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**February/March 2015 Teacher's Guide**

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# About the Guide

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Articles from past issues of *ChemMatters* can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains all *ChemMatters* issues from February 1983 to April 2013.

The *ChemMatters* DVDincludes *an* Index that covers all issues from February 1983 to April 2013.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558.

Purchase information can be found online at: [www.acs.org/chemmatters](http://chemistry.org/chemmatters/cd3.html)

# Student Questions (from the articles)

**ChemDemos Demystified**

The burning candle

* 1. List three observations made in the burning candle demonstration when the beaker is placed over the burning candle.
  2. What is the formula for paraffin wax?
  3. Describe the change in moles of gaseous reactants and products as the burning of paraffin proceeds.
  4. Explain in your own words why the water level inside the beaker rises.
  5. What role does air pressure play in your explanation?

The deflected stream of water

* 1. Describe what happens when a stream of water is brought close to a charged rod or balloon.
  2. In the water molecule, why is oxygen negative and hydrogen positive?

Faulty demonstration of the greenhouse effect

* 1. What happens in this greenhouse effect demonstration after the heat lamp is turned on, but before the carbon dioxide is added?
  2. What happens after the carbon dioxide is added?
  3. Why is this NOT a good demonstration of the greenhouse effect?

**Liquid to Foam: How Egg Whites Change Texture**

1. Name three food items that the article says require a beaten egg white foam.
2. What is the chemical composition of egg whites?
3. Proteins are made up of amino acids. How many amino acids exist naturally?
4. What part of amino acid structure makes each amino acid unique?
5. What does the term “hydrophilic” refer to?
6. When proteins fold, where are the hydrophobic amino acids located?
7. When egg whites are beaten, what happens to the proteins?
8. What is the primary purpose of beating egg whites in a recipe like the angel food cake described in the article?
9. Name the scientists who first showed by experimentation that trace amounts of copper stabilized egg white foam.
10. What protein in egg white forms a stabilizing complex with copper?
11. What is the name of the most common covalent bond that forms between amino acids containing sulfur-hydrogen side groups?

**Fermentable Foods: Trouble in Your Diet**

* 1. What is meant by the term “macronutrients”?
  2. How are gluten and celiac disease related?
  3. What is the connection between irritable bowel syndrome and FODMAP?
  4. What is the difference between irritable bowel syndrome and celiac disease?
  5. Oligosaccharides are classified as a type of carbohydrate. What are their chemical characteristics?
  6. What happens to oligosaccharides made from glucose subunits when they reach the small intestine?
  7. What happens when oligosaccharides made from the sugars galactose or fructose reach the small intestine, compared with those oligosaccharides made from glucose subunits?
  8. What sugar is produced when amylase breaks down the disaccharide maltose?
  9. What are the sugar components of the disaccharide lactose, compared with those found in maltose?
  10. How do undigested sugars produce a bloated feeling as well as diarrhea in the intestine?
  11. Why do people with irritable bowel syndrome differ in terms of what sugars produce their condition?
  12. Explain the difference between celiac disease and FODMAP intolerance.
  13. What does the “F” in FODMAPs stand for?

**3D Printers: The Next Print Revolution**

1. Why did Mario consider his smartphone case essential during cross-country training?
2. Since Mario was unable to repair his smartphone case, why didn’t he just order a new clip?
3. How does some of the motion of a 3D printer resemble that of an elevator?
4. Explain the horizontal motion of a 3D printer.
5. What is the difference in printing done by a 2D printer and a 3D printer?
6. What directs a 3D printer to produce the layers required to form a 3D image?
7. How does material come to be extruded from the printer heads of a 3D printer? Explain how this works.
8. Describe the physical characteristics of common plastics used by 3D printers.
9. Explain how the plastic materials that feed the 3D printer heads help conserve petroleum resources.
10. What are monomers?
11. What is the meaning of the subscript “n” in the chemical formula, (C8H8·C4H6·C3H3N)n, for the ABS polymer?
12. What role do 3D printers play in the engineering design process?

