Sugar Rays — Evolutionary Plant Theories

Secrets of the Sequence Video Series on the Life Sciences • Grades 9 — 12

Teaching materials developed by **VCU** Life Sciences

Virginia Commonwealth University

Classroom Tested Lesson

Video Description

"Secrets of the Sequence," Show 150, Episode 2

"Sugar Rays – Evolutionary Plant Theories" – approximately 9 minutes viewing time

Sugar created from rays of sunlight! It goes on everywhere from sun up to sun down. During photosynthesis, the green pigment in plants, known as chlorophyll, ingests carbon dioxide and converts it to stored energy in the form of carbohydrates and sugars while emitting oxygen. By examining the genomes of certain green-colored bacteria, scientists are looking back in time to study our beginnings. They are finding out that life actually began in a poisonous atmosphere, where organisms, over millions of years, slowly learned the process of producing oxygen. Evidence of this change is literally etched in stone.

Ward Television
Producer: Dale Minor
Associate Producer: Mara Mlyn
Featuring: Alan Jay Kaufman, Geology, University of Maryland, Jon Eisen, Evolutionary Biologist, The Institute for Genomic Research
Lesson Author; Reviewers: Jim Bledsoe, Ann Griffin; Catherine Dahl, Dick Rezba
Trial Testing Teachers: Regina Ahmann, Martin Shields

National and State Science Standards of Learning

National Science Education Standards Connection

Content Standard C: Life Science

As a result of their activities in grades 9 - 12, all students should develop an understanding of:

- The cell
- Molecular basis of heredity
- Biological evolution
- Interdependence of organisms
- Matter, energy and organization in living systems
- Behavior of organisms

Selected State Science Standards Connections

Use http://www.eduhound.com (click on "Standards by State") or a search engine to access additional state science standards.

California
Ecology

6. Stability in an ecosystem is a balance between competing effects. As a basis for understanding this concept:

d) Students know how water, carbon, and nitrogen cycle between abiotic resources and organic matter in the ecosystem and how oxygen cycles through photosynthesis and respiration.

g) Students know how to distinguish between the accommodation of an individual organism to its environment and the gradual adaptation of a lineage or organisms through genetic change.

Evolution

7. The frequency of an allele in a gene pool of a population depends on many factors and may be stable or unstable over time. As a basis for understanding this concept:

d) Students know variation within a species increases the likelihood that at least some members of a species will survive under changed environmental conditions.

8. Evolution is the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept:

e) Students know how to analyze fossil evidence with regard to biological diversity, episodic speciation, and mass extinction.

Georgia

Performance Science Standards for Biology

Habits of Mind

SCSh1. Students will evaluate the importance of curiosity, honesty, openness, and skepticism in science.
SCSh2. Students will use standard safety practices for all classroom laboratory and field investigations.
SCSh4. Students use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.
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The Nature of Science

SCSh8. Students will understand important features of the process of scientific inquiry. Co-Requisite – Content
SB3. Students will derive the relationship between single-celled and multi-celled organisms and the increasing complexity of systems.
a. Relate the complexity and organization of organisms to their ability for obtaining, transforming, transporting, releasing, and eliminating the matter and energy used to sustain the organism.
b. Examine the evolutionary basis of modern classification systems. (six kingdoms)
SB4. Students will assess the dependence of all organisms on one another and the flow of energy and matter within their ecosystems.
e. Relate plant adaptations, including tropisms, to the ability to survive stressful environmental conditions.

Overview

In this video students learn how organisms may have evolved to use sunlight to make food. Anthropologists and paleontologists, who previously dominated the field of evolutionary origins, primarily emphasized a macro approach – in other words, examining skeletons. Today, many of the scientists who are pushing back the boundaries of our origins by looking at early evolutionary processes are microbiologists. Armed with the ability to study genome sequences, researchers can now look at an organism's genome for a record of the entire history of that organism and its genes.

Approximately 4 billion years ago our world was a hostile environment for life. The planet was covered in water with an atmosphere of carbon dioxide or methane. It is likely that early primitive life existed in an anaerobic environment and in fact thrived in the absence of oxygen. Although oxygen is now necessary for most life to exist, it can also be harmful because it can damage cells and contribute to aging. Evidence suggests living molecules evolved in the absence of cells and eventually started to carry out biological processes such as carbon fixation and photosynthesis and encoded this ability in DNA-like molecules. Fossils showing very early traces of iron-oxide provide evidence that primitive life evolved into organisms that produced oxygen and could also survive in it. Using information encoded in DNA, scientists are pushing evolutionary history further back. A genome of an organism can be read as a history book because an organism's genome contains within it a record of its entire biological history.

