

Knows characteristics and movement patterns of the nine planets in our solar system (e.g., planets differ in size, composition, and surface features; planets move around the Sun in elliptical orbits; some planets have moons, rings of particles, and other satellites orbiting them).

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that the position of an object can be described by locating it relative to another object or the background.

LEVEL 2 (GRADES 3–5)

Knows that an object's motion can be described by tracing and measuring its position over time.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

Mathematics Standards

3. Uses basic and advanced procedures while performing the processes of computation.

LEVEL 2 (GRADES 3–5)

Adds, subtracts, multiplies, and divides whole numbers and decimals.

Solves real-world problems involving number operations (e.g., computations with dollars and cents).

LEVEL 3 (GRADES 6–8)

Adds, subtracts, multiplies, and divides whole numbers, fractions, decimals, integers, and rational numbers.

6. Understands and applies basic and advanced concepts of statistics and data analysis.

LEVEL 1 (GRADES K–2)

Understands that observations about objects or events can be organized and displayed in simple graphs.

LEVEL 2 (GRADES 3–5)

Understands that data represent specific pieces of information about real-world objects or activities.

Organizes and displays data in simple bar graphs, pie charts, and line graphs.

Reads and interprets simple bar graphs, pie charts, and line graphs.

LEVEL 3 (GRADES 6–8)

Reads and interprets data in charts, tables, plots (e.g., stem-and-leaf, box-and-whiskers, scatter), and graphs (e.g., bar, circle, line).

Organizes and displays data using tables, graphs (e.g., line, circle, bar), frequency distributions, and plots (e.g., stem-and-leaf, box-and-whiskers, scatter).

LEVEL 4 (GRADES 9–12)

Selects and uses the best method of representing and describing a set of data (e.g., scatter plot, line graph, two-way table).

9. Understands the general nature and uses of mathematics.

LEVEL 2 (GRADES 3–5)

Understands that numbers and the operations performed on them can be used to describe things in the real world and predict what might occur.

Understands that mathematical ideas and concepts can be represented concretely, graphically, and symbolically.

LEVEL 3 (GRADES 6–8)

Understands that mathematicians often represent real things using abstract ideas like numbers or lines; they then work with these abstractions to learn about the things they represent.

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 — When the Sky Is Falling

Procedure

- Provide a description of the type of sand surface into which the projectiles will be dropped.
- Prior to drop tests, write down:

  Drop distance (L) that will be used ___________________

- For each projectile that will be used, measure:

  Mass

  Diameter

- Then, for each projectile, calculate:

  Volume

  Density

  Velocity

  Kinetic energy

- Record the data in a table, including these parameters:

  Projectile description

  Mass (g)

  Diameter (cm)

  Volume (cm^3)

  Density (g/cm^3)

  Velocity (cm/sec)

  Kinetic energy ($g\text{-}cm^2/sec^2$)

- After the drop test, record the drop height and the diameter of the crater formed by the projectile.
- Required equations:

  Density = mass/volume

  Kinetic energy (KE) = $1/2(m^*v^2)$

  Velocity, $v = (2^*g^*L)^{1/2}$, where g = acceleration due to gravity = 9.8 m/s^2

  Volume = $4/3(\text{pi}^*r^3)$, where pi = 3.14159

  R = radius = 1/2(diameter)

- Plot four graphs, of crater diameter versus

  1. Projectile mass
  2. Projectile volume
  3. Projectile diameter
  4. Projectile kinetic energy

Which parameter(s) show the strongest relationship to crater size? What mathematical relationships are exhibited?

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-010-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Monitoring the Sun's Corona

Objective

To learn how spacecraft use the relative positions of the Sun, Earth, and a spacecraft to study the Sun's outer region, called the corona.

Time Required: 1 hour

Saturn System Analogy: Cassini's Radio Science Subsystem

Keywords: Corona, Plasma, Solar Conjunction

One of the giant antennas in NASA's Deep Space Network.

MATERIALS

1. Shared Effect Demonstration

- Laser pointer. *The laser pointer will serve as the transmitted signal.*
- Clear plastic food wrap. *Wrap that is wrinkled and has many layers is recommended, mounted on a coat-hanger or cardboard frame for easy handling. The food wrap will serve as the coronal plasma. Transparent packaging tape can also be used.*
- Projection screen or a large sheet of white paper. *The projection screen or white paper will serve as the signal receiver.*
- Two large binder clips

2. Direct Analog Demonstration

- High-intensity AA or AAA flashlight with a removable reflector that uses a grain-of-wheat size bulb. *The flashlight should be able to stand in view of the students so that the tiny, brilliant filament is visible. The flashlight will serve as part of the transmitter.*
- Separate pieces of transparent red and blue filter material. *This can be a candy wrapper, cellophane gift wrapping material, colored food wrap, or commercial photographic filter material. The filter material will also serve as part of the transmitter.*

- Clear plastic food wrap. *Wrap that is wrinkled and has many layers is recommended, mounted on a coathanger or cardboard frame for easy handling. The food wrap will serve as the coronal plasma. Transparent packaging tape can also be used.*

3. Hybrid Demonstration

- Overhead projector. *The projector serves as part of the transmitter.*
- Projection screen or a large sheet of white paper. *The projection screen or white paper will serve as the signal receiver.*
- Opaque cardboard or paper to completely cover the projector top
- Ruler; tape measure; fine-point pencil
- Transparent red and blue filter material. *This can be a candy wrapper, cellophane gift wrapping material, colored food wrap, or commercial photographic filter material. The filter material will also serve as part of the transmitter.*
- Clear plastic food wrap. *Wrap that is wrinkled and has many layers is recommended, mounted on a coathanger or cardboard frame for easy handling. The food wrap will serve as the coronal plasma. Transparent packaging tape can also be used.*

Discussion

On many space missions, a spacecraft observed from Earth can be seen to travel behind the Sun. This spacecraft–Sun–Earth alignment is called solar conjunction. During solar conjunction, the increased distance from Earth and the interference of solar radio emissions seriously degrade the quality of transmitted information — known as telemetry — from a spacecraft to Earth, where NASA's Deep Space Network antennas receive the information. During solar conjunction, scientists have the opportunity to study the Sun's outermost layer, called the corona.

The corona is composed of plasma, a "gas" of atoms broken down into negatively charged electrons and positively charged ions. The corona is the source of the solar wind, a stream of plasma that blows out from the Sun at speeds from 300 to 1600 kilometers per second (200 to 1000 miles per second). The solar wind is so strong and far-reaching that it can be detected by spacecraft flying beyond Pluto.

Telemetry from a spacecraft is transmitted back to Earth via radio waves. When in solar conjunction, these radio waves must pass through both the corona and solar wind. The electrified nature of the corona and solar wind can distort the signal before it reaches Earth. Over a period of a few days, radio waves from a spacecraft in solar conjunction may pass through plasma that is dense enough and variable enough to noticeably affect reception. (This phenomenon can be compared to the way water waves distort the view of objects on the floor of a swimming pool or to the twinkling of stars caused by Earth's atmosphere.) By analyzing variations in the telemetry data from a spacecraft in solar conjunction, scientists can study the corona and solar wind. For example, if a spacecraft can transmit at two widely different radio frequencies, scientists can assess the density variation of electrons in the plasma through which the telemetry signal passes. In the two-color demonstrations described below, the ratio of frequencies for red and blue is less than half of the ratio for the radio frequencies used. Thus, this optical demonstration will not easily display the differences in the signals seen with radio waves.

Background

The bending of light and radio waves by a medium depends on the refractive index of the medium and the thickness of the refracting (bending) layer. Radio signals from a spacecraft in solar conjunction traverse millions of kilometers of very low refractivity solar plasma while the light waves in these demonstrations traverse very thin layers of plastic with more refractivity.

The physics of the light-plastic and radio-plasma interactions are not the same. But these demonstrations using light present results that are analogous to the real investigations researchers do. The physics of the interactions (not just the results) are analogous for radio studies of planetary atmospheres, during which the radio signals pass through a planet's atmosphere on their way to Earth (a geometric condition called an occultation).

Procedure

Three methods using visible-light sources illustrate the effects of solar plasma on spacecraft-transmitted radio waves. In the Direct Analog Demonstration, the flashlight serves as the "spacecraft" and the students are the "receivers" of the Deep Space Network.

Shared Effect Demonstration

Darken the room, if possible. Project the laser beam toward the screen using one binder clip as a stand and the other clip to hold the laser's switch in the "ON" position (no specific distance from laser to screen is required). The projected laser light will look like a "clean" point of light.

CAUTION: BE CAREFUL NOT TO SHINE THE LASER BEAM INTO ANYONE'S EYES. EYE DAMAGE CAN RESULT.

Pass the plastic wrap across the laser beam. Observe how the laser beam is broadened, distorted, bent, and scattered. Move the plastic wrap across the beam and at different distances from the laser pointer. Observe how the laser beam changes due to the variations in the density and position of the plastic wrap.

Direct Analog Demonstration

With the flashlight bulb exposed (remove the reflector assembly), wrap the colored filter material around the flashlight so that the emitted light is colored. The combination of the filter and light serves as the spacecraft sending radio signals. Have the students observe the emitted light as you pass the plastic wrap between the students and the bulb. Students will notice the distortion of the light. Switch colored filters and repeat. Are there noticeable differences in the distortion of red and blue light? The light rays from the flashlight should traverse the same strip of plastic wrap if possible.