**Air Travel: Separating Fact from Fiction**

1. How common is the fear of flying?
2. Compare the safety of flying in an airplane to traveling in a car.
3. Describe what creates air pressure?
4. How is air pressure affected by altitude?
5. Commercial jets typically cruise at altitudes from 30,000 to 40,000 feet. What are the advantages of flying so high?
6. At sea level the pressure is 14.7 pounds per square inch (psi). Why is the airplane cabin not pressurized to 14.7 (psi) when in flight?
7. Airplanes cabins are pressurized to 10.9 psi. Why is this pressure used?
8. As the airplane ascends why do your ears pop?
9. List three ways to open the Eustachian tube to relieve the pressure.
10. Why would a person have to exert super human strength to open the airplane door when in flight?
11. What is “suction”?
    1. If a hole opens in an airplane, the outrushing of air only lasts for a few seconds. Explain why.
    2. How does the reduced pressure in the airplane affect carbonated beverages?

# Answers to Student Questions (from the articles)

**ChemDemos Demystified**

The burning candle

* 1. **List three observations made in the burning candle demonstration when the beaker is placed over the burning candle.** *Observations made when the beaker is placed over the burning candle:*

1. *The flame grows smaller,*
2. *The flame goes out,*
3. *A smoke trail appears, and*
4. *The water level inside the beaker rises.*
   1. **What is the formula for paraffin wax?** *The formula for paraffin wax is C25H52.*
   2. **Describe the change in moles of gaseous reactants and products as the burning of paraffin proceeds.** *The reaction begins with one mole of wax (solid) and 38 moles of oxygen gas. As the reaction proceeds, the wax and oxygen are consumed and 25 moles of carbon dioxide and 26 moles of water vapor are produced. Some of the carbon dioxide is dissolved in the water, and (almost) all of the water vapor condenses into liquid water.*
   3. **Explain in your own words why the water level inside the beaker rises.** *Answers to “why the water level inside the beaker rises” may vary, but these ideas should be part of a good explanation:*
      1. Although more gas is produced than is consumed, some oxygen is consumed, some of the CO2 produced dissolves and most of the water vapor produced condenses, leaving less gas in the beaker after the reaction than before the reaction, and
      2. The temperature of the gases inside the beaker decreases after the candle goes out, and with lower temperature comes lower pressure, so the gas pressure inside the beaker is less than air pressure outside the beaker. This causes the outside atmosphere to push the water up into the beaker, decreasing the volume of gas inside the beaker until the air pressure outside and the gas pressure inside the beaker are equal.
   4. **What role does air pressure play in your explanation?** A greater a*ir pressure outside the beaker than the gas pressure inside the beaker is the cause of the water level rise.*

The deflected stream of water

* 1. **Describe what happens when a charged rod or balloon is brought close to a stream of water.** “*As the balloon or glass rod moves close, the stream of water deflects toward it at a dramatic angle.”*
  2. **In the water molecule, why is oxygen negative and hydrogen positive?** *In the water molecule, oxygen is negative and hydrogen is positive because oxygen atoms, being more electronegative, pull electrons away from the less electronegative hydrogen atoms in each oxygen-hydrogen bond.*

Faulty demonstration of the greenhouse effect

* 1. **What happens in this greenhouse effect demonstration after the heat lamp is turned on, but before the carbon dioxide is added?** *In this greenhouse demonstration, after the heat lamp is turned on, the rocks inside the beaker get warmer.*
  2. **What happens after the carbon dioxide is added?** *After carbon dioxide is added, the temperature in that beaker increases by 1–2 oF within 5–15 seconds.*
  3. **Why is this NOT a good demonstration of the greenhouse effect?** *This is a faulty demonstration of the greenhouse effect because the greenhouse effect is based on the fact that carbon dioxide absorbs infrared radiation and re-emits it into the atmosphere. In this demonstration, the carbon dioxide merely sits on the bottom of the beaker, trapping the heat (infrared radiation) of the rocks inside the beaker, not allowing it to escape into the air around it. In the other beaker, the air inside circulates with outside air, allowing heat to flow out of that beaker.*