Testing: A sample related multiple choice item from State Standardized Exams

During Photosynthesis, energy from the sun is trapped in…

1. chemical bonds*
2. the nuclei of atoms
3. enzymes
4. golgi bodies

Source: Mississippi Subject Area Testing Program Biology Test 1

Video Preparation

Preview the video and make note of the locations at which you will later pause the video for discussion.

Before Viewing

1. Review the following words and their roots that are used in the video:
   - *Photosynthesis - production of sugars through the action of light (synthesize - to make [with], photo – light)*
   - *Aerobic – able to live and grow only where free oxygen is available (aer – air, bic [bios] – life)*
   - *Anaerobic – able to live and grow without oxygen (an – without, aer – air, bic [bios] – life)*
   - *Anoxic – without oxygen*
   - *Ozone – oxygen molecule O_3 that protects life on earth from ultraviolet rays*
   - *Photoautotroph – photo-light, auto-self, troph-nourish (nourishes itself by light)*
   - *Evolution – the theory that organisms change gradually over long periods of time*

2. Ask students to list and record on the board the steps they remember in the photosynthesis-respiration cycle.
   This is to determine what they already know and to focus them on the concepts to be learned in the video.

3. Tell students to watch the video carefully as it reviews these steps and note how the steps compare with theirs.

4. Ask: "What kinds of organisms produce oxygen? What kinds of organisms use oxygen?"
   Photoautotrophs (photosynthesizers) like plants produce oxygen. All aerobic organisms including plants consume oxygen in cellular respiration.

During Viewing

1. START the video.

2. PAUSE the video (3:21 minutes into the video) immediately after the narrator says, "Oxygen is necessary for life but is also destructive".
   Ask: "In what ways might oxygen be destructive?"
   Oxygen damages cells
   Oxygen speeds aging
   Oxygen rusts iron
   Oxygen fuels fire

3. PAUSE the video (6:45 minutes into the video) after the narrator says, "*Chlorobium tepidum*, however, needs space closer to the surface."

   Discuss with the students how deep sea hydrothermal vents, or black smokers, work. For information refer to http://www.amnh.org/nationalcenter/expeditions/blacksmokers/black_smokers.html. There's even a great video to explain it. This is an opportunity to explain how those conditions are potentially similar to early earth: very hot, rich in minerals, etc. Also explain how chemoautotrophs make their own food using chemicals dissolved in the water instead of using the sunlight.

4. RESUME the video and play to the end.

After Viewing

1. Compare the steps of photosynthesis that the students had recorded earlier on the board with those outlined in the video. Replay the introduction to 2:05 minutes if needed. Have students revise the information on the board as necessary.

2. Ask: "Why do scientists study the genome sequences of primitive organisms?"
   The genome contains within it the entire record of the biological history of that organism and its genes.

3. Discuss the significance of the "link" suggested by the featured organism in the video (*Chlorobium tepidum*) and what implications it has for the study of evolution.

   - *Early primitive organisms could not produce oxygen nor could they survive in it.*
   - *The "link" organism produced oxygen but could not tolerate it.*
   - *Later more advanced organisms produced oxygen and could survive in it.*

By comparing the genomes from primitive and more advanced organisms, many similar genes can be found – far more than originally expected suggesting a clear "link" in the evolution of primitive organisms to more advanced organisms, although it is still unclear what triggered primitive organisms to start producing oxygen.

Teacher Notes for the Student Activity: Light, Pigments, Plants and Photosynthesis

Introduction

George Wald of Harvard University won the Nobel Prize in 1967 in Biology. Although his primary interest was the effects of light on vision, he also studied plants and published the classic paper entitled "Life and Light" in ***Scientific***

American. In it he described the importance of pigments in living systems because they can absorb energy (light) at specific wavelengths, thereby making that energy available to these systems.

Pigments are life's response to sunlight. They absorb light in specific wavelengths. Chlorophyll, for example, absorbs light in the red and blue range and reflects light in the green range. Appendix A, attached to the student handout, provides students with additional information on pigments.

In this activity students will measure the rate of photosynthesis for the plant Elodea in the presence of white light, then in the presence of red and green light. Certain wavelengths are assumed to be more productive than others. Students will follow the protocol and see for themselves what happens.