Hybrid Demonstration

Punch a small (less than 5 millimeters), sharp-edged circular hole in the middle of the cardboard projector cover. Tape a color filter over the hole. A colored spot will be projected onto the screen. Have the students observe the colored spot. Pass the plastic wrap over the hole. Students will notice the distortion of the image of the hole. Switch colored filters and repeat. Are there noticeable differences in the distortion of the image of the hole? The light beam from the projector should traverse the same strip of plastic wrap if possible.

Extension

These demonstrations can be quantified using a solar cell and a multimeter. Record the voltage at specific, repeatable points where light from the source passes through the plastic. Several vendors offer light-measuring photometry systems that acquire data and plot it under computer control. Such systems can be adapted for the measurements in this activity. Computerized data acquisition is common in many laboratories.

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.

12. Understands the nature of scientific inquiry.

LEVEL I (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 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.

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).

LEVEL 4 (GRADES 9–12)

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.

Uses technology (e.g., hand tools, measuring instruments, calculators, computers) and mathematics (e.g., measurement, formulas, charts, graphs) to perform accurate scientific investigations and communications.

***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 — Monitoring the Sun's Corona

Procedure

The teacher will set up and describe the three demonstrations for you.

Shared Effect Demonstration

- Project the laser beam onto the screen. Observe how the beam looks on the screen.
- Pass a piece of plastic wrap across the laser beam. Observe how the beam is affected by the plastic wrap.
- Try this at different distances from the laser and observe the effect.
- What role does the distance of the plastic wrap "plasma" from the laser play in distorting the beam?

Direct Analog Demonstration

- Wrap a piece of colored filter material around the flashlight bulb — don't let the bulb melt the filter.
- Pass the plastic wrap across the beam of light. Observe how the light source is distorted.
- Repeat this by passing the plastic wrap at different distances across the beam of light and with the other colored filter. What role does the distance of the plastic wrap "plasma" from the flashlight play in distorting the beam? Is more distortion seen with one color or the other? Why or why not?

Hybrid Demonstration

- Punch a small, sharp-edged circular hole in the middle of the cardboard cover.
- Tape the colored filter material over the hole.
- Pass the plastic wrap across the beam of light. Observe how the image is distorted.
- Repeat this after changing the colored filter. Is more distortion seen with one color or the other? Why or why not?

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-022-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Can a Spacecraft Use Solar Panels at Saturn?

Objective

To demonstrate the effect of the inverse square law of illumination with distance.

Time Required: 1 hour

Saturn System Analogy: The reduction in solar illumination at Saturn's distance compared to Earth's distance from the Sun.

Keywords: Current, Illumination, Inverse Square Law, Photovoltaic, Power, Spacecraft Power, Solar Cell, Solar Energy, Voltage

MATERIALS

- One silicon solar cell (available at an electronics parts store for a few dollars)
- Standard metal window screen material. *A strip somewhat wider than the solar cell and long enough for 10 layers to be placed in front of the cell is necessary. (A hardware store might have free scrap available. If not, a strip of this size costs less than $5.)*
- Digital multimeter (available at an electronics parts store for $10 to $30)
- Optional: desk lamp (available at any variety store for a few dollars)

Background

Students of all ages ask why spacecraft at Mars can use solar panels when Cassini cannot make use of solar power at Saturn. Working with a simulated Saturnian illumination environment, students will use commercially available solar cells to determine the approximate power output of a solar cell at Saturn.

One of the laws of physics states that as energy radiates equally in all directions from a source, the intensity (brightness) decreases at a rate that is proportional to the square of the distance that the energy has traveled. In other words, if a light bulb is turned on and you measure the illumination 1 meter (about 1 yard) from the light bulb (the source) and then you measure the brightness of the light 2 meters (approximately 2 yards) away from the light bulb, the illumination 2 meters away is 4 times weaker than the illumination at 1 meter from the bulb. Doubling the distance reduces the illumination by a factor of two squared, or four. Tripling the distance reduces the illumination by a factor of three squared, or nine times. This is called the "inverse square law" and is applicable to all forms of electromagnetic radiation as well as to the force of gravity, sound intensity, and other forms of energy transfer.

Solar panels convert solar energy directly to electricity using photovoltaic cells. When sunlight strikes the photovoltaic cell, a small voltage is generated. Wires connected to the cell permit an electric current to flow through circuits to power various electrical and electronic components. Electricity generated this way is used on Earth and on spacecraft to power electronics, motors, and science instruments.

Missions to Mars and Venus, as well as satellites in Earth orbit, have solar panels. However, at increasing distance from the Sun, the amount of available sunlight drops below the level at which the use of solar panels is practical. Either the spacecraft must be very small or the solar panels must be very large. Beyond Jupiter's distance, solar panels cannot produce enough power to operate a spacecraft, no matter what size the panels and spacecraft are.

Facts You Need

- Earth is 149,600,000 kilometers (92,970,000 miles) from the Sun.
- Saturn is 1,429,400,000 kilometers (888,200,000 miles) from the Sun (9.555 times more distant than Earth).
- Cassini needs 628 watts of power to operate all its systems at Saturn.

Procedure

1. Measure the dimensions of the power-generating area of the solar cell with a millimeter ruler (sometimes the protective case is much larger than the actual working area).
2. Attach the leads of the solar cell to the same color leads of the digital multimeter (red is positive, black is negative; no damage will be done if the leads are mismatched). Alligator or wire clips on the multimeter leads will be easier to use than standard probes, or use alligator clip jumpers (also available from electronics parts stores) to make the connections.
3. Set the multimeter to current (or voltage) and turn it on.
4. Record the current and then switch to voltage and record that value, both as generated by the solar cell under: (1) ambient room light, (2) direct, mid-day sunlight, and (3) at measured, recorded distances from a bare 100-watt light bulb. If the meter settings are adjustable, the multimeter range can be set under 5 volts and less than a few tens of milliamperes for most single solar cells.
5. Now place 10 layers of metal window screen mesh between the light source(s) and the solar cell. It may be easiest to simply wrap the mesh around the cell 10 times. This will simulate the amount of sunlight falling on Saturn.

If the solar cell is not covered with a protective case, be careful not to damage the active surface of the solar cell. Also, be careful to avoid shorting the solar cell with the metal mesh. Plastic food wrap will provide minimal but effective scratch and short circuit protection. Small clear pieces of glass or plastic or a clear transparent plastic box with holes for the leads can be used to provide more protection.

For proper comparisons, the current and voltage measurements should be made with the same transparent protective layers in place for both direct lighting and mesh-reduced lighting experiments. Record current and voltage generated by the mesh-covered solar cell at the same places as the measurements made when it was uncovered.

Calculations

- Determine the active, electricity-generating area of the solar cell by multiplying the measured length times the width.
- Compute the power generated by the cell under the varied lighting conditions: multiply the voltage times the current.
- If measurements were made at different distances from a light bulb, plot the power output as a function of distance from the bulb. Also, compute some ratios between various distances from the bulb and compare the power ratios from those distance pairs — does the power go down as the square of the distance?
- Using the ratio of direct-Sun power output to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Earth's surface.
- Using the ratio of direct-Sun output from the window screen wrapped solar cell to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Saturn's distance from the Sun and compare to the first array size.
- Compare the ratio of array sizes computed above with the square of Saturn's distance from the Sun, relative to Earth (i.e., 9.555^2). This is an indication of how well the transmission of 10 layers of window screen actually mimics the decrease in illumination at Saturn's distance from the Sun. How many layers of your window screen reduce the illumination by 9.555^2?

Extension

Several vendors offer light-measuring photometry systems that acquire data and plot it under computer control. Such systems can be adapted for quantitative measurements of the illumination or voltage/current/power generated. Computerized data acquisition is common in many laboratories.

Determine whether a cloudy day on Earth equals the amount of sunlight falling on Saturn's cloud tops. How many minutes after sunset does skylight illuminating your solar cell equal the direct sunlight falling on Saturn?

Distance from the Sun is not the only limitation in using solar cells to power Cassini at Saturn. The environment at Saturn is much colder than the environment around Earth. The extreme cold affects the efficiency of energy generation by silicon solar cells. What are some possible ways of boosting the efficiency of a solar cell at Saturn? Are there other types of solar cells (other than silicon) that are more efficient and/or more resistant to temperature extremes?

Education Standards

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

Mathematics Standards

3. Uses basic and advanced procedures while performing the processes of computation.

LEVEL 2 (GRADES 3–5)

Solves real-world problems involving number operations (e.g., computations with dollars and cents).

LEVEL 3 (GRADES 6–8)

Adds, subtracts, multiplies, and divides whole numbers, fractions, decimals, integers, and rational numbers.

Understands exponentiation of rational numbers and root-extraction (e.g., squares and square roots, cubes and cube roots).

4. Understands and applies basic and advanced properties of the concepts of measurement.

LEVEL 3 (GRADES 6–8)

Understands the relationships among linear dimensions, area, and volume and the corresponding uses of units, square units, and cubic units of measure.