**Liquid to Foam: How Egg Whites Change Texture**

1. **Name three food items that the article says require a beaten egg white foam.**

*There are many food items that require egg white foam in reality, but the article identifies chocolate soufflé, meringue cookies and angel food cake.*

1. **What is the chemical composition of egg whites?**

*Egg whites are 10% protein and 90% water.*

1. **Proteins are made up of amino acids. How many amino acids exist naturally?**

*There are 20 naturally-occurring amino acids.*

1. **What part of amino acid structure makes each amino acid unique?**

*Each amino acid has a chemical side chain attached to the backbone of the molecule and every side chain is different.*

1. **What does the term “hydrophilic” refer to?**

*Hydrophilic refers to substances that are attracted to water. The opposite is hydrophobic.*

1. **When proteins fold, where are the hydrophobic amino acids located?**

*Hydrophobic amino acids are generally located in the interior of the protein creating a hydrophobic core, with the hydrophilic amino acids on the outside.*

1. **When egg whites are beaten, what happens to the proteins?**

*When egg white proteins are whipped they partially unravel and their hydrophobic regions are exposed to air. As a result, the tiny air bubbles formed by the eggbeater are soon coated with unraveled proteins.*

1. **What is the primary purpose of beating egg whites in a recipe like the angel food cake described in the article?**

*The primary purpose in beating the egg white is to create air bubbles in the cake. The air bubbles form when egg whites are whipped. Proteins help stabilize these bubbles in a foam structure. The protein in the egg whites simply holds the air bubbles in place.*

1. **Name the scientists who first showed by experimentation that trace amounts of copper stabilized egg white foam.**

*The article names three people that showed by experiment that trace amounts of copper stabilize egg white foam—Harold McGee, a science writer, Sharon Long and Winslow Briggs, both Stanford biologists.*

1. **Which protein in egg white forms a stabilizing complex with copper?**

*The article identifies conalbumin as the egg white protein that bonds with copper to form a complex that stabilizes the foam.*

1. **What is the name of the most common covalent bond that forms between amino acids containing sulfur-hydrogen side groups?**

*The most common covalent bond between amino acids with H-S groups is the* disulfide *bond.*

**Fermentable Foods: Trouble in Your Diet**

1. **What is meant by the term “macronutrients”?**

*Macronutrients refer to organic compounds that you need in large quantities to store energy.*

1. **How are gluten and celiac disease related?**

*Gluten, which is a group of proteins found in many grains, can cause celiac disease in some people.*

1. **What is the connection between irritable bowel syndrome and FODMAP?**

*Irritable bowel syndrome can be caused by foods that contain a range of carbohydrates (sugars) that are represented by the letters in the FODMAP acronym. Sugars included are* ***F****ermentable* ***O****ligosaccharides,* ***D****isaccharides,* ***M****onosaccharides,* ***a****nd* ***P****olyols*

1. **What is the difference between irritable bowel syndrome and celiac disease?**

*Irritable bowel syndrome is due to a person’s intolerance for certain FODMAPs that are consumed. Celiac disease is classified as an immunological disease, which means that a person’s immune system reacts to a foreign substance such as gluten. It is the same type of reaction associated with allergies.*

1. **Oligosaccharides are classified as a type of carbohydrate. What are their chemical characteristics?**

*They are organic compounds which contain carbon as well as hydrogen and oxygen in a 2:1 ratio, as in water. They are made up of simple sugars (monosaccharides) which are joined together to form chains. Oligosaccharides are small molecules containing between 3 and 10 monosaccharides.*

1. **What happens to oligosaccharides made from glucose subunits when they reach the small intestine?**

*In the small intestine, an enzyme called pancreatic amylase chemically breaks apart the bonds connecting any glucose subunits in the oligosaccharides, resulting in individual glucose molecules.*

1. **What happens when oligosaccharides made from the sugars galactose or fructose reach the small intestine compared with those oligosaccharides made from glucose subunits?**