Materials

Each group will need the following available from most biological supply houses:

- Elodea sprigs (Carolina Biological cat # HT-16-2102)
- Volumeter
  - Size #1 one-hole rubber stopper (Carolina Biological cat # HT-71-2432)
  - 1 piece of 5mm OD Pyrex glass tubing about 35 cm long(Carolina Biological cat # HT-71-1145) Note: A trial test teacher reported using 15 cm pieces of tubing that worked fine
  - Test tube 18mm x 150mm (Carolina Biological cat # HT-71-0016)
- 3% $NaHCO_3$ (baking soda)
- 500mL Erlenmeyer flask
- Light source (such as a desk lamp or clamp light with a 100w bulb)
- Food coloring (red and green)
- Overhead transparency pen or wax pencil (Carolina Biological cat # HT-65-7730)
- clock

Preparation:

Pre-make the bent glass tubing pieces or have the students make their own using the following steps:

1. Score a length of glass tubing with a triangular file to make it approximately 35cm long.
2. Hold the glass tubing with a thumb and forefinger on either side of the scored line and carefully snap off that segment of the tubing. Heat the cut ends with a flame from a Bunsen burner to ensure smoother insertion into the stopper.
3. Heat the cut piece of tubing using a Bunsen burner approximately 15cm from its end, rolling the tubing back and forth between the fingers. When the tubing is soft, gently bend it into a 90^0 angle.
4. Lubricate a rubber stopper with glycerin and carefully push the short arm of the tubing into the stopper while twisting. Hold the tubing close to the stopper while inserting it.

Procedure*

1. Give each student a copy of Appendix A on photosynthetic pigments to read before they begin the lab activity
2. Divide students into pairs and give each pair a copy of the Student Handout – Effect of Light Color on Rate of Photosynthesis.

- You may wish to have students balance the second equation in the introduction to their Handout:

  $C_6H_{12}O_6$ + __6_O_2 → __6__CO_2 + ___6_H_2O + energy[1].

3. Distribute a pre-made volumeter to each lab pair, or demonstrate each step of the instructions as a class activity so that each pair can make their own.
4. Have the students do the experiment in the order of white → red → green. If time is a concern, have different student groups test different colors so all of the colors are being tested at the same time. If time permits, have students test a different color. Collect the class data at the end of the experiment and find averages.

*Alternative Procedure

If you have computer interfaced dissolved oxygen and carbon dioxide sensors, you may wish to use them instead of the volumeter described above. Instead of inserting the stopper with glass tubing, simply insert the sensor into the test tube with the Elodea. The top of the test tube around the sensor can be sealed with aluminum foil.

Safety

If students make their own L-shaped pieces of glass tubing or if they insert the tubing into a rubber stopper, be sure you emphasize and model good safety procedures for them to follow.

Hints

- Have students determine as a class the number of drops of food coloring to use so that the water color is standardized among the groups.
- Fill the flask full with water so that the test tube is covered up to the rubber stopper and no light can leak in around the stopper.
- Arrange the groups' flasks equidistant around the light source.

Extensions:

- Use a spectrophotometer to measure the wavelength of light transmitted by each water color and vary the water color
- Use a light intensity meter to measure the light output of the desk lamps and vary the light intensity
- Have students investigate another variable of their own choosing that might affect the rate of photosynthesis. They could explore the effects of varied temperature, pH, light intensity, etc.

Student Handout: Effect of Light Color on Rate of Photosynthesis

Name ____

Introduction:

Role of white light

Plants and other photosynthesizing organisms, transform solar energy and CO_2 into carbohydrates. Without solar energy, photosynthesis cannot occur. Release of oxygen from a plant demonstrates that photosynthesis is taking place as specified by the equation

$$6CO_2 + 6H_2O \xrightarrow{\text{solar energy}} C_6H_{12}O_6 + 6O_2 \text{ .}$$

However, part of the oxygen released from photosynthesis is taken up by aerobic cellular respiration

$$C_6H_{12}O_6 + \_\_\_O_2 \longrightarrow \_\_\_CO_2 + \_\_\_\_H_2O + \text{energy}^1.$$

[1]Can you balance this equation?

Aerobic cellular respiration is essential because it supplies energy for any type of cell activities such as active transport, cell division, and muscle contraction and so on. When measuring the rate of photosynthesis, one must take into account the oxygen that is consumed by respiration.

In this experiment, you will measure the rate of photosynthesis for *Elodea* in the presence of white light, then in the presence of red & green light. White sunlight is composed of a full range of color light. This can be demonstrated by passing a light through a prism and observing the range of colors coming out of it. Each color occupies a specific range of wavelengths, and different plant pigments absorb light (colors) at specific wavelengths. Chlorophyll a and b absorb most of the violet and orange light, but do not absorb green light.

