Chemistry and Compost

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Introduction

Earth Day is a time to reflect on the interdependent roles of humans and the environment. The theme "ChemisTREE" for Chemists Celebrate Earth Day focuses on the connections between humans, chemistry and plants. In this activity you will explore that interaction by constructing a compost system and examining the biodegradability of various types of trash.

Green Chemistry Principles (See 12 Principles for a complete list.)

- Prevent pollution rather than clean it up afterward.
- Use renewable sources of material.
- Design materials to biodegrade.

Associated Chemistry Topics

- Properties of matter
- Scientific method
- Cycles
- Oxidation

Vocabulary

Aerobic – with oxygen present; typical of well-managed compost systems.

Anaerobic – without oxygen present; typical of landfills.

Biodegradable – capable of being broken down, especially into innocuous products, by the action of living things (as microorganisms). In soil, 90% of the organic carbon in a polymer must degrade into carbon dioxide within 180 days to be considered biodegradable by international standards for biodegradable plastics.

Cellulose – a molecule composed of glucose molecules (see **Chemical Structure 3**). Plants use this polysaccharide as a support structure in their cell walls. Cellulose is not easily broken down by human or animal enzymes.

Compost – a nutrient-rich mixture that consists largely of decayed plant material.

Glucose – a sweet, colorless, six-carbon sugar $C_6H_{12}O_6$ (see **Chemical Structure 1**). A carbohydrate referred to as a monosaccharide because it cannot be broken down into simpler units by hydrolysis reactions. The most common sugar in nature and the sugar most commonly fermented to ethanol.

Green Chemistry – designing chemical products and processes to reduce or eliminate the use or generation of hazardous materials.

Hydrolysis – a chemical reaction of a compound with a molecule of water.

Oxidation – the loss of electrons, the gain of oxygen atoms, or the loss of hydrogen atoms.

Oxidation of Carbon: $C + O_2 \rightarrow CO_2$

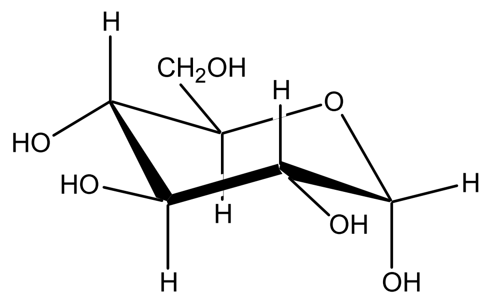
Polysaccharide – a large molecule composed of repeating sugar units; a carbohydrate that can be decomposed by hydrolysis into two or more monosaccharides.

Polystyrene – a plastic material composed of a polymer of styrene (see **Chemical Structure 4**); marketed under the trade name of Styrofoam®.

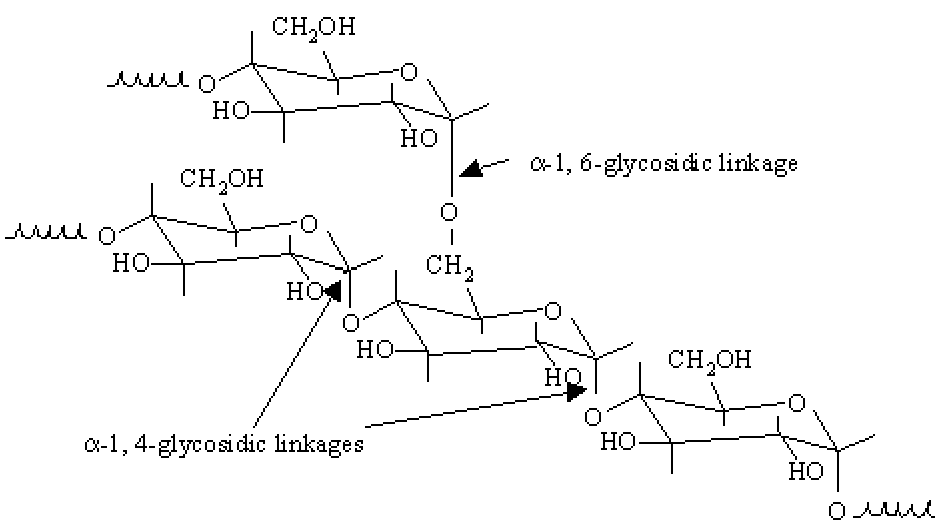
Starch – a polymer molecule composed of long chains of α-glucose molecules linked together (repeating unit $C_{12}H_{16}O_5$; see **Chemical Structure 2**). Plants store glucose for their energy needs in this polysaccharide. Starch can be easily broken down by human and animal enzyme systems. It is converted completely back into glucose via acid hydrolysis.