6. Understands and applies basic and advanced concepts of statistics and data analysis.

LEVEL 2 (GRADES 3–5)

Understands that data represent specific pieces of information about real-world objects or activities.

Science Standards

9. Understands the sources and properties of energy.

LEVEL 1 (GRADES K–2)

Knows that the Sun supplies heat and light to Earth.

Knows that electricity in circuits can produce light, heat, sound, and magnetic effects.

LEVEL 3 (GRADES 6–8)

Knows that energy is a property of many substances (e.g., heat energy is in the disorderly motion of molecules and in radiation; chemical energy is in the arrangement of atoms; mechanical energy is in moving bodies or in elastically distorted shapes; electrical energy is in the attraction or repulsion between charges).

Knows that electrical circuits provide a means of transferring electrical energy to produce heat, light, sound, and chemical changes.

12. Understands the nature of scientific inquiry.

LEVEL 2 (GRADES 3–5)

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

LEVEL 4 (GRADES 9–12)

Uses technology (e.g., hand tools, measuring instruments, calculators, computers) and mathematics (e.g., measurement, formulas, charts, graphs) to perform accurate scientific investigations and communications.

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 — Can a Spacecraft Use Solar Panels at Saturn?

Procedure

1. Measure the dimensions of the active, power-generating area of the solar cell with a millimeter ruler (sometimes the protective case is much larger than the actual working area).

2. Attach the leads of the solar cell to the same color leads of the digital multimeter (red is positive, black is negative; no damage will be done if the leads are mismatched).

3. Set the multimeter to current (or voltage) and turn it on.

4. Record the current and then switch to voltage and record that value, both as generated by the solar cell under: (1) ambient room light; (2) direct, mid-day sunlight; and (3) at measured, recorded distances from a bare 100-watt light bulb. If the meter settings are adjustable, the multimeter range can be set under 5 volts and less than a few tens of milliamperes for most single solar cells.

5. Now place 10 layers of metal window screen mesh between the light source(s) and the solar cell. It may be easiest to simply wrap the mesh around the cell 10 times. This will simulate the amount of sunlight falling on Saturn.

Calculations

- Determine the active, electricity-generating area of the solar cell by multiplying the measured length times the width.

- Compute the power generated by the cell under the varied lighting conditions: multiply the voltage times the current.

- Plot the power output as a function of distance from the bulb. Also, do some ratios between various distances from the bulb and compare the power ratios from those pairs — does the power go down as the square of the distance?

- Using the ratio of direct-Sun power output to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Earth's surface.

- Using the ratio of direct-Sun output from the screen-wrapped solar cell to active solar cell area, compute the area of a solar cell array necessary to generate 628 watts at Saturn's distance from the Sun and compare to the first array size.

- Compare the ratio of array sizes computed above with the square of Saturn's distance from the Sun, relative to Earth (i.e., 9.5552). This is an indication of how well the transmission of 10 layers of window screen actually mimics the decrease in illumination at Saturn's distance from the Sun. How many layers of your window screen reduce the illumination by 9.5552?

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-019-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

The Spinning World of Spacecraft Reaction Wheels

Objective

To demonstrate how reaction wheels (also known as momentum wheels) take advantage of Newton's Third Law to control a spacecraft's orientation.

Time Required: 1 hour

Saturn System Analogy: Cassini's Reaction Wheel Assembly and its use during orbital operations at Saturn

Keywords: Gyroscope, Interplanetary, Momentum, Orientation, Reaction

MATERIALS

- Cassini spacecraft paper model (available through the Cassini web site at *http://saturn.jpl.nasa.gov/cassini/english/teachers/classroom.shtml/*); also suitable are paper models of interplanetary spacecraft (available free from NASA at *http://spacelink.nasa.gov*); or commercially made models (an Internet search on "spacecraft models" will provide sources).
- Small battery-powered electric motor (available at discount hobby stores); for example, the 3-volt miniature DC motor available for $4 at *http://www.ScientificsOnline.com/Products/*
- One or more small wheels (available at hobby shops that carry an assortment of wheels intended for toy cars, airplanes, etc.). *Wheels should be different sizes that can be attached to the motor shaft. Each should weigh a few ounces and be an inch or two in diameter.*
- D-cell battery. *This will provide half of a 3-volt motor's rated performance, which is just about right.*
- About 6 feet of thin wire pair, 28 gauge or so (available at electronics parts stores and hardware stores that carry a wide ranges of wire gauges). *Use stranded rather than solid-conductor wire to provide flexibility. The thinner, longer, and more flexible, the better.*
- Optional: a switch or pushbutton, with a normally open circuit (available from electronics parts stores for a few dollars). *If the switch is not used, the motor is controlled by touching the wire to the battery terminal.*
- Optional: a potentiometer (available from electronics parts stores) or other means to vary the voltage supplied to the motor

Discussion

Most spacecraft require a specific orientation, known as the spacecraft attitude, to do the work we assign the robots. Small rocket engines (control jets) are sometimes used alone, or in combination with other systems. Reaction wheels are used by many interplanetary spacecraft as well as Earth-orbiters such as the Hubble Space Telescope and communications satellites to orient the spacecraft, specifically to point instruments, antennas, or other subsystems at chosen targets.

A spacecraft's reaction wheels are typically a few kilograms to tens of kilograms of mass and are driven by electric motors powered by the spacecraft's electrical power supply. They are managed and controlled by the spacecraft's onboard attitude control computer.

Reaction wheels should not be confused with gyroscopes. Reaction wheels provide the physical means to rotate a spacecraft, based on the principle of angular momentum transfer and Newton's Third Law of action–reaction.

Gyroscopes provide attitude reference information, based on precession and rigidity-in-space principles. As a gyroscope spins, it resists being tipped over. In spaceflight operations, this means that a spinning gyroscope provides a stable reference to a specific direction. This is the principle of "rigidity-in-space." If a gyroscope is forced to tip, it will tip in a direction 90 degrees from the direction of the push. This is precession. In aircraft, the principle of precession is used in turn indicators to displace a pointer needle left or right of center as the plane makes a turn.

Setup

The experimenter obtains a toy or educational spacecraft model and equips it with a small electric motor with a small wheel attached to its shaft. The assembly is suspended from a support, and the motor is activated. The teacher explains the observed motion of the spacecraft, and relates how real spacecraft use electric power and reaction wheels to manage their pointing attitude.

This demonstration may be done by a presenter in front of an audience, or it may be done by individual experimenters.

To set up the demonstration:

1. Build a model to represent a spacecraft.
2. Attach wires to the motor (soldering is best), and tape the motor to the spacecraft, routing the wire through the spacecraft appropriately. Alternately, make cardboard pieces shaped like instruments and antennas and tape or glue them to the body of the motor.
3. Suspend the assembly by its wires from a support, so that at least 2 feet of fine wire is between the support and the spacecraft. Align the motor shaft with the supporting wire, that is, straight up and down.
4. For the simplest operation, at the other end of the wire pair attach one conductor to the negative side of the battery, using tape. Prepare to touch the other conductor intermittently to the positive battery terminal.
5. Additional parts will minimize potential electrical circuitry problems. The battery can be placed in a holder. Solder one lead to one motor wire. Solder the other battery holder lead to one end of the switch. Attach the other motor wire to the other side of the switch.
6. Test to make sure the motor and wheel spin when the switch is turned to the on position, imparting a twist to the spacecraft.

Procedure

Suspend the motorized "spacecraft." Activate the motor and observe the spacecraft. The motor quickly accelerates the wheel's mass, and the reaction from this action imparts a change to the spacecraft's orientation. While the motor continues to run at the same speed, the attitude change is gradually overcome by the force of the twisted supporting wire, returning the spacecraft to its original position or close by. If the reaction to turning the motor on is violent, find a means to reduce the voltage applied to the motor, such as by inserting a potentiometer into the circuit.

Explain that the observed spacecraft motion demonstrates the following:

1. The spacecraft's attitude is changed by changing the angular momentum (the quantity of spin) held by the spacecraft and the wheel.
2. An interfering force (the supporting wire's twist) eventually nulls the result.

Reverse the polarity of the battery, and observe that the motor runs (and the spacecraft rotates) in the opposite direction.

Extension

Add a potentiometer to the circuit. Does the "spacecraft" turn a greater or lesser amount when the motor's final shaft speed is limited?

Try different wheel masses on the shaft (including no wheel at all). For a constant maximum speed, what rotating mass generates the maximum turn angle?

Extrapolate by thinking, or further refining the demonstration:

1. To rotate the spacecraft one way, you begin to rotate the wheel the other way. Once you have accelerated the wheel to a constant rotation rate and it continues spinning, the spacecraft will not continue to twist, unless some other force is applied (such as the force the wire's twist imparts in the demonstration).
2. If you had three motorized wheels, each of them mounted orthogonally, you could control the spacecraft's rotation in any direction.

In space operations, interfering forces, such as the twisting wire in the demonstration, are minimal. This allows reaction wheels to work very efficiently in controlling and maintaining a spacecraft's desired attitude. What forces, both internal and external to the spacecraft, might interfere with attitude maintenance? Example answers include atmospheric drag, pressure of sunlight, magnetic torque, and reaction wheel bearing friction.