What is your prediction about how the three colors of light used in this experiment will affect the rate of photosynthesis? ____

____

____

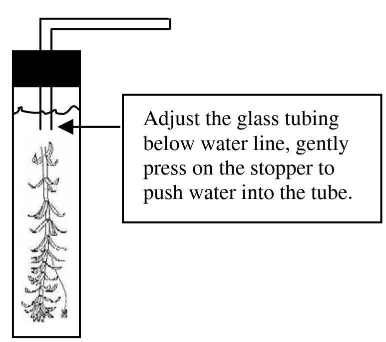
Safety

Follow the safety procedures demonstrated by your teacher if you are bending the glass tubing or inserting the tubing into the stopper that is needed for the volumeter.

PART 1: White light.

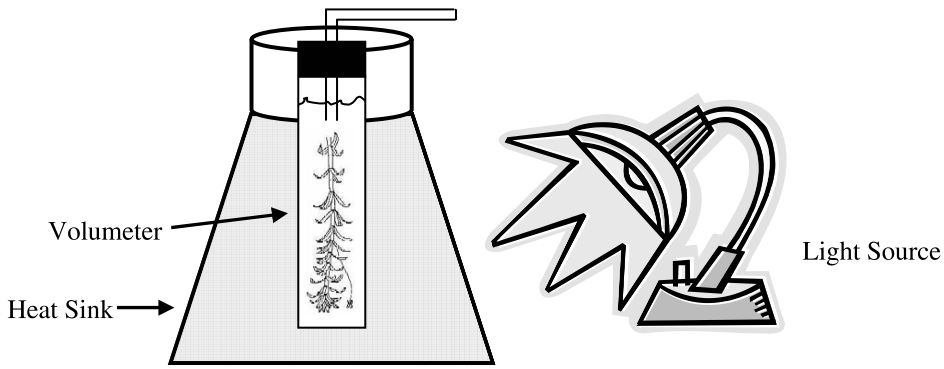
Assembling the volumeter:

1. Place a cutting of *Elodea* in a test tube with a rubber stopper outfitted with a bent piece of glass tubing as shown in Figure 1. Make sure the cut end of the *Elodea* is up.
2. Fill the test tube with 3% solution of $NaHCO_3$ (sodium bicarbonate). $NaHCO_3$ is a source of CO_2 for photosynthesis. Add enough solution so that when the stopper is in place, the solution travels up the bent glass tube to about a quarter of its height. Mark the location of the liquid in the glass tubing with a pen or wax pencil.



3. Place the volumeter into a flask full of water (Figure 2) and turn the light on.

Figure 2



4. When the level of the solution starts to move up the tube, begin counting time. After 15 minutes record how far the solution moved up the glass tubing in mm from the original mark.
   _______ mm / 15 min   This is *net photosynthesis.*
5. Record your data in the table below.

PART 2: Colors of Light – Red - Green

1. Add the number of red food coloring drops designated by your teacher to the flask of water used to absorb heat, and add fresh $NaHCO_3$ solution to the test tube.
2. Remove all the marks from the apparatus and mark the new position of the solution.
3. Repeat Steps 4 & 5 from Part I and record your results in the table below.
4. After 15 minutes, pour out the red water and fill the flask with fresh water. Add the designated number of green food coloring drops, and add fresh $NaHCO_3$ solution to the test tube. Repeat Steps 4 & 5 from Part I and record your results in the table below.
5. Your teacher will ask you to report your lab groups' values in order to calculate the class average values.

Rate of photosynthesis

RATE	GROUP VALUE	CLASS AVG.
Net photosynthesis – WHITE Light (mm/15 min)		
Net photosynthesis – RED Light (mm/15 min)		
Net photosynthesis – GREEN Light (mm/15 min)		

Questions:

1. Compare the rate of photosynthesis with white light with the rate of photosynthesis with red and green light.

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2. Based on your knowledge of plants, pigments, and light explain your results. ____________________

Appendix A: Photosynthetic Pigments

Pigments are colorful compounds.

Pigments are chemical compounds which reflect only certain wavelengths of visible light. This makes them appear "colorful". Flowers, corals, and even animal skin contain pigments which give them their colors. More important than their reflection of light is the ability of pigments to **absorb** certain wavelengths.

Because they interact with light to absorb only certain wavelengths, pigments are useful to plants and other **autotrophs** --organisms which make their own food using **photosynthesis**. In plants, algae, and cyanobacteria, pigments are the means by which the energy of sunlight is captured for photosynthesis. However, since each pigment reacts with only a narrow range of the spectrum, there is usually a need to produce several kinds of pigments, each of a different color, to capture more of the sun's energy.

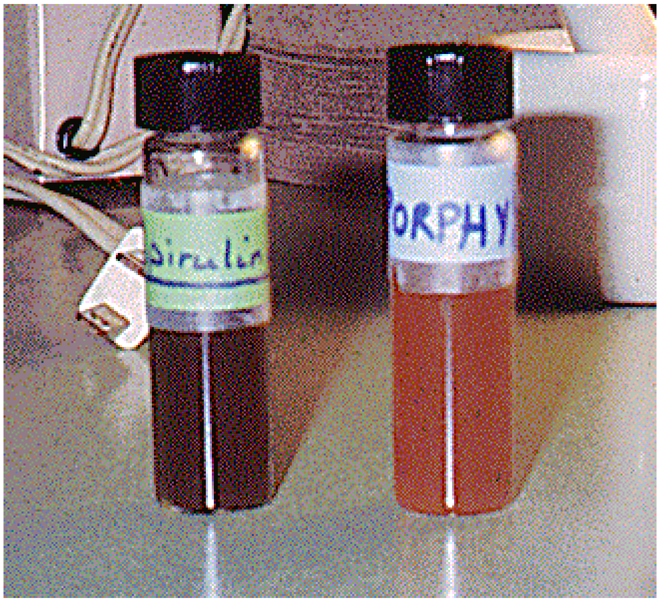
There are three basic classes of pigments
1. **Chlorophylls** are greenish pigments which contain a **porphyrin ring**. This is a stable ring-shaped molecule around which electrons are free to migrate. Because the electrons move freely, the ring has the potential to gain or lose electrons easily, and thus the potential to provide energized electrons to other molecules. This is the fundamental process by which chlorophyll "captures" the energy of sunlight.

There are several kinds of chlorophyll, the most important being chlorophyll "a". This is the molecule which makes photosynthesis possible, by passing its energized electrons on to molecules which will manufacture sugars. All plants, algae, and cyanobacteria which photosynthesize contain chlorophyll "a". A second kind of chlorophyll is chlorophyll "b", which occurs only in "green algae" and in the plants. A third form of chlorophyll which is common is (not surprisingly) called chlorophyll "c", and is found only in the photosynthetic members of the Chromista as well as the dinoflagellates. The differences between the chlorophylls of these major groups were one of the first clues that they were not as closely related as previously thought.

2. **Carotenoids** are usually red, orange, or yellow pigments, and include the familiar compound carotene, which gives carrots their color. These compounds are composed of two small six-carbon rings connected by a "chain" of carbon atoms. As a result, they do not dissolve in water, and must be attached to membranes within the cell. Carotenoids cannot transfer sunlight energy directly to the photosynthetic pathway, but must pass their absorbed energy to chlorophyll. For this reason, they are called **accessory pigments**. One very visible accessory pigment is **fucoxanthin** the brown pigment which colors kelps and other brown algae as well as the diatoms.

3. **Phycobilins** are water-soluble pigments, and are therefore found in the cytoplasm, or in the stroma of the chloroplast. They occur only in Cyanobacteria and Rhodophyta.

The picture on the next page shows the two classes of phycobilins that may be extracted from these "algae". The vial on the left contains the bluish pigment **phycocyanin**, which gives the Cyanobacteria their name. The vial on the right contains the reddish pigment **phycoerythrin**, which gives the red algae their common name.



Phycobilins are not only useful to the organisms which use them for soaking up light energy; they have also found use as research tools. Both pycocyanin and phycoerythrin fluoresce at a particular wavelength. That is, when they are exposed to strong light, they absorb the light energy, and release it by emitting light of a very narrow range of wavelengths. The light produced by this fluorescence is so distinctive and reliable, that phycobilins may be used as chemical "tags". The pigments are chemically bonded to antibodies, which are then put into a solution of cells. When the solution is sprayed as a stream of fine droplets past a laser and computer sensor, a machine can identify whether the cells in the droplets have been "tagged" by the antibodies. This has found extensive use in cancer research, for "tagging" tumor cells.

Source: http://www.ucmp.berkeley.edu/glossary/gloss3/pigments.html

Additional Resources

Because Web sites frequently change, some of these resources may no longer be available. Use a search engine and related key words to locate new Web sites.

http://www.mbl.edu/animals/Limulus/vision/Wald/photosynthesis.html
– George Wald and Photosynthesis

http://www.chm.bris.ac.uk/motm/chlorophyll/chlorophyll_h.htm
– Molecule of the Month - Chlorophyll

Genomic Revolution
http://www.ornl.gov/sci/techresources/Human_Genome/education/education.shtmL
This Web site of the government-funded Human Genome Project has links about genomics, the history of the project, and more.

Secrets of the Sequence Videos and Lessons
This video and 49 others with their accompanying lessons are available *at no charge* from www.vcu.edu/lifesci/sosq