Chemical Structures

1. α-D-Glucose

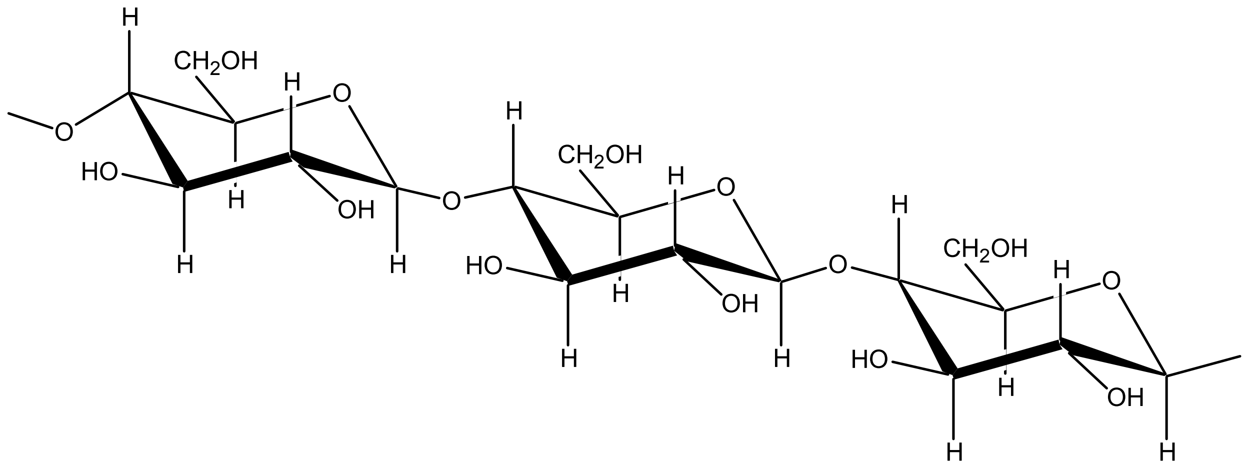


2. Starch

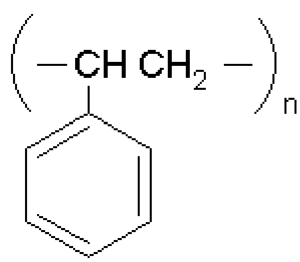


Source: Biofuels: Glossary of Terms for the Biomass Feedstock Composition and Properties Database
http://www.ott.doe.gov/biofuels/glossary.html

3. Cellulose



4. Polystyrene (Styrofoam®)



Background

Life on earth is based on cycles. Chemists and biologists study many different cycles. You may have studied the carbon, water, photosynthesis, or glycolysis cycles in your science classes. **Figure 1** is a diagram showing the general cycle of carbon on the earth. Plants use carbon from the atmosphere to make glucose through photosynthesis. When plants die, the carbon dioxide is returned to the atmosphere through decay processes. Animals and humans return carbon dioxide to the atmosphere through respiration, and other human activities may capture or release carbon dioxide.