If a spacecraft is orbiting close enough to a planet with an atmosphere and it has an appendage like a long boom, that boom can be a source of drag (force) on the spacecraft and cause the spacecraft to rotate. This is analogous to dragging an oar through the water to turn a boat.

Solar photon pressure acting on spacecraft surfaces can act to rotate the spacecraft (like the twist imparted by the supporting wire in the demonstration). Solar photon pressure is analogous to wind affecting a weather vane. A weather vane rotates into the breeze because of the pressure of the wind. Similarly, solar photons exert a pressure on the spacecraft.

Another interfering force is the gravity gradient. Portions of a spacecraft closer to a planet are attracted slightly more by the planet's gravity than are portions that are farther away.

Consider: if you were to keep adding energy to the wheel in this demonstration, you could overcome more and more of the "interfering" force that the supporting wire makes evident. Of course, continuing to do this would eventually mean the motor would have to be going unacceptably fast.

Because of momentum built up in a spacecraft's reaction wheels due to these "interfering" forces, a spacecraft periodically has to slow down its reaction wheels. But to do so without changing the spacecraft's attitude in an undesired way, the spacecraft has to use thrusters (or some other means, like magnetic torquers) to brace itself and "hold still" in space. These events are called "reaction wheel desaturation maneuvers" or simply "desats."

Education Standards

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

Science Standards

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that the position and motion of an object can be changed by pushing or pulling.

LEVEL 2 (GRADES 3–5)

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).

LEVEL 4 (GRADES 9–12)

Knows that laws of motion can be used to determine the effects of forces on the motion of objects (e.g., objects change their motion only when a net force is applied; whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object; the magnitude of the change in motion can be calculated using the relationship $F = ma$, which is independent of the nature of the force).

Technology Standards

4. Understands the nature of technological design.

LEVEL 2 (GRADES 3–5)

Knows constraints that must be considered when designing a solution to a problem (e.g., cost, materials, time, space, safety, scientific laws, engineering principles, construction techniques, appearance, environmental impact, what will happen if the solution fails).

Evaluates a product or design (e.g., considers how well the product or design met the challenge to solve a problem; considers the ability of the product or design to meet constraints), and makes modifications based on results.

LEVEL 3 (GRADES 6–8)

Implements a proposed design (e.g., organizes materials and other resources, plans one's work, makes use of group collaboration when appropriate, chooses suitable tools and techniques, works with appropriate measurement methods to ensure accuracy).

Evaluates the ability of a technological design to meet criteria established in the original purpose (e.g., considers factors that might affect acceptability and suitability for intended users or beneficiaries; develop measures of quality with respect to these factors), suggests improvements, and tries proposed modifications.

LEVEL 4 (GRADES 9–12)

Evaluates a designed solution and its consequences based on the needs or criteria the solution was designed to meet.

5. Understands the nature and operation of systems.

LEVEL 1 (GRADES K–2)

Knows that when parts are put together, they can do things that they couldn't do by themselves.

LEVEL 2 (GRADES 3–5)

Knows that when things are made up of many parts, the parts usually affect one another.

Understands the relationships between elements (i.e., components, such as people or parts) in systems.

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 — The Spinning World of Spacecraft Reaction Wheels

Procedure

A battery-powered motor is suspended by its wires such that the rotating shaft is oriented vertically, parallel to the wires and the force of gravity. Wheels of different sizes (and alternatively, none at all) are attached to the shaft one at a time and the motor is activated.

When the motor is activated, the shaft (+wheel) turns and the motor body also turns. Does the motor body turn in the same direction as the shaft rotates? State Newton's Law that explains this.

With respect to when the motor is first switched on, when does the motor body turn the most?

What happens if the polarity of the electricity feeding the motor is switched?

Using wheels of different size (with fixed motor speed), observe the amount the motor body turns with each. With which wheel does the motor body turn more? Is wheel diameter or mass the important parameter, or is a combination of both?

If available, use resistors or a potentiometer to vary the shaft rotation speed. Does the motor body turn more with higher or lower shaft speed? Why?

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades K–12

EB-2001-12-003-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

What Is Synchronous Rotation?

Objective

To combine an analogous situation in the classroom with direct observations already made so that students will better understand the rotation and orbital revolution of planets.

Time Required: 1 hour

Saturn System Analogy: Moons that are locked in synchronous rotation with Saturn (e.g., Iapetus)

Keywords: Center of Figure, Center of Mass, Hemisphere, Revolution, Rotation, Synchronous

MATERIALS

- Desk chair that rotates
- Rubber, styrofoam, or tennis ball
- Pencil or long dowel
- Marking pen
- Desk lamp or overhead projector
- Optional: strong adhesive tape

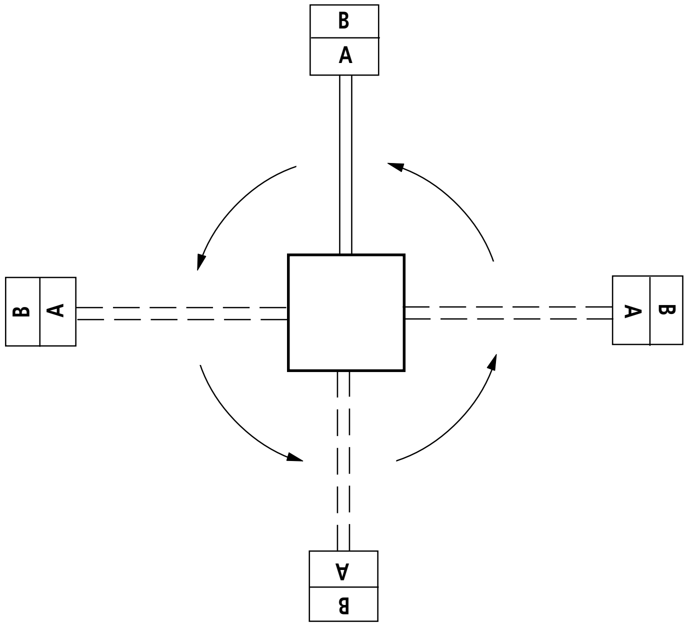
Discussion

Anyone who looks at the Moon notices that the same features always appear facing Earth. A natural conclusion might be that the Moon does not rotate. In fact, the Moon is rotating synchronously as it orbits around Earth (i.e., it is spinning at the same speed that it is going around Earth). Synchronous rotation is common throughout the solar system. It is found among the satellites of Mars, Jupiter, and Saturn. Pluto and its moon Charon are locked in mutual synchronous rotation, with both of them keeping the same faces towards each other.

Objects in Earth orbit are in free fall. A satellite assumes what is called a gravity gradient orientation, with the heavy end facing down indefinitely. (This is very convenient for some types of spacecraft, such as weather satellites.) Thus, the satellite is in synchronous rotation because it keeps the same end oriented towards Earth's center, completing one rotation as it completes one revolution around the world.

The fact that we see the Moon in synchronous rotation tells us something about the distribution of mass inside it. Specifically, "the center of mass" of the Moon is offset from the "center of figure" (its geometric center) by a few kilometers. This offset is enough to make the Moon assume a gravity gradient orientation and is indicated by its synchronous rotation.

To understand the difference between center of mass and center of figure, consider a barbell. A regular barbell has equal metal weights separated by a rod. Its center of mass is found in the middle of the rod, where it balances. Geometrically, the center of figure is at the same point.



A moon in synchronous rotation keeps the same hemisphere facing the planet, just as this diagram illustrates. At each position, side "A" on the small block faces the larger block. For that to be so, the smaller block is observed to rotate 90 degrees between each position. Though detached from Earth, the Moon behaves this way. Pluto and its moon Charon behave exactly as this diagram shows: Pluto and Charon keep the same faces towards each other.

Now consider a special barbell that has one set of weights replaced by wood shaped just like the metal weights. The geometric center of figure is still in the middle of the rod. But the center of mass is now much closer to the metal-weighted end — grab the special barbell in the middle of the rod to confirm the displacement of the center of mass.

Procedure

Stick the pencil or dowel (for use as a handle) through the ball along a diameter; this simulates the Moon. With the marking pen, write a large letter or number every 90 degrees around the circumference of the ball. The handle will either be held at arm's length by a student sitting in the chair or it can be taped to the armrest of the chair. Place the chair (Earth) a few feet away from the desk lamp or overhead projector (the Sun). The students can stay in their seats for this demonstration or they can gather in a circle around the Sun–Earth–Moon system.

Ask the students if the Moon rotates. Most will say no, since they have seen the same face of the Moon whenever they have looked up in the sky at it. Choose a student to sit in the chair and watch the ball-Moon with numbers/letters on its quadrants.

Slowly turn the student in the chair and ask that student if the view of the Moon is changing. The answer will be no; the hemisphere the student observes is always the same. In contrast, the other students will see the different quadrants appear as the chair makes one full rotation. This proves that the Moon rotates, even though it presents the same face to Earth (the student in the chair).

Historical and Scientific Notes

Synchronous rotation is common among the many moons orbiting planets in the solar system. Synchronous rotation beyond the Earth–Moon system may first have become apparent with Jean Dominique Cassini's discovery of Saturn's moon Iapetus in 1671. He found that he could see this satellite on only one side of its orbit around Saturn.