*Compared with glucose-based oligosaccharides, those made with galactose or fructose cannot be broken apart into smaller units by amylase. Rather there are other enzymes that can break up these types of oligosaccharides. However, people differ in terms of how much of these oligosaccharides they can handle—from large, to modest, to almost nothing at all. Any unreacted or undigested oligosaccharides move into the large intestine where they can cause bloating and diarrhea.*

1. **What sugar is produced when amylase breaks down the disaccharide maltose?**

*The maltose is broken down into two glucose units.*

1. **What are the sugar components of the disaccharide lactose, compared with those found in maltose?**

*The two sugar units of lactose are glucose and galactose, whereas maltose is made up of two glucose units.*

1. **How do undigested sugars produce a bloated feeling as well as diarrhea in the intestine?**

*These undigested sugars contribute to a fermentation process through bacterial action. Various gases are produced which makes for a bloated feeling (an expanding “balloon”!).   
In addition, the sugars draw in water from the cells that line the intestinal wall, making the contents of the intestine (the stool) watery. And you have diarrhea!*

1. **Why do people with irritable bowel syndrome differ in terms of what sugars produce their condition?**

*One reason people differ in terms of the sugars that produce their condition is because people differ in terms of how much of a food containing one or more of the FODMAP sugars can be tolerated. The other reason is that people differ in how much of a needed enzyme (e.g., amylase, lactase) they can produce.*

1. **Explain the difference between celiac disease and FODMAP intolerance.**

*Celiac disease is an immunological disease which means that a person’s immune system mistakenly identifies gluten in food as dangerous. This immune response damages the lining of the small intestine, producing severe digestive complications. FODMAP intolerance is not an autoimmune disease but rather a digestive disorder that produces an irritable bowel from the ingestion of certain sugars which are not fully digested which results in these sugars fermenting in the large intestine and producing abdominal pain, bloating and diarrhea.*

1. **What does the F in FODMAPs stand for?**

*The F in FODMAPs stands for the process of fermentation, which is the culprit responsible for producing the irritability associated with bloating and diarrhea in irritable bowel syndrome.*

**3D Printers: The Next Print Revolution**

1. **Why did Mario consider his smartphone case essential during cross-country training?**

*Mario needs his smartphone case clipped to the strap on his arm so that he can listen to his favorite music while training for long cross-country races.*

1. **Since Mario was unable to repair his smartphone case, why didn’t he just order a new clip?**

*Mario didn’t want to wait weeks for a new smartphone case clip to arrive from the manufacturer because, without the new clip, he couldn’t listen to music during his cross-country training runs.*

1. **How does some of the motion of a 3D printer resemble that of an elevator?**

*A flat plate inside the 3D p­­­rinter moves up and down vertically resembling a small elevator platform.*

1. **Explain the horizontal motion of a 3D printer.**

*Above the plate, the 3D printer heads move horizontally back-and-forth along a rod while the rod slides back-and-forth in the opposite direction.*

1. **What is the difference in printing done by a 2D printer and a 3D printer?**

*A 2D printer produces single one-dimensional lines and places one right after the other to make two dimensions; a 3D printer produces two-dimensional layers and stacks them into a three dimensional object.*

1. **What directs a 3D printer to produce the layers required to form a 3D image?**

*A 3D printer contains a computer file that describes a 3D object by virtually slicing it into thin layers; relays the slices to the printer; and directs the printer to recreate the object by printing and stacking the layers.*

1. **How does material come to be extruded from the printer heads of a 3D printer? Explain how this works.**

*Strips of plastic are fed into each printer head where they are heated to melting temperature, and then squeezed onto the printing surface. As the plastic from the printer head cools it joins other pieces of plastic and solidifies to form a layer of the object.*

1. **Describe the physical characteristics of common plastics used by 3D printers.**

*Plastics commonly used in 3D printers are thermoplastics, meaning they are solids but, upon heating, soften to become moldable and then harden again upon cooling. These printer materials must also be fairly impact-resistant. Two of these plastics are acrylonitrile butadiene styrene (ABS), a hard rigid plastic that comes in many colors, and polylactic acid (PLA), objects made from this can be made in solid colors, as well as translucent and glow-in-the-dark forms. ABS and PLA are excellent materials for 3D printing because they are thermoplastics that can be heated and molded over and over again, and they are resistant to impact.*

1. **Explain how the plastic materials that feed the 3D printer heads help conserve petroleum resources.**

*PLA is not a petroleum product; it is not made from crude oil. PLA, made from plant products such as corn starch, is considered a renewable resource because plants can be grown again, so we don’t need to extract petroleum from the ground to produce PLA.*

1. **What are monomers?**

*Monomers are the repeating units of large chain molecules called polymers.*

1. **What is the meaning of the subscript “n” in the chemical formula, (C8H8·C4H6·C3H3N)n, for the ABS polymer?**

*The ABS polymer is formed by “n” number of repetitions of the three monomers (styrene, 1,3-butadiene, and acrylonitrile) shown in figure 1.*

1. **What role do 3D printers play in the engineering design process?**

*3D printers are used by engineers to quickly build and test their prototype designs to be certain that they function well before building a permanent structure.*

**Air Travel: Separating Fact from Fiction**

1. **How common is the fear of flying?**

*One out of every four people have a fear of flying.*

1. **Compare the safety of flying in an airplane to traveling in a car.**

*Flying in an airplane is 2,200 times safer than riding in a car.*

1. **Describe what creates air pressure.**

*Air pressure is caused by the molecules of air colliding with objects in all directions and exerting a force on its surfaces.*

1. **How is air pressure affected by altitude?**

*As the altitude increases there are fewer air molecules so there are fewer collisions and less force, so as altitude increases the air pressure decreases.*

1. **Commercial jets typically cruise at altitudes from 30,000 to 40,000 feet. What are the advantages of flying so high?**

*At these high altitudes the airplanes are above the clouds and inclement weather. There is less turbulence as a result. Since there are fewer air molecules there is less air resistance so airplanes can fly further and faster at this altitude.*

1. **At sea level the pressure is 14.7 pounds per square inch (psi). Why is the airplane cabin not pressurized to 14.7 psi when in flight?**

*Airplane cabins are not pressurized to 14.7 psi because the external pressure at high altitudes could be as low as 4.4 psi and, if the cabin was pressurized to 14.7 psi, the fuselage would need to be much stronger to withstand this much internal pressure.*

1. **Airplanes cabins are pressurized to 10.9 psi. Why is this pressure used?**

*A pressure of 10.9 psi is used because this is the air pressure at 8000 feet, and most people do fine breathing air at this pressure and do not notice the decreased oxygen level.*

1. **As the airplane ascends why do your ears pop?**

*Ears pop because as the airplane rises and the pressure decreases the Eustachian tube opens to let a little air out to lower the pressure in the middle ear so that it is equal to the external pressure.*

1. **List three ways to open the Eustachian tube to relieve the pressure.**

*Three ways to relieve the pressure in the middle ear are chew gum, swallow and yawn.*

1. **Why would a person have to exert super human strength to open the airplane door when in flight?**

*The airplane doors open inward. Due to the difference between the external pressure (4.4 psi) and the cabin pressure (10.9 psi) there is a force of 16,848 pounds holding the door closed. A person would have to exert a force greater than that in order to open the door.*

1. **What is “suction”?**

*“Suction” is the result of air moving from high pressure to low pressure.*

1. **If a hole opens in an airplane, the outrushing of air only lasts for a few seconds. Explain why.**

*The outrushing of air only last a few seconds until the cabin pressure is equal to the outside pressure.*

1. **How does the reduced pressure in the airplane affect carbonated beverages?**

*With reduced pressure it is easier for the bubbles of carbon dioxide gas dissolved in the beverage to escape and with less pressure pushing down on the fluid the bubbles can grow bigger and release more carbon dioxide. This makes the beverage go flat faster.*

# *ChemMatters* Puzzle: Redox Jumble

*Redox* stands for *red*uction-*ox*idation, an important topic in any chemistry course. It takes many pages in a textbook to deal with its many aspects. In section A of this puzzle, we give you 20 terms, in case you have not covered them in class yet.

In section C, we have picked out five of those terms. Deciding which five is one of your tasks, but we will help you in section B by providing five clues. Once you know a term, transfer its letters to the blanks in a, b, c, d, and e in section C.

The seven letters that are denoted by an up arrow can also be *unscrambled*to form a common redox term, as described by a clue on the bottom of this page. Cover it up if you do not wish to see it.

A. Here are 20 words, arranged alphabetically, commonly used in redox discussions. Add suffixes such as -*s,* or –*ing,* if needed. Note the varying number of letters in each.

amps anode cathode cell

charges electron faraday gain

loss negative oxidize oxidation

potential positive reduce reduction

terminal volt voltaic voltage

B. We have taken five terms (labeled “a,” “b,” “c,” “d,” and “e”) from section A and devised a clue for each, written in the next paragraph. These (plus their length) should allow you to fill in their blanks. For example, the term labeled “a” cannot match “anode” since that term has 5 letters, not 4. It also cannot be “gain” since that 4-letter word does not seem to apply to the clue for the term labeled “a.”

CLUES:

a. 1 Joule/coulomb

b. a redox lab apparatus

c. positive or negative, as examples

d. make Fe 2+ 🡪 Fe3+ as an example.

e. the fate of an oxidizing agent is to get \_\_\_ .

C. The blanks: a. \_\_ \_\_ \_\_ \_\_

**↑**   **↑**

b. \_\_ \_\_ \_\_ \_\_

**↑**

c. \_\_ \_\_ \_\_ \_\_ \_\_ \_\_ \_\_

**↑** **↑**

d. \_\_ \_\_ \_\_ \_\_ \_\_ \_\_ \_\_

**↑**

e . \_\_ \_\_ \_\_ \_\_ \_\_ \_\_ \_\_

**↑**

D.There are seven letters denoted with an arrow **(↑).** Unscramble them to yield a final redox term. A clue for this term is “site of reduction “

# Answers to the *ChemMatters* Puzzle

The five terms are as follows:

a is VOLT 1 Joule of energy per unit charge (in coulombs) = 1 volt

b is CELL contains two electrodes (and a salt bridge, if electrolytic)

c is CHARGES positive and negative labels. For example electrons are negative,

and alpha particles positive in charge.

d is OXIDIZE oxidation number is getting *more* positive.

e is REDUCED in its drive to get more negative, the oxidizing agent gains

electrons from the other reactant. It is *itself* reduced.

The designated arrows yield the 7 letters O T C H A E D, an anagram of CATHODE .

The final clue is “site where reduction occurs.” The *cathode* of a cell is where reduction occurs, regardless of its charge or the type of cell in use.

# Correlations to the Next Generation Science Standards

|  |  |
| --- | --- |
| **Article** | **NGSS** |
| **ChemDemos Demystified** | |  | | --- | | **HS-PS1-5.**  Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. |   **Crosscutting Concepts:**   * Cause and effect: Mechanism and explanation * Scale, proportion, and quantity * Systems and system models   **Science and Engineering Practices:**   * Developing and using models * Constructing explanations (for science) and designing solutions (for engineering)   **Nature of Science:**   * Science models, laws, mechanisms, and theories explain natural phenomena * Scientific knowledge assumes an order and consistency in natural systems. |
| **From Liquid to Foam: How Egg Whites Change Texture** | |  | | --- | | **HS-PS1-6**  Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.  **HS-PS1-3.**  Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.  **Crosscutting Concepts:**   * Cause and effect: Mechanism and explanation * Structure and Function * Stability and Change   **Science and Engineering Practices**:   * Asking questions (for science) and defining problems (for engineering) * Planning and carrying out investigations * Constructing evidence (for science) and designing solutions (for engineering)   **Nature of Science**:   * Scientific investigations use a variety of methods. * Science models, laws, mechanisms and theories explain natural phenomena. | |
| **Fermentable Foods: Trouble in Your Diet** | |  | | --- | | **HS-LS1-6.** Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules**.**  **HS-ETS1-3.**  Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. |   **Crosscutting Concepts:**   * Cause and Effect: Mechanism and explanation * Systems and system models   **Science and Engineering Practices:**   * Planning and carrying out investigations * Obtaining, evaluating, and communicating information   **Nature of Science:**   * Scientific knowledge is based on empirical evidence. * Science models, laws, mechanisms and theories explain natural phenomena. * Science addresses questions about the natural world. |
| **3D Printers: The Next Print Revolution** | |  | | --- | | **HS-ETS1-4.** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.  **HS-PS2-6.** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.  **Crosscutting Concepts:**   * Patterns * Structure and Function   **Science and Engineering Practices:**   * Developing and using models * Constructing evidence (for science) and designing solutions (for engineering)   **Nature of Science**:   * Science addresses questions about the natural and material world. | |
| **Air Travel: Separating Fact from Fiction** | |  | | --- | | **HS-PS2.3.** Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.  **HS-PS2-6.** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. | | **Crosscutting Concepts:**   * Cause and effect: mechanism and explanation * Scale, proportion, and quantity * Systems and System Models * Structure & Function   **Science and Engineering Practices**:   * Asking questions (for science) and defining problems (for engineering) * Developing and using models * Analyzing and interpreting data * Using mathematics and computational thinking * Obtaining, evaluating, and communicating information   **Nature of Science**:   * Science models, laws, mechanisms, and theories explain natural phenomena. * Scientific knowledge assumes an order and consistency in natural systems. | |

# Common Core State Standards Connections for all the Articles

**RST.9-10.1** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

**RST.9-10.2:** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

**RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

**RST.11-12.2:** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

***In addition***, the teacher could assign writing to include the following **Common Core State Standards**:

**WHST.9-10.2** Develop the topic with well-chosen, relevant, and sufficient facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience’s knowledge of the topic.

**WHST.9-10.2F**: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).

**WHST.11-12.1E:** Provide a concluding statement or section that follows from or supports the argument presented.

**WHST.11-12.2**  Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience’s knowledge of the topic.

# Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

**Directions for all Anticipation Guides: *Before reading***, in the first column, write “A” or “D” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

## ChemDemos Demystified

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Sometimes the explanation for demonstrations found in textbooks is incorrect. |
|  |  | 1. The air you breathe contains about 40% oxygen. |
|  |  | 1. Paraffin wax used in most candles is a carbohydrate. |
|  |  | 1. A burning candle produces more moles of gaseous products than the gaseous reactants that are consumed. |
|  |  | 1. A glass rod can become electrically charged when rubbed with silk cloth. |
|  |  | 1. Opposite charges repel. |
|  |  | 1. Tap water is electrically neutral, with an equal number of positive and negative charges. |
|  |  | 1. Water vapor and carbon dioxide contribute to the greenhouse effect. |
|  |  | 1. Carbon dioxide absorbs infrared radiation. |
|  |  | 1. Carbon dioxide is less dense than air. |

## From Liquid to Foam: How Egg Whites Change Texture

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The soft, light texture of meringue cookies, chocolate soufflé, and angel food cake is due to fat. |
|  |  | 1. Egg whites are mostly protein. |
|  |  | 1. Whipping egg whites causes proteins to unfold and stretch out. |
|  |  | 1. All amino acids are hydrophilic, meaning they are attracted to water molecules. |
|  |  | 1. Adding flour or sugar helps stabilize egg white foam. |
|  |  | 1. Copper bowls have been used to whip egg whites for at least 250 years. |
|  |  | 1. Copper is highly toxic. |
|  |  | 1. Whipped egg whites form just as quickly in glass bowls as copper bowls. |
|  |  | 1. Julia Child, the famