Photosynthesis and Biomass Growth

Karen S. Harrell
Jennifer Pratt

Middle and High School/Biology, Chemistry and Environmental Science

For the Teacher

Today, corn plants are being used to create a renewable energy source called ethanol. Ethanol is used in our gas tanks to power our cars and is one of the leading alternatives to natural gas. We all know that Earth's fossil fuel supply is finite so fuels like ethanol provide an essential replacement for petroleum products. Plant research is the starting point for alternative fuel production. Throughout NREL's Biofuels Program, scientists are uncovering ways to transform plant biomass into innovative and beneficial materials, such as fuel, plastic and fiber. In addition, biomass research is necessary for efficient food production and for understanding the numerous other products that plants provide.

Introduce your students to the power of plants! Photosynthesis is arguably the most important energy transformation and is a fundamental concept for students of all ages. Projects listed in this section should be used as an exciting starting point for both classroom and science fair projects. Most of the materials are easily obtainable at your local home or garden center. We encourage you to modify the experiments to fit your curriculum needs.

National Science Education Standards by the National Academy of Sciences

Science Content Standards: 5-8

Science As Inquiry
- Content Standard A:
"Abilities necessary to do scientific inquiry"
"Understandings about scientific inquiry"

Life Science
– Content Standard C:
"Regulation and behavior"
"Populations and ecosystems"
"Diversity and adaptations of organisms"

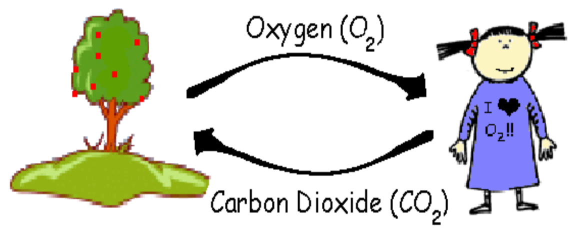
Science and Technology
– Content Standard E:
"Abilities of technological design"
"Understandings about science and technology"

Science in Personal and Social Perspectives
– Content Standard F:
"Personal health"
"Populations, resources, and environments"
"Natural hazards"
"Risks and benefits"
"Science and technology in society"

Science Content Standards: 9-12
Science As Inquiry
- Content Standard A:
"Abilities necessary to do scientific inquiry"
"Understandings about scientific inquiry"
Life Science
- Content Standard C:
"Interdependence of organisms" "Matter, energy, and organization in living systems"
Science and Technology
– Content Standard E:
"Abilities of technological design"
"Understandings about science and technology"
Science in Personal and Social Perspectives
– Content Standard F:
"Personal and community health" "Population growth"
"Natural resources"
"Environmental quality"
"Natural and human-induced hazards"
"Science and technology in local, national, and global challenges"

Technology Description

Why are plant leaves green? How do plants get energy to live? Do plants "breathe"? All of these questions can be answered with one idea, **photosynthesis**. Photosynthesis is a process where plants take the sun's light energy and change it into **glucose**, a kind of sugar. A green chemical in the in plant leaves, called **chlorophyll,** makes it all happen and gives plants their green color.



When you breathe, your body uses oxygen (O_2) and gives off carbon dioxide (CO_2). Since all animals breathe in oxygen, why don't we ever run out? During photosynthesis, plants use carbon dioxide and release oxygen, so animals and plants have a **symbiotic** relationship; we rely on each other to survive!

Photosynthesis

$$CO_2 + \text{Water} \xrightarrow[\text{Sunlight}]{\text{Chlorophyll}} O_2 + \text{Glucose}$$

Plants, trees and aquatic algae all create energy (in the form of glucose) through photosynthesis. Since people can't make their own energy from the sun, we eat food instead. We can use the energy stored in plants in other ways too! Scientists are interested in **biomass** energy for things such as fuel for your car. Biomass can be found all over the world and there is an endless supply since it can keep growing! Such things as corn stalks that are leftover from harvesting and forest brush that may cause a fire hazard can be converted into fuels. These biomass fuels burn cleaner than gas or oil does, so it is also safer for the environment. The only problem is that right now, biomass fuels are not as economical (or cheap) as we would like. Scientists are trying to find ways to grow biomass in ways where they can get the most energy with the lowest cost. Can you discover some ways in which we should grow biomass? Use the ideas below or come up with your own!