We now know that Iapetus is in synchronous rotation and that one hemisphere reflects light well (permitting Cassini to see the moon when that hemisphere faced Earth) while the other hemisphere is a very poor reflector (making Iapetus invisible in his telescope). The dark hemisphere of Iapetus faces the direction Iapetus moves in its orbit. The origin of Iapetus' two-faced behavior is an open question, hopefully to be answered by the Cassini spacecraft.

Additional Observations and Questions

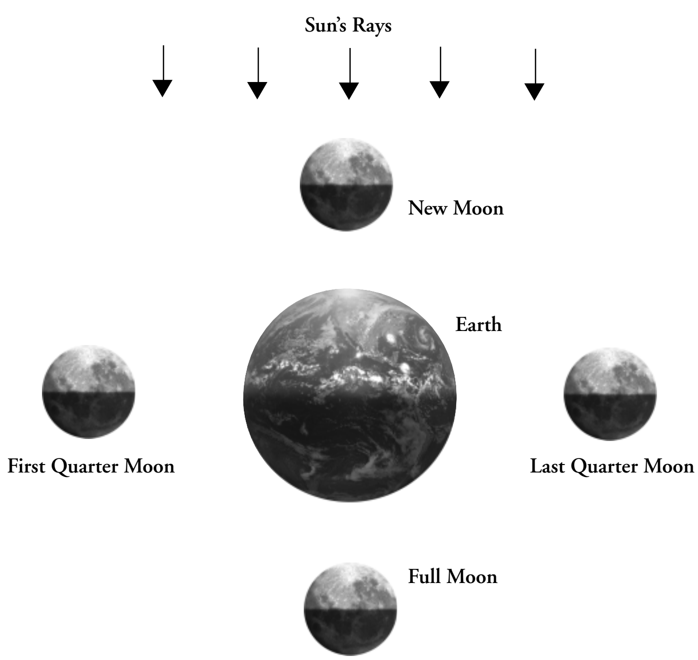
Careful observers will also distinguish the day and night sides of the ball-Moon. The student in the chair will see the changing shape of the illuminated portion of the ball-Moon — its phases — as he/she carries it around one revolution. The students surrounding the "Sun–Earth–Moon" system will not see the phase change, though each one will see the ball-Moon with a different phase — crescent, half, gibbous, full — due to each student's individual viewing angle.

The illuminated hemisphere always faces the Sun and looks virtually the same for all lunar positions for an observer anywhere outside the Earth–Moon system. The fraction of the illuminated hemisphere visible to an observer inside the system changes over a full revolution of the Moon.

This demonstration assumes that the Moon orbits Earth in a perfect circle and that we can see only one-half of the Moon's spherical surface. In fact, the Moon's orbit is elliptical. The elliptical orbit changes the Moon's orbital speed over time, causing it to move faster and slower than the exact synchronous speed of a circular orbit. Because it is sometimes ahead and sometimes behind where it would be in a circular orbit (and because of variations in the angle of its orbital plane relative to that of Earth), we can actually observe up to 59 percent of the surface. Over several months, careful binocular or telescopic observations of features near the edge of the lunar disk show this effect, which is called libration.

How are tides caused in Earth's oceans? The water responds to the gradient in the Moon's gravity (across the diameter of Earth) and bulges of water, causing high tides, appear on opposite sides of our planet.

The different types and relative infrequency of solar and lunar eclipses are related to the ellipticity and inclination of the Moon's orbit. Why?



View from above Earth's North Pole. (Figure is not to scale.) The illuminated hemisphere always faces the Sun and looks the same for all lunar positions for an observer anywhere outside the Earth–Moon system. The fraction of the illuminated hemisphere visible to an observer inside the system changes over a full revolution of the Moon.

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 the position and motion of an object can be described by locating it relative to another object in the background.

LEVEL 2 (GRADES 3–5)

Knows that Earth's gravity pulls any object toward it without touching it.

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).

LEVEL 3 (GRADES 6–8)

Understands general concepts related to gravitational force (e.g., every object exerts gravitational force on every other object; this force depends on the mass of the objects and their distance from one another; gravitational force is hard to detect unless at least one of the objects, such as Earth, has a lot of mass).

Understands effects of balanced and unbalanced forces on an object's motion (e.g., if more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude; unbalanced forces such as friction will cause changes in the speed or direction of an object's motion).

Knows that an object that is not being subjected to a force will continue to move at a constant speed and in a straight line.

LEVEL 4 (GRADES 9–12)

Knows that the strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

Knows that laws of motion can be used to determine the effects of forces on the motion of objects (e.g., objects change their motion only when a net force is applied; whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object; the magnitude of the change in motion can be calculated using the relationship $F = ma$, which is independent of the nature of the force).

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

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.

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

LEVEL 3 (GRADES 6–8)

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

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Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.

Student Worksheet — Synchronous Rotation

Procedure

1. One student sits in the rotating chair holding the marked-up ball. What marking does the student see? What marking do the other students see?

2. The seated student rotates one-quarter turn (90 degrees).

3. Discuss which marking you see on the ball versus which marking the student in the chair sees.

4. The seated student rotates (in the same direction as before) another quarter turn.

5. Again, compare the marking the you see versus the marking the student in the chair sees.

6. Continue rotating by quarter turns until the seated student returns to the starting position.

Questions

Does the Moon rotate?

Does the student in the chair think that the “moon” rotates?

Can you determine the day and night sides of the moon with this experiment? How?

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-006-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Unveiling Titan's Surface

Objective

To make measurements of topographic features and to draw maps based on these data. This will be done in a way that is analogous to making radar measurements of topography through vegetation (on Earth) or through clouds (on Venus, Titan, and Earth).

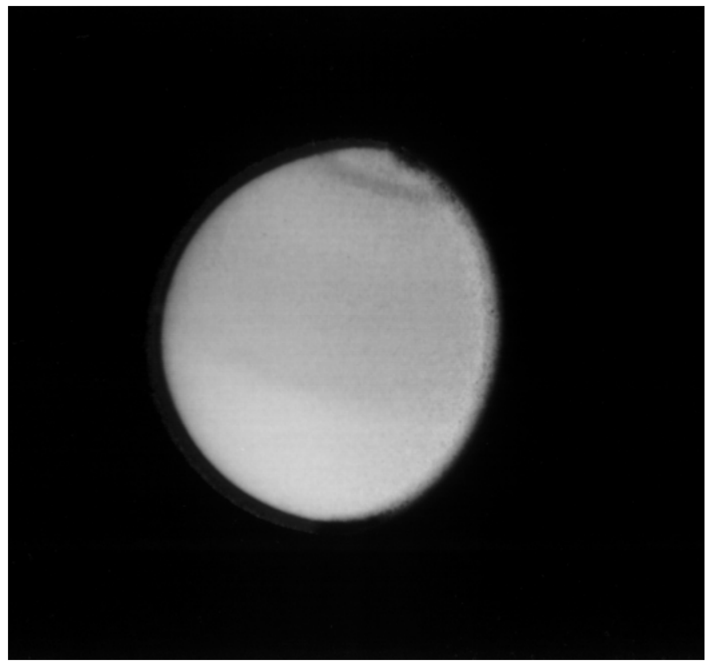
Time Required: 1–2 hours

Saturn System Analogy: Titan's surface unveiled by Cassini radar

Keywords: Contour Map, Radar, Relief, Topography

MATERIALS

- A sturdy cardboard shoe box, shipping carton with its top, or boot box
- Green styrofoam (commonly used in floral arrangements) cut to fit in the bottom of the box
- A tool for shaping the styrofoam (a large spoon will suffice)
- A sharpened pencil or similar object to punch holes in the box top
- A plastic coffee stirrer (about 5 inches long) or other long thin object like a bicycle spoke, a wooden kebab skewer, or a chopstick — to use as a depth gauge
- Adhesive tape and a ruler or tape measure
- A blank 3- by 5-inch index card
- Graph paper: several pieces with the same grid size



Titan, Saturn's largest moon, as seen by the Voyager 2 spacecraft.

Discussion

Titan's visibly opaque atmosphere shrouds the satellite's surface from our eyes. When the two Voyager spacecraft imaged Titan during their 1980 and 1981 flybys, scientists saw only the haze and cloud tops of the moon's thick, nitrogen-rich atmosphere.

Unlike a photographic camera that needs an outside light source, radar provides its own illumination. Cassini's radar will project pulses of radar energy toward Titan to strike the surface and echo back to the instrument. The amount of energy received by the instrument dictates how bright the resulting image is and is a function of the type of surface being measured. The round trip travel time of each energy pulse determines the location of the echoing surface. This technique, called synthetic aperture radar (SAR), is used to capture images of surfaces that are cloud shrouded (e.g., Titan, Venus, and Earth) or dark (e.g., the night side of Earth). SAR can even detect structures shrouded by rain forest vegetation. By supplying its own illumination and operating at radio frequencies that can penetrate the atmosphere and clouds, a radar instrument can image Titan's surface.

Procedure

Shape the top of the styrofoam into an irregular pattern. Spare pieces of styrofoam can be cemented on top to form mountains or plateaus. Place the styrofoam in the box. Tape a piece of graph paper over the box lid. Using the pencil or other sharp object, punch a hole at each intersection of the grid on the paper. The holes should be large enough for the depth gauge to fit through.

Preparing the Height Code Card

Pick any random hole in the graph paper–covered lid and insert the depth gauge into the box until it touches bottom. Place the index card next to the depth gauge and mark a line on the card where the top of the depth gauge is and label it with a zero. This is an arbitrary height reference, analogous to sea level on Earth. Beginning with the height reference, mark off and label 0.5-centimeter increments on the index card through 10 centimeters up and down from the arbitrary height reference.

Collecting the Data

Students should record height data, intersection-by-intersection, inside a corresponding square on their own graph paper. It is convenient to have students work in small groups so that several equivalent data sets are produced for the continuation of this activity. (Alternatively, each individual can make several copies of his/her data set as he/she goes along.)

Begin measuring heights at one corner of the topography box and proceed in a systematic manner around the grid. Students insert the depth gauge into each hole and measure the corresponding height on the height code card. Students should round heights to the nearest 0.5 centimeter and record them on their graph paper.

Constructing the Contour Map

In order to better visualize the surface being studied, mapmakers prepare contour maps that show elevation variations. This is accomplished by first picking a contour interval. For this exercise, try an interval of 2 centimeters or 1 centimeter.

Instruct the students to draw lines (curving, if necessary) connecting points of equal elevation, rounding X.5-centimeter values up to (X+1) centimeter consistently around the map. Students should be instructed that contour lines may not cross, but can close on themselves, indicating hills or basins. Students can compare their completed maps with the shaped styrofoam.

Extension

Use a finer grid pattern and a depth gauge with smaller increments to make a higher resolution set of measurements and contour map. (The area of higher resolution measurement may need to be limited to save time.)

Use a millimeter ruler for a height code "card," collect data, and make a new contour map with the original grid and/or the finer grid.

What is the effect if the depth gauge is not vertical? The map will be the same if the angle and orientation of the gauge are the same for each measurement point. If the angle and orientation vary, the map will be distorted. Advanced students can perform an analysis using trigonometric functions.

Education Standards

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

Science Standards

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)

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.

LEVEL 3 (GRADES 6–8)

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

Geography Standards

1. Understands the characteristics and uses of maps, globes, and other geographic tools and technologies.

LEVEL 2 (GRADES 3–5)

Interprets topography using aerial photos and maps.

Uses map grids (e.g., latitude and longitude or alphanumeric system) to plot absolute location.

LEVEL 3 (GRADES 6–8)

Knows the characteristics and purposes of geographic databases (e.g., databases containing census data, land-use data, topographic information).

LEVEL 4 (GRADES 9–12)

Transforms primary data into maps, graphs, and charts (e.g., charts developed from recent census data ranking selected information on various topics, cartograms depicting the relative sizes of Latin American countries based on their urban populations).

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Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.

Student Worksheet — Unveiling Titan's Surface

Procedure

1. Shape the styrofoam with mountains, valleys, craters, and other landforms, and then place it inside the box.

2. Tape graph paper over the box lid.

3. Using the pencil, punch holes in the box lid at the grid intersections of the graph paper.

4. Prepare the height code card by inserting the depth gauge into the box lid until it touches the bottom. This fixes an artificial "sea level" on a "planet" that has no ocean.

5. Place the index card next to the depth gauge and mark where the top of the gauge is on the card. Mark this as zero.

6. Beginning with the zero mark, measure off and mark 0.5-centimeter increments on the index card.

7. By following a systematic pattern across the box lid, measure the height of the depth gauge as it is inserted at different intersections across the box lid.

8. Record the data at the corresponding intersections on another piece of graph paper.

9. Using the graph paper with the recorded height values, draw lines connecting the points with the same height reading. How does the contour map compare with the measured surface? How could the map be improved to better match the actual surface?

National Aeronautics and
Space Administration

Educational Product

Educators & Students	Grades 3–12

EB-2001-12-020-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Waves

Objective

To demonstrate traveling, standing, transverse, and longitudinal waves.

Time Required: 1 hour

Saturn System Analogy: Many of Cassini's instruments collect transverse electromagnetic waves to learn about the Saturn system.

The cameras, spectrometers, radar, and radio receivers all provide information about Saturn and its rings, moons, and magnetosphere. The Huygens probe carries a microphone that will detect longitudinal pressure waves — sound — in the atmosphere of Titan.

Keywords: Amplitude, Earthquake Waves, Electromagnetic Waves, Frequency, Longitudinal, Node, P Waves, Period, S Waves, Sound Waves, Standing Waves, Transverse, Traveling Waves, Wavelength, Waves

MATERIALS

- Coiled spring toy (Slinky® or equivalent)
- Fixed attachment point for the spring

Discussion

Simple, *transverse* waves (Figures 1a, 1b) travel through many different media. Examples include water waves, S-type earthquake waves, and all electromagnetic waves, from radio signals through light to x-rays and gamma rays. Similarly, *longitudinal* waves (Figure 2) are common, from P-type earthquake waves to the sound waves we detect with our ears. These two types of waves can be easily demonstrated with a Slinky® or equivalent coiled spring toy.

Transverse and longitudinal waves can both be observed as *traveling waves* (Figures 1a, 1b, 2) and as *standing waves* (Figure 3). A traveling wave moves along the medium, carrying energy from the origin outward. A standing wave is confined, and must have a precise relationship between its characteristic size (called its wavelength, the distance from peak to peak or valley to valley) and the size of its confining volume. Specifically, a standing wave must have an integral number (1, 2, 3, etc.) of 1/2-wavelengths in the confinement zone. A standing wave can be considered a collection of traveling waves that, together, sum up so that there are nodes (positions of no wave motion) at the ends of the confinement zone, possibly with additional nodes between the ends.

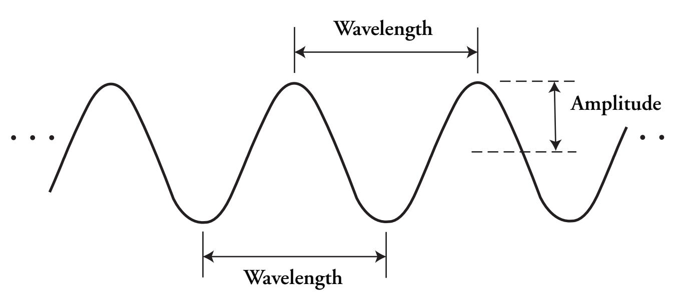


Figure 1a. A transverse wave (sinusoid, traveling, like swells at sea).

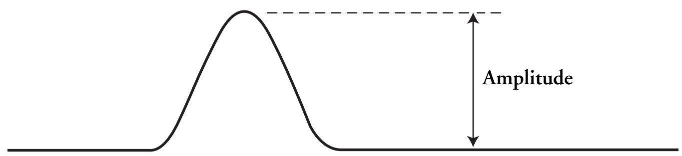


Figure 1b. A transverse wave (randomly shaped pulse, traveling).

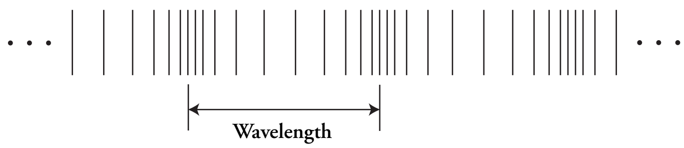


Figure 2. A longitudinal wave.

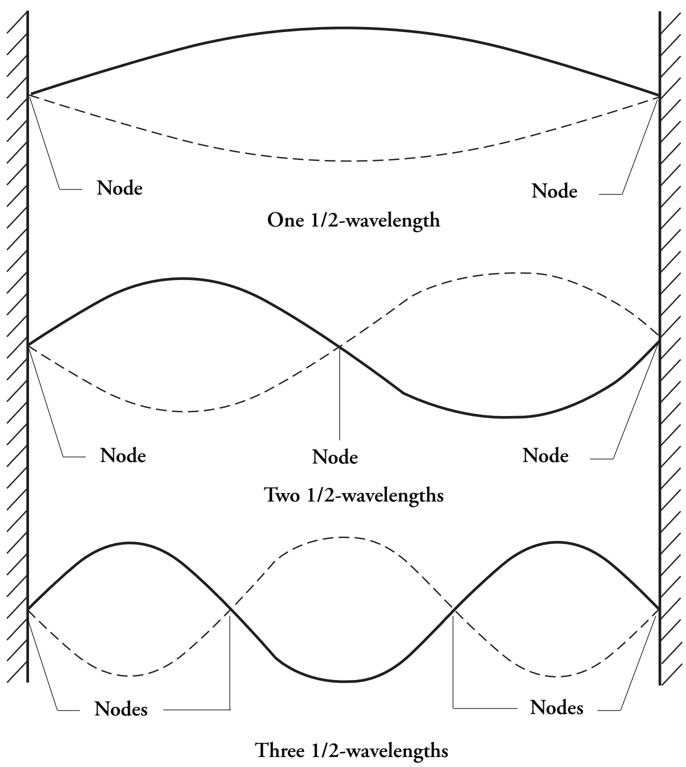


Figure 3. Standing transverse waves. Longitudinal waves may also be standing, but are difficult to illustrate.

