



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 phe-

nomena 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 Saturn light intensity is Setup # _____

The setup for Earth's sunlight is Setup # _____

My Saturn simulation location is: _____

Setup Parameters

Setup #1

Setup #2

Weight of Spinach

Light Meter Reading

Water Displacement Measurements

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