Good sources of information about photosynthesis, biofuel and agricultural research include:

Arizona State University photosynthesis research
http://photoscience.la.asu.edu/photosyn/default.html

Department of Energy biofuel site
http://www.ott.doe.gov/biofuels/students.html

Department of Agriculture biofuel site
http://www.nal.usda.gov/ttic/biofuels/nonusda.htm

State of Florida Agricultural Science
http://www.florida-agriculture.com/PlanetAg/

Vocabulary

Biomass: Plant material, vegetation, or agricultural waste used as a fuel or energy source.

Chlorophyll: Green pigment in the Chloroplast that aids in creating sugar (glucose) from sunlight.

Chromatography: A process used to separate mixtures by differences in absorbency.

Control: A standard of comparison for checking or verifying the results of an experiment.

Ecosystem: Organisms and their environment functioning as a whole.

Glucose: Sugar created in photosynthesis and the main energy source for our bodies. ($C_6H_{12}O_6$)

Interdependence: Relying on each other.

Photosynthesis: "Putting together with light." This process uses sunlight to create chemical energy (sugar) in plants and some other organisms.

Pigment: Coloring or dye. Chlorophyll is a green pigment.

Pollutants: Waste material that contaminates air, soil or water.

Symbiotic: Organisms mutually needing or helping each other.

Variable: Something that is changed.

Wetland: A lowland area, such as a marsh or swamp that is saturated with moisture.

Project Ideas

1 How do modern farming techniques affect the growth of biomass?

Learning Objectives: The population of the Earth continues to grow about 7.4 million people a year, reaching 6.3 billion people in 2003 (http://www.census.gov/). That is a lot of mouths to feed! With new advances in science and technology, we are able to create crops that are bigger and better through genetic alterations, pesticides, new fertilizers and synthetic (or fake) hormones. As the population of the world continues to increase and farming area decreases, there is a widespread need for farmers to produce "miracle crops." This project will help you discover and understand the benefits and problems that arise with crop modifications.

Control and Variables: In this project, you will be selecting one or more modern farming technique to look at more closely. You can choose to do several, however you must remember that you will need to have a **control** set-up so that you can compare your results to the control (the control would have no modifications). To start, you would want to set up one growth chamber (like an aquarium or large glass container) with several plants and a modern farming technique. Set up another growth chamber the same as the first, but do not add a modern farming technique. Then you can compare the two results.

You may also choose to do more than one modification, such as "how do pesticides and hormones affect plant growth." In this case, be sure to have a control with no modifications, a control with just pesticide treatment and another with just hormone treatment. This way you can see what changes occurred when they were separate and which ones only occur when they are used together.

Materials and Equipment:

Growth Chambers (2 minimum)

Plants (3-4 per growth chamber)

Scale

Choose one or more of the following:

Plant hormone (Gibberellin: Sigma $25.00)

"Miracle Grow" Fertilizer (All purpose fertilizer: Home Depot $4.00)

Pesticides (Ortho Insect and Disease Control: Home Depot $14.00)

Safety and Environment Requirements: When using materials such as insecticides and hormones, gloves and safety glasses should always be worn. Some plant hormones, such as Gibberellin, are poisonous, so should not be used on food plants that will be eaten. With all experiments, be sure to wash hands thoroughly after application and handling.

Suggestions: Since you will want to look for changes in growth, plants in the different growing chambers should be as similar as possible. You can use a scale to weigh biomass before and after the experiment. Regular observations will identify other changes as well, so a journal will help to keep track of changes such as colors, leaf conditions, general appearance and smell.

Other Ideas: After you have looked at the affects of a modern farming technique on your plant species, try a different species, such as a food plant or a flowering plant. Are the effects the same as what you saw before? How do aquatic plants react to the same variable?

There are also other ways to avoid pests, such as **biological controls**. This is when a predator of the pest is brought into the area to get rid of the problem. What are the risks and advantages to this method? Would they be less risky? Would this method be as quick or cost efficient as a pesticide?

In addition, consider having a discussion about genetically engineered food crops, such as those that produce their own pesticides. Should they be used for food? What is the controversy between organic and non-organic products? How do your results make you feel about these issues?