Setup

Attach one end of the spring to a file cabinet, bookshelf, or other solid, fixed piece of furniture or the wall of the room. The end should not be free to move when attached, and should not come loose when the spring is shaken violently. A student can hold the “fixed” end, but must hold it tightly and in one position.

Procedure

Extend the spring across the room. Once it has settled, generate a traveling transverse wave by using a finger to make a quick pull and release in a vertical orientation. Try this several times, observing the reflection of the wave after it reaches the fixed end of the spring.

When the spring is again quiet, generate a traveling longitudinal wave by compressing a group of coils (totaling about 1 centimeter thick) towards yourself and then releasing the group. A compression/rarefaction combination will travel along the spring, and may reflect if the initial wave is strong enough. Repeat this several times. Is there a difference in wave speed for transverse and longitudinal waves? (The answer for P and S earthquake waves is yes.)

Now generate a standing wave. Using your arm, move the end of the spring up and down at a slow rate. Find the frequency necessary to get a single U-shape (transforming to an inverted U) of the spring between the moving end and the fixed end. When the shape is found, only small-amplitude arm motions are necessary to maintain it, which has a wavelength that is twice the length of the extended spring. This can be interpreted as the wave and its reflection exactly canceling out their respective motions at the fixed end and at your hand. Points where there is zero motion are called nodes.

Increase your arm-waving frequency. The spring’s shape is disrupted, and waves and reflections interfere with each other and make chaotic spring motion until the correct frequency (twice the first one) is found. This new frequency permits a U/inverted U pair to form in the spring with one node in between. Now one wavelength is equal to the distance from your hand to the fixed end. Try higher frequency arm-waving to put 1.5 wavelengths (three U's, separated by two nodes + the two ends) and 2 wavelengths (four U's, separated by 3 nodes + the two ends) along the spring. Because of the nature of spring dynamics, it may be necessary to increase or decrease the distance between the ends of the spring to get more half-wavelengths excited.

How are wavelength and frequency related? The answer is inversely: shorter wavelengths have higher frequencies.

Extension

The standing waves in the demonstration were made by shaking the spring vertically, yielding waves with vertical polarization. Similarly, waves can be made by shaking the spring horizontally (harder for students to see from their seats).

If the spring is shaken with a circular arm motion (easier than maintaining pure vertical motion), the U-shape also follows a circular path (like a jump rope). This is circular polarization. But if one looks along the length of the spring and observes only vertical or horizontal motion (a long, thin rectangle cut into cardboard will make this easier to see), one can observe that the circular motion resolves into an equal combination of vertical and horizontal polarizations. These are analogs to polarization observed in electromagnetic waves that have practical applications in daily life, such as in glare-reduction sunglasses, and in spaceflight for communications to/from spacecraft.

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 motions.

LEVEL 1 (GRADES K–2)

Knows that things move in many different ways (e.g., straight line, zigzag, vibration, circular motion).

LEVEL 3 (GRADES 6–8)

Knows that vibrations (e.g., sounds, earthquakes) move at different speeds in different materials, have different wavelengths, and set up wave-like disturbances that spread away from the source.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

LEVEL 2 (GRADES 3–5)

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

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 — Waves

Procedure

Observe the different waves generated by your teacher with the spring toy.

List waves you can observe that are transverse waves.

List waves you can observe that are longitudinal waves.

What type(s) of wave(s) do earthquakes generate? There is a way to estimate an earthquake's distance from the arrival times of its waves. What are typical wave speeds that permit this?

What is polarization? In what common product is it used? How does it work and what are the results?

In what room of your home is it easy to demonstrate standing sound waves? (Hint: Some people like to sing there.)

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 3–12

EB-2001-12-016-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Waves and Interference

Objective

To allow students to experience wave interference with their own senses.

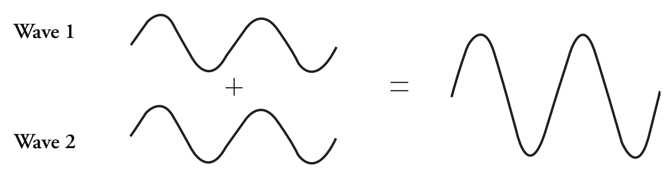
Time Required: 1 hour

Saturn System Analogy: Cassini's Composite Infrared Spectrometer (CIRS) uses the interference of electromagnetic radiation in the infrared region of the spectrum to precisely measure the chemical compositions of planetary atmospheres.

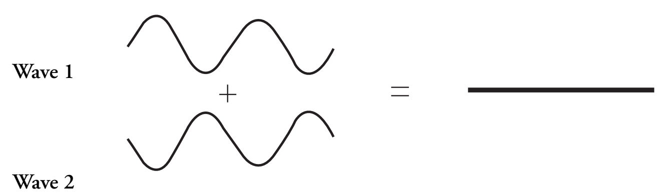
Keywords: Amplitude, Constructive/Destructive Interference, Electromagnetic, Interference, Sound, Waves

MATERIALS

- Cassette or CD player, preferably stereo and adjustable for left–right balance (a "boombox" is ideal).
- Homemade cassette recording of telephone dial tone (multiple sets with minimum duration 15 seconds, or better, a single recording of two minutes or longer). *A better but more expensive alternative is a commercial cassette or CD with a single-frequency tone that can be played. These are available for setting recording levels [CD→cassette] and setting stereo equalizer levels, and can sometimes be found on CD player lens-cleaning disks. An electronic keyboard can generate the necessary tone for recording on a cassette. Lastly, a 12VDC piezo buzzer (e.g., Radio Shack no. 273-059, about $3) can be connected to a 9V battery to generate a continuous high-pitched tone. Depending on the acoustics of the room, a low pitch or a high pitch may demonstrate the phenomena more definitively. Experiment in advance with both.*



Constructive Interference



Destructive Interference

Interfering waves may combine constructively (top part of the illustration) or destructively (bottom part). Waves may only partially interfere with the sum of the amplitudes being somewhere between totally constructive or totally destructive interference.

Discussion

All waves exhibit interference phenomena, the effects of their passing through one another as they travel. It is easy to see water-wave interference as ripples cross each other in places they have extra-high peaks or extra-low valleys (high amplitude) where individual wave-peaks or wave-valleys cross paths. In other places, the water surface may briefly be smooth and flat where a peak meets a valley and their sum is zero (zero amplitude). Water waves and light waves (in fact, all electromagnetic waves from long-wave radio through light to x-rays and gamma rays) are transverse waves, exhibiting peaks and valleys as they travel along their paths.

Sound waves are longitudinal pressure waves, in which a wave-carrying medium (e.g., air, water, rock, wood) in a volume changes its density (or, equivalently, pressure) as the wave passes through it. In just the same way as the peaks and valleys of a transverse wave combine, pressure waves can combine for increased amplitude (greater density or pressure) or nulling out (matching the average density or air pressure of surrounding volumes) at a particular point. Our ears provide an easy means of finding amplitude maxima and minima when sound waves interfere. This activity demonstrates these effects.

Procedure

Play the tone through either the left or right speaker (only one of them) at a comfortable level so it can be heard around the classroom. Have students walk around the room (they can start by simply circling their desks) listening for changes in sound volume (sound intensity). Explain that sound waves coming from the speaker reflect off the floor, ceiling, walls, desks, and various other objects in the room. Sometimes the waves add up (interfere constructively) and make a louder sound at a particular spot. Sometimes they cancel each other out (interfere destructively) and reduce the sound volume at some other spot. Map the room by having individual children stop at a spot where the tone is loud (or weak).

Repeat the experiment, but have the tone coming from both speakers equally. The pattern will be different because two sets of waves are moving through the room, bouncing off the same objects but with slightly different distances and angles from objects to speakers. The two wave sets are able to interfere with each other and their various reflections at different places.

With either one or two speakers active, have the students listen for differences in volume by changing from a standing position to a kneeling position. This demonstrates the three-dimensional nature of sound wave propagation.

Extension

Take the sound generator out to the playground or open field (an area with few sound reflectors.) Repeat the classroom experiments using one and two speakers. Is the pattern more regular? Is there more or less three-dimensionality to the pattern? What would happen in a large, empty room like a gymnasium? Why don't we notice interference when we listen to voice or music from stereo sound systems?

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.

9. Understands the sources and properties of energy.

LEVEL I: PRIMARY (GRADES K–2)

Knows that sound is produced by vibrating objects.

11. Understands the nature of scientific knowledge,

LEVEL 1 (GRADES K–2)

Knows that scientific investigations generally work the same way in different places and normally produce results that can be duplicated.

LEVEL 2 (GRADES 3–5)

Knows that although the same scientific investigation may give slightly different results when it is carried out by different persons, or at different times or places, the general evidence collected from the investigation should be replicable by others.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

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

LEVEL 2 (GRADES 3–5)

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).

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).

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

13. Understands the scientific enterprise.

LEVEL 1 (GRADES K–2)

Knows that in science it is helpful to work with a team and share findings with others.

LEVEL 2 (GRADES 3–5)

Knows that scientists and engineers often work in teams to accomplish a task.

***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 — Waves and Interference

Procedure

Prepare a map of your room, including desks and aisles. Your teacher will play a tone through the speaker of a sound system. Walk around the room listening for changes in sound volume (sound intensity). Mark spots on the map where the sound peaks in loudness (volume or amplitude) and where the sound is at a minimum. You may repeat the mapping with the tone coming from two speakers.

Questions

Equally tall students should compare their maps. Are they the same? Why might they be different?

Students with different heights can compare maps. Are there differences? Why or why not?

If you made single speaker and dual speaker maps, compare them. Are they different? Why?

What would happen if a different pitch (tone) were used?

Can you think of other types of waves that act like sound waves?

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades K–12

EB-2001-12-013-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

Which Way Should I Point?

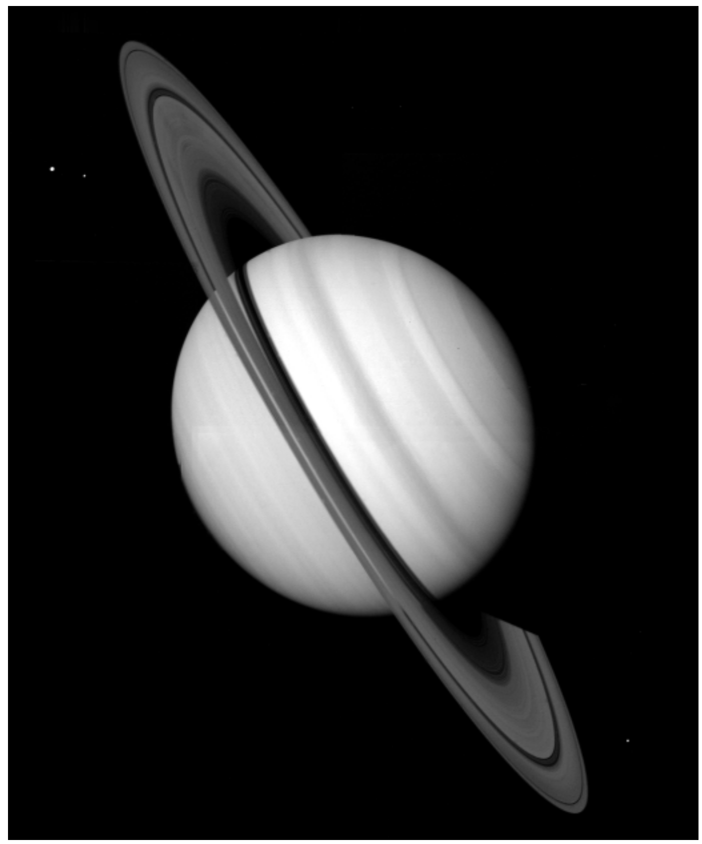
Objective

To illustrate the need for cooperation among competing interests to make scientific measurements of planetary phenomena using “body-fixed” instruments.

Time Required: 1 hour

Saturn System Analogy: Cassini orbiter science investigations

Keywords: Field of View, Orientation, Rotation



Saturn and three of its moons as seen by Voyager 1.

MATERIALS

- A desk chair that swivels
- A board that is wide and thick enough to support three people
- A brimmed hat, preferably a cowboy or outback hat
- One small toy telescope
- One pair of binoculars
- A broom handle (available at hardware stores or large wholesale kitchen supply stores)
- Three student volunteers
- An image or drawing of Saturn: this can be a photograph, a store-bought cut-out, or a download from the Internet (*http://www.jpl.nasa.gov/cassini/english/pic/saturnsystem.html*)

Discussion

The Voyager and Galileo spacecraft had some instruments mounted on a scan platform. This scan platform is a platform that can move independently from the rest of the spacecraft, something like a robotic arm.

Cassini, in contrast, does not have a scan platform. All of Cassini's science instruments are attached directly to the main body of the spacecraft. As a result, in order to orient an instrument to point at Saturn (or any other target), the entire spacecraft must move. This means that while the camera is taking a picture of Saturn, all of the other instruments must look in their pre-defined directions, which may not be parallel to the camera's direction. This makes coordinating observations and data collection using the 12 instruments very difficult.

Procedure

Mount the image of Saturn somewhere in the classroom.

Place the board on the swivel chair. Have the first student volunteer sit on the center of the board and have the student hold the hat upside-down on top of his/her head. The hat represents Cassini's high-gain antenna (the main communication antenna for the spacecraft).

Give the student the small toy telescope and instruct him/her that the telescope can only move up and down. The telescope represents the Magnetospheric Imaging Instrument (MIMI, *http://saturn.jpl.nasa.gov/cassini/Science/MAPS/MIMI.shtml*).

With someone holding one end of the board so that it does not tip over, place the second student volunteer on the other end of the board with his/her back to the person in the center. Give the second student the binoculars. These binoculars represent the Imaging Science Subsystem (the cameras, ISS, *http://saturn.jpl.nasa.gov/cassini/Science/MAPS/ISS.shtml*). One lens of the binoculars is the wide-angle camera and the other lens is the narrow-angle camera. Instruct the student that he/she can only look straight ahead.

Place the third student volunteer on the other end of the board with his/her back toward the person in the center. Give the third student the broom handle and instruct him/her to hold it out in front. The broom handle represents the Magnetometer (MAG, *http://saturn.jpl.nasa.gov/cassini/Science/MAPS/MAG.shtml*).

Taking Data with the "Spacecraft"

Now that all three of the students are in position, it's time to acquire some data about Saturn, which is mounted somewhere in the classroom (first procedure step). Let's try to collect some data.

The magnetometer (MAG) is collecting data on Saturn's magnetic field. Therefore, as long as the instrument is turned on, it does not need to point in any particular direction (for the purpose of this demonstration).

The Magnetospheric Imaging Instrument (MIMI) and Imaging Science Subsystem (ISS) are a whole different story. Since both ISS and MIMI need to actually look (point) at Saturn to collect data, it's obvious that they cannot collect data at the same time. In real mission planning, there is a sequence of events that is predefined wherein one of these instruments collects data, and then the other has a chance. The discussion comes when both science teams want to collect data at the same time. The mission planning team then needs to negotiate a bargain between the two teams.

Remember that this demonstration only uses three of Cassini's 12 instruments!

Extension

Demonstrate the difference between a body-mounted-instrument spacecraft like Cassini and a spacecraft with a scan platform like Galileo. This illustrates the difficulties presented to the Cassini science and engineering teams when they plan data collection using multiple instruments. Now let's examine how Galileo works.

The Galileo spacecraft is somewhat similar in design to Cassini. Galileo has a main antenna at the top of the spacecraft, a central core of electronics, and a main engine at the bottom of the spacecraft. Science instruments are mounted on the outside of the central core. A major difference between Galileo and Cassini is the movable scan platform that allows Galileo's remote sensing instruments (cameras and others) to be positioned to take data almost independent of the spacecraft's orientation.

On the Galileo spacecraft, your student camera (the student with the binoculars) is now free to move his binoculars in order to capture a target. Repeat the procedure used for Cassini, but as you slowly rotate the chair, allow the "camera" to stay pointed at Saturn until the chair is rotated so much that the "camera" is on the other side of the spacecraft from Saturn.

Technology Standards

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

4. Understands the nature of technological design.

LEVEL 1 (GRADES K–2)

Knows that people are always inventing new ways to solve problems and accomplish work (e.g., a computer is a machine that helps people work and play).

LEVEL 2 (GRADES 3–5)

Knows constraints that must be considered when designing a solution to a problem (e.g., cost, materials, time, space, safety, scientific laws, engineering principles, construction techniques, appearance, environmental impact, what will happen if the solution fails).

Uses appropriate tools, techniques, and quantitative measurements to implement proposed solutions.

LEVEL 3 (GRADES 6–8)

Evaluates the ability of a technological design to meet criteria established in the original purpose (e.g., considers factors that might affect acceptability and suitability for intended users or beneficiaries; develops measures of quality with respect to these factors), suggests improvements, and tries proposed modifications.

LEVEL 4 (GRADES 9–12)

Evaluates a designed solution and its consequences based on the needs or criteria the solution was designed to meet.

5. Understands the nature and operation of systems.

LEVEL 1 (GRADES K–2)

Understands how some elements of simple systems work together (e.g., people in a restaurant, parts of a bicycle).

LEVEL 2 (GRADES 3–5)

Knows that when things are made up of many parts, the parts usually affect one another.

Understands the relationships between elements (i.e., components, such as people or parts) in systems.

LEVEL 3 (GRADES 6–8)

Knows that systems are usually linked to other systems, both internally and externally, and can contain subsystems as well as operate as subsystems.

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 — Which Way Should I Point?

Procedure

The instructor will engage you, the student, in this demonstration. Some additional questions to answer include:

With the body-mounted-instrument spacecraft, can both instruments take data about Saturn at the same time?

If the answer to the first question is "no," how can the two instruments both collect data about Saturn?

Is it easier for the two instruments on the Galileo spacecraft (with the movable scan platform) to collect data at the same time?

Which spacecraft design, the body-mounted-instrument spacecraft or the one with the scan platform, do you think costs more to build? Why?