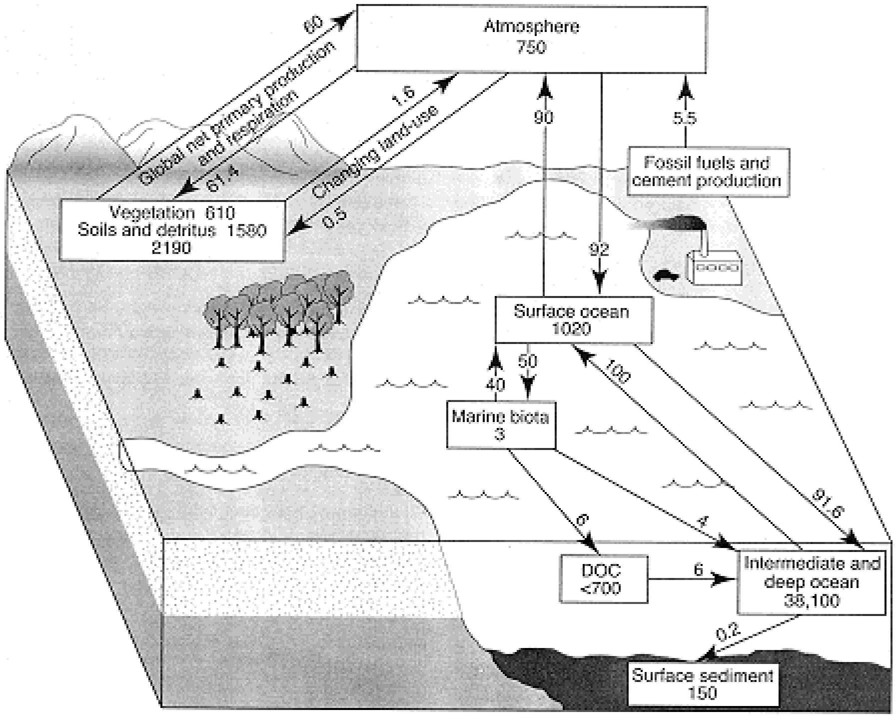


Fig. 1: The Carbon Cycle
Source: Carbon Cycle Diagram in gigatons of carbon (Gt C), http://www.whrc.org/science/carbon/carbon.htm
from Schimel, et al. 1995. CO_2 and the carbon cycle.
In: Climate Change 1994. Cambridge University Press: Cambridge, UK.

Over time, humans have learned that their activities impact the cycles in the environment. Materials do not always decompose, fuels are consumed faster than they are replenished, and wastes are generated that contaminate and compromise the cycles of the land, air and water. Cleaning up pollution involves a tremendous investment of time and energy. Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. In this way, chemists can design useful materials that are safe and environmentally friendly. By relying on renewable, bio-based materials and designing chemicals for degradation into benign substances, green chemistry is safeguarding the earth's cycles to ensure a sustainable future. Green chemistry has been described as "preventative medicine for the environment."[1]

Decomposition, often referred to as composting, is nature's way to recycle the energy and atoms in material that has passed its useful life. A compost system uses water, air and microorganisms to oxidize and break down, or biodegrade, complex materials into simpler elements and molecules. This process is very different from the landfill system, which attempts to isolate waste materials from water and air and prevent decomposition.

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[1] Dr. Lynn Goldman, Assistant Administrator of Prevention, Pesticides, and Toxic Substances, Environmental Protection Agency (July 11, 1996).

The carbon atoms that are a part of starch molecules can be oxidized to carbon dioxide by the process of composting. Growing trees, like all photosynthetic organisms, can then use the carbon dioxide to build new starch molecules. The starch can later be harvested and made into useful materials. At the end of their life, the plant-based materials can be composted, returning the carbon atoms to the cycle.

This cycle of plant-based carbon is sustainable on a much shorter time scale than the cycle for petroleum-based carbon. Carbon enters trees from the atmosphere, and exits trees into the atmosphere, forming a complete cycle with no net increase in atmospheric carbon. However, petroleum was formed from plants that lived long ago, and when petroleum-based carbon is returned to the atmosphere, the net amount of carbon dioxide increases. The carbon in petroleum has been absent from the atmosphere for so long that it is no longer a part of the "cycle" as we know it.

By designing products from plant material, chemists can work with nature to produce safe and environmentally friendly materials. When the product is ready to be thrown away, these materials may be composted. The simpler decomposed material can then be reused, either in the ecosystem or in additional industrial applications.

ECO-FOAM® and NatureWorks™ are just two examples of new alternative packaging materials made from renewable plant material, starch, instead of petroleum-based chemicals. Plants store the majority of their energy in starch, which is simply sugar (glucose) units connected in a long chain (see **Chemical Structures 1** and **2**). Relying on starch to make packing materials means that the raw material can be grown each year from plants instead of being extracted from petroleum resources. Starch-based materials are also readily biodegradable because microorganisms can easily digest starch.

Materials

1. Four cups of prepared compost. If prepared compost is not available, a mixture of several different plant materials such as wood shavings, lettuce scraps, small wood chips, carrot peelings, newspaper strips, apple cores, pieces of paper egg cartons, bread crusts, chopped straw, banana peels, weeds, or grass clippings can be used.
2. Two containers to hold compost. Use available plastic cartons or make Soda Bottle Bioreactors. See the Cornell Composting Web Site: “Building a Soda Bottle Bioreactor” at http://www.cfe.cornell.edu/compost/soda.html for photos and instructions.[2]
3. Balance
4. Non-mercury thermometer
5. pH paper
6. Samples of waste material (i.e. paper, cardboard, plastic, Styrofoam®). Use what is available to you. The size or mass of the samples should be similar in order to make valid comparisons. Some examples are below:

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[2] Authors: Nancy M. Trautmann, Tom Richard, Marianne E. Krasny, Patrick Cushing, Stephanie Hyson, Richard Northrup, Elaina Olynciw, Barbara Poseluzny

- Eco-film® biodegradable protective packaging film
- NatureWorks™ biodegradable plastic wrap
- Earth Shell® biodegradable food service packaging material
- ECO-FOAM® biodegradable, loose-fill packaging material
- Overhead projector plastic film
- Plastic grocery bag
- Plastic bubble wrap
- Polystyrene (or Styrofoam®)
- Newspaper
- Other paper or plastic waste materials of your choice

Procedure

1. Prepare enough containers or bioreactors to accommodate each of the different waste material samples. Be sure to label the containers appropriately, i.e. number each container and keep track of which waste material sample corresponds to which container number.
2. Divide the compost evenly between the empty cartons or bioreactors and record the mass of compost in each carton. Moisture in your compost will account for a significant portion of its mass; drier material will lead to greater experimental accuracy.
3. Cut the samples of waste material into the same approximate size that will fit into each container.
4. Record the mass of each sample of waste material and place each in a container with compost.
5. Be sure the compost is moist and is completely surrounding the sample. Be sure to record the mass of water you use to moisten the compost, though too much moisture will create anaerobic conditions
6. Write down the changes you think will occur to the waste materials – summarize your thoughts as a two-sentence hypothesis.
7. Prepare a table to record your observations over the next several weeks. Observations should include characteristics such as mass, temperature, pH, moisture, odor and overall appearance. Your table should include columns to record date, time and sample number. An additional column for miscellaneous observations may also be helpful.
8. Monitor the conditions (temperature, pH, moisture, odor, appearance) of the compost and the waste material over the next several weeks. You may need to add water occasionally to keep the compost moist; record how much additional water you added and the date and time when it was added.
9. Share your data with the other groups and collect the data from other groups. Be sure you have all the information you need to answer the questions below.
10. Analyze the class data to answer the following questions:

Questions

1. Describe the initial and final conditions of your cartons – composition, weight, temperature, pH, moisture, odor, appearance etc., of both the compost and the waste material sample.
2. What was your hypothesis? What is your conclusion based on the data you collected? Does your conclusion match your initial hypothesis? If not, account for the discrepancy. How do your results compare with those of the rest of the class?
3. Which sample of waste material changed the most? The least? (Make sure to describe the change in your answer.)
4. Summarize the similarities and differences between the structures, physical properties and biodegradability of starch, cellulose and polystyrene.
5. You are responsible for buying disposable packaging materials (bags, cups plates, etc) for your company. Choose two of the samples you composted and write a two-page report. A full analysis will include raw material source, production process, chemical structure, cost, performance characteristics and biodegradability of each of the samples. Conclude by justifying the purchase of one product instead of the other.

Instructional Notes

Grade Level (Target Audience): 8-12

Estimated Time of Activity:

Initial set up: 1-3 hours
Observation and data collection: 4-8 weeks
Write up: 2-4 hours

Materials (per group of four)

1. Four cups of prepared compost. If prepared compost is not available, a mixture of several different plant materials such as wood shavings, lettuce scraps, small wood chips, carrot peelings, newspaper strips, apple cores, pieces of paper egg cartons, bread crusts, chopped straw, banana peels, weeds, or grass clippings can be used.
2. Two containers to hold compost. Use available plastic cartons or make a Soda Bottle Bioreactor: See the Cornell Composting Web Site: "Building a Soda Bottle Bioreactor" at http://www.cfe.cornell.edu/compost/soda.html for photos and instructions. [3]
3. Balance capable of measuring the mass of the containers and compost (expect 500 g to 2 Kg)
4. Non-mercury, Celsius thermometer
5. pH paper
6. Two samples of waste material (i.e. paper, cardboard, plastic, Styrofoam®). Use what is available to you. The size or mass of the samples should be similar in order to make valid comparisons. Some examples are below:
   - Eco-film® biodegradable protective packaging film
   - NatureWorks™ biodegradable plastic wrap
   - Earth Shell® biodegradable food service packaging material
   - ECO-FOAM® biodegradable, loosefill packaging material
   - Overhead projector plastic film
   - Plastic grocery bag
   - Plastic bubble wrap
   - Polystyrene (or Styrofoam®)
   - Newspaper
   - Other paper or plastic waste materials of your choice

This procedure is very adaptable to available materials and time. Provide two waste samples and sufficient compost and containers for two bioreactors per group of four students. Have each group monitor their waste samples and then share their data with the class. (Sample data tables are provided in a separate document.)

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[3] Authors: Nancy M. Trautmann, Tom Richard, Marianne E. Krasny, Patrick Cushing, Stephanie Hyson, Richard Northrup, Elaina Olynciw, Barbara Poseluzny

Considerations and Adaptations

Considerations: This procedure is very adaptable to available materials and time. Depending on the level of the students, the number of group members and number of different samples can be adapted.

Less Advanced: For younger students, consider providing before and after samples rather than having them be responsible for composting their own samples. They can make observations on these two samples in one hour. Third through fifth grade students should be able to propose a hypothesis after you have introduced the activity.

More Advanced: For a more extended study, have students alter the conditions of the bioreactors, for example exclude oxygen by providing excess water, or decrease temperature by setting the samples on ice or in a refrigerator. Keep in mind it is difficult to analyze the results if more than two variables are being used, especially with the quantity of bioreactors being observed. Use of a computer program for analyzing the data is strongly encouraged.

Answers to Questions

The answers are specific to the individual samples.

References:

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CORNELL Composting
- http://www.cfe.cornell.edu/compost/Composting_Homepage.html

Biofuels: Glossary of Terms for the Biomass Feedstock Composition and Properties Database
- http://www.ott.doe.gov/biofuels/glossary.html

Encyclopedia.com
- http://www.encyclopedia.com/index.asp

Earth Shell®, biodegradable food service packaging material
- http://www.earthshell.com/

Eco-film®, biodegradable protective packaging film from Cortec
- http://www.vciplastic.com/bio_films.htm

ECO-FOAM®
- http://www.eco-foam.com/education.asp
- Classroom Activities: http://www.eco-foam.com/education.asp

Global Carbon Cycle - Woods Hole Research Center
- http://www.whrc.org/science/carbon/carbon.htm

Green Chemistry Institute
- http://chemistry.org/greenchemistryinstitute

KidTech, Magic Nuudle®
- http://www.magicnuudles.com/home.htm
- Ecology Lesson: http://www.magicnuudles.com/lessonplans/Nuudle_ecology_LP.htm

Merriam-Webster Online
- http://www.m-w.com/home.htm

NatureWorks Plastic Packaging
- http://www.cargilldow.com/corporate/package.asp

Polystyrene Packaging Council Homepage
- http://www.polystyrene.org/index.html