Good sources of information and discussion about farming techniques and pesticides include:

Carson, Rachel (1962) Silent Spring
Note: *This book may not be appropriate for all age levels*

EPA fact sheets and current pesticide information:
http://www.epa.gov/pesticides/

Current issues and problems facing the use of pesticides:
http://www.beyondpesticides.org

2 Is natural sunlight, imitation sunlight, fluorescent light or incandescent light best for plants?

Learning Objectives: In this activity, students observe how sunlight separates into a variety of colors when passed through a prism, and these visible colors correspond to different wavelengths in the electromagnetic spectrum. Plant **pigments** reflect or absorb the wavelengths resulting in the wide variety of plant color. In this experiment, discover what happens when plants are grown under various types of light. Will different light sources generate a change in the size, color and rate of the growth responses?

Control and Variables:
Control- Plant type, temperature, amount of light, and planting medium should all be the same. Collect the data at the same time for all plants.
Variables- Different types of light. Water according to the plants needs.

Materials and Equipment:

Prism (www.boreal.com, $6.00)

Light fixtures (Home Depot, $10.00 each)

Grow light bulb (Home Depot, $10.00 each)

Fluorescent bulb

Incandescent bulb

Rapid radish seeds (www.boreal.com, $10.00/50)

16 mini peat plant pots

Potting Soil

Labels

Graph paper

Sample Data Table

DATE	HEIGHT	COLOR	NUMBER OF LEAVES

Safety and Environmental Requirements: Electrical shocks and SERIOUS INJURY CAN OCCUR if the light fixtures are mishandled. Adult supervision is necessary!

Suggestions:

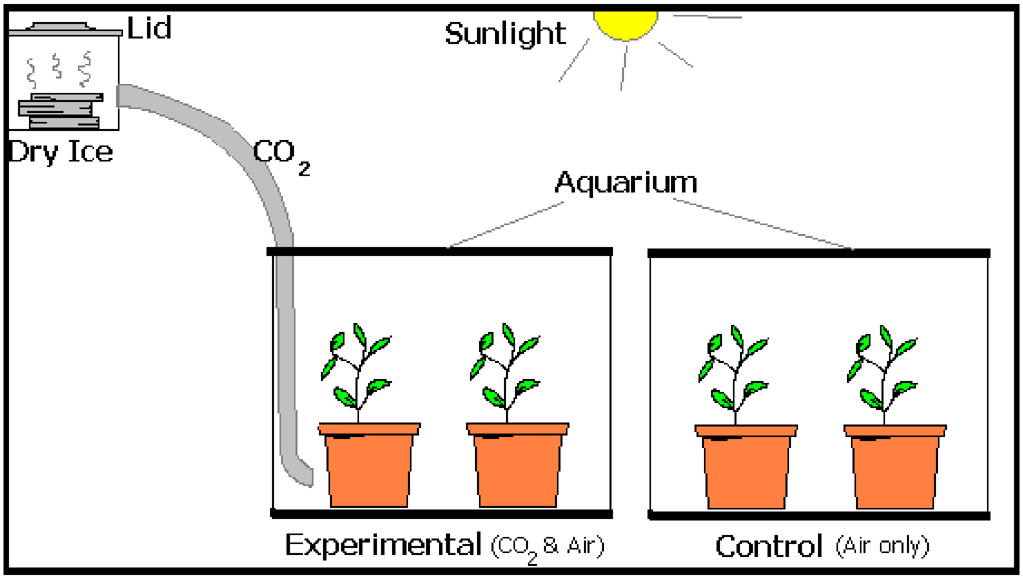
- Grow four radish seedlings under each light source. Collect data after germination for 3-6 weeks.
- You are encouraged to run this experiment with a variety of plant types, such as coleus, geraniums, or sunflowers.
- Does reflected light also impact plant growth? Design an experiment to see if tomatoes produce more fruit surrounded by red plastic mulch; cucumbers and cantaloupe surrounded by blue!

Good sources of information about plants and gardening products include:

Fun site that shows videos of seed germinations.
http://sunflower.bio.indiana.edu/~rhangart/

Colored mulch gardening supplies
http//www.gardeners.com/

Organic garden supplies
http://www.seedsofchange.com/



3 How does varying CO_2 levels affect the rate of growth in plants?

Learning Objectives: Understanding how carbon dioxide (CO2) levels affect biomass growth is key to under-standing environmental concerns such as global warming, rainforest destruction and much more. Since carbon dioxide is often released into the environment by factories, cars and natural processes, it is important to know how plants will react to changes in the air.

Control and Variables: When setting up your experiment, run a control as well. In this project, you would have one aquarium with plants in it and an outside carbon dioxide source. Another aquarium would be set up the same way, but without the carbon dioxide. Remember to keep the soil, temperature, moisture levels and time run the same for both aquaria. Try to keep the plants as close to the same as possible, with the species, size and number of leaves all similar.

Materials and Equipment:

2 Aquaria or other types of growth chambers (even 2 large glass jars will work!)

Thermometer

At least four plants with a minimum of 5-6 leaves per plant

CO_2 Source:

- Dry ice can be purchased at places that sell ice, such as grocery or ice cream stores.
- If your school has a CO_2 cylinder, that would also work well.

Safety and Environment Requirements: Dry ice can cause severe burns, so be sure to always have adult supervision and insulated gloves. Dry ice is a solid form of CO_2, so it gives off CO_2 gases (which is what we want for this project). Be sure that the room you are working in is ventilated well and you have a fresh supply of air. Also, CO_2 compressed cylinders are under a lot of pressure and should be handled with great care.

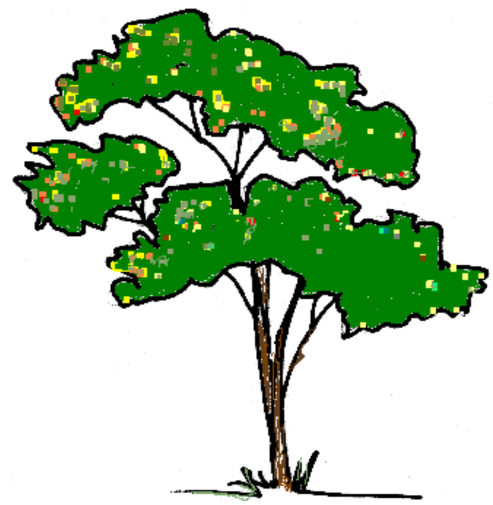
Suggestions: Plants should have a minimum of 5-6 leaves and be of about equal size. Calculate total leaf area at beginning and end of the experiment for each plant (graph paper may be useful). If dry ice is used, consider that CO_2 is heavier than air. Like its name suggests, dry ice is very cold (-109.3 °F or -78.5 °C) so the gas from the ice may be too cold for your plants, depending on how you set up your experiment.

Other Ideas: Collect data in varying concentrations of CO_2 to find a pattern of biomass growth. Graph the results and see if you can find a fitting equation (if you have this math background). According to your results, how will global warming affect the growth of plants in different regions of the world, such as high elevations, deserts, rainforests, and tundra?

Good sources of information about global warming include:

EPA Global Warming Website for Kids:
www.epa.gov/globalwarming/kids

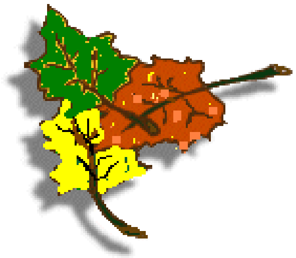
Rainforest Action Network for Kids:
http://www.ran.org/kids_action/



4 What are the true colors of leaves?

Learning Objective: This experiment uses chromatography techniques to separate the pigments found in leaves. Students come away with an understanding of extraction methods and information on the three main groups of plant pigments - chlorophyll (green), carotenoids (yellow-orange) and anthocyanins (blue-red).

Control and Variables:
Control - Rubbing alcohol solvent
Variables - Variety of plant material



Materials and Equipment:

Coffee filters, cut 2-3 cm wide, approximately 10 cm long strips (depending on jar size).

Assortment of leaves and petals

Tape

Pencil

Small clear jar

Rubbing alcohol

Safety and Environmental Requirements: Use caution when using alcohol! It is flammable and should not be splashed into eyes or on skin. Goggles, gloves and a protective lab coat are needed!

Suggestions:

- Place the leaf upside down. At a spot 2 cm from the bottom of the filter strip, rub gently on the leaf with the pencil point. Make the rubbing approximately the size of a penny. Re-adjust the leaf and continue rubbing until the spot on the filter paper is dark. The transferred pigment should be placed above the solvent level, with about 1 cm of the strip in the solvent. Tape the strip to the top of the jar. Remove once the solvent reaches the top; dry for comparisons.
- Discuss the fact that the reds, yellows, and oranges that we see in fall are always present in leaves, but are obscured by the green of chlorophyll in spring and summer. Green bananas show chlorophyll too! As the chlorophyll breaks down the yellow pigments can be seen.
- Conduct this test with leaves grown in Project 2.
- Scientists at NREL use solvents such as water and alcohol to separate the chemicals in biomass. Can you design an experiment to capture a plant's fragrance? *Recommended plants*: lavender, rosemary, rose petals; *Recommended solvents*: try sunflower oil, olive oil or hot water.
- Here's a great demo! Tea is a solution that extracts plant compounds to flavor water. The sugar that we generally use to sweeten tea is sucrose. Amazingly, when you add the sucrose to hot tea, there is a chemical reaction changing sucrose to two other sugars: glucose and fructose. These two sugars make tea nearly 10% sweeter than tea that was sweetened when cold!

5 How do aquatic plants survive underwater? Do they still need light to make oxygen?

Learning Objectives: We know that plants need sunlight for photosynthesis. What happens when the plants are underwater? In this activity, you will discover how aquatic plants react to different intensities of light. Following this activity you will also be able to set up an aquarium with aquatic plants and organisms in order to demonstrate the **interdependence** of plants and animals.

Control and Variables: In order to understand what happens to aquatic plants when they are placed in the sunlight, you will be setting up a wide range of aquatic plant samples. In your containers, you should have the same volume of water and amount of plants so that you can compare the results between the control and variables. Also, make sure the water and plants are from the same supply. Try to keep the conditions for all the containers as close to the same as possible. Different temperatures and light sources will make plants act differently.

Materials and Equipment:

Aquatic plants: Elodea can be found in many ponds. It can also be purchased at pet stores for about $1.75/ plant.

6 Jars or glass containers

Scale

Dissolved Oxygen (DO) Test Kit (PETCO: $12.00)
DO meter may be substituted

UV light source (must be available 24 hours/ day)

Pipette

Thermometer

Beta Fish or goldfish for the end of the activity (optional)

Safety and Environment Requirements: Always use safety glasses and gloves when working with chemicals and heat.

Suggestions: Set up 6 jars with equal volumes of water and biomass. Place two jars in 24 hours of UV light, two jars in 24 hours of darkness, and two in 12 hours of UV light and 12 hours in darkness. Measure the dissolved oxygen (DO) levels every 24 hours and record. Get DO levels before starting your experiment also so that you can see if it has changed over time. Where is the dissolved oxygen going or coming from? What does this mean in a freshwater environment? Do the DO levels increase, decrease or stay the same over time?

Other Ideas: After running your experiment, consider how aquatic and terrestrial (land) systems are similar/ different. Create an aquatic

ecosystem using the oxygen/ carbon dioxide cycle that we have learned about. How would you create an ecosystem on land? Consider moving life to Mars or to the International Space Station. What would you need to live in either of those places?

Good sources of information on biomes and ecosystems include:

Create your own personal ecosystem or one on Mars at: http://www.lehigh.edu/~japa/wbi.

Information about the International Space Station (including sighting information) can be found at: http://spaceflight.nasa.gov/station/

Lots of information about water systems and biomes of the world: http://mbgnet.mobot.org/

6 What happens when plants are crowded?

Learning Objective:
When we have plants in our house, we usually only have one or two plants in each pot. However, in many eco-systems there are lots of plants and trees crowded together. This is one reason why the rainforest is so amazing to us! In this experiment, you will document ways in which plants change their growth strategies to compensate for lack of nutrients, light and root space. Can you think about ways that plants survive in crowded conditions?

Control and Variables:
Control - Plants grown without crowding
Variables – Similar plants grown in small, congested areas, 2" pots recommended with up to 4 plants

Materials and Equipment:

Up to 24 sets of plants (use vegetables grown from seeds or a variety of house plants)

6 - 2" pots

6 – 6" pots

Potting soil

Metric Ruler

Graph Paper

2 Root-Vue Farms *optional* (www.Boreal.com, $52.00)

Safety and Environmental Requirements: No special requirements needed.

Suggestions:
- Use the data generated from this experiment to compare and contrast growth patterns between crowded and uncrowed plants.
- Plants are amazing in how they can survive under adverse conditions. In the rainforests, understory plants devised ways of using just one fleck of light to provide the energy for growth and

reproduction. This system took millions of years to evolve. Identify the structural differences between plants that like shade and plants that need full sun.

- What short-term strategies did your plants exhibit? Did your vegetable plants produce seeds? Plants that are stressed often try to reproduce before their nutrients are lost. How is this triggered?
- Take one medium-sized plant and remove one leave at a regulated rate to represent predation. How many leaves can be "eaten" before the plant changes?
- Bonsai trees first appeared over a thousand years ago! It is an ancient practice first started by the Chinese where plant roots are restricted from growing, so the plant does not have enough nutrients to develop naturally. You may want to research bonsai trees and start your own bonsai tree project!

Good sources of information about rainforests and bonsai include:

Rainforest Education
http://www.rainforesteducation.com/

American Bonsai Society
http://www.absbonsai.org/

7 Can a cascade of wetlands be a pollution solution?

Learning Objectives
Often overlooked in the past, **wetland** ecosystems are now recognized as playing a vital part in earth's water cycle. Through this exercise, children gain an understanding of the complexity of wetlands and measure the impact of pollution on common wetland species.

CONTROL AND VARIABLES
Control - Container of cattails without any **pollutants.**
Variables – Similar plants treated with pollutants.

Materials and Equipment

4 – 6"containers of cattails or bulrushes (Approximately $25.00 in local garden centers)

For every 2 liters of water add:
½ cup sunflower oil
1 cup sand and soil mix

Epson salt (optional)

Graph Paper

Metric Ruler

Saucers to collect runoff water

Bucket (optional)

Safety and Environmental Requirements

No special requirements needed.

Suggestions

- First, measure and record the height and health of your plants.
- In this experiment, the first "wetland" should be watered with the polluted water. Runoff water from the first is then used to water the second, and so on. Document the characteristics and volume of each watering.
- Water the plants three to seven days with the polluted water, documenting changes in the plants. What happened to the sediments? Where is the oil deposited? Are all the plants alive? Are the pollutants hurting them?
- Irrigated agricultural lands often leave salt residue in the soil. Will high salt concentrations harm plant growth? If time is available, use salt as a pollutant and check the impacts after a few months.
- Wetlands are not just cattails marshes; there are untold varieties of plant species in these eco-systems.

  Would a floating plant, such as duckweed or water hyacinths, help the cattails filter the pollutants? Explain why.
- What are the current laws regarding wetlands? Can a developer fill in to build a house? What about the birds and animals that live there?
- Search the Internet to find a city that uses wetlands in their water purification systems.

Good sources of information about wetlands include:

Environmental Protection Agency wetland homepage
http://www.epa.gov/OWOW/wetlands/index.html

In depth information on midwestern wetlands.
http://www.npwrc.usgs.gov/resource/1998/mnplant/mnplant.htm

Florida State University wetland research center.
http://aquat1.ifas.ufl.edu/welcome.html

Additional Suggestions

What growing medium produces more biomass: regular soil or a hydroponic solution?

What percentage of a plant's mass and nutrients are contained in its roots? Stems? Leaves?

Collect soils from across your state and run soil tests on each. Make a prediction on which agricultural crop would grow best in each soil.

How do plants climb? Do plants grow toward light? How does light direction effect plant growth?

Test inorganic vs. organic growing techniques.

How much can you dilute a pesticide while retaining its effectiveness?

How successful are natural pest deterrents?

What are the fastest growing grasses in your area? Trees?

What factors positively influence seed germination? Experiment with variables such as seed orientation, planting depth, or soil types, temperature.

What are the effects of magnetic or electrical fields on plant development?

Do different size seeds have different germination rates? How strong are germinating seeds? Does the size of the seed correspond to the final size of the plant?

Which edible seeds sprout in water?
Will frozen seeds sprout?
Place uncut, hydroponically grown tomatoes near grow lights for a few weeks and see if you can make the seeds sprout inside the tomato!!

What are the effects of oil, salt or bleach on algal growth?

Which plants and vegetables make the best dye?

References

National Renewable Energy Laboratory, *Science Projects in Renewable Energy and Energy Efficiency.* Boulder, CO, 1991 American Solar Energy Society, pp. 41-45.

Unknown, "Experiment of the Week - Sweet Tea #220" in The Teacher's Corner, 2001 May 13, [Cited 2003 July 8], Available:http://www.theteachers corner.net/science/experiments/tea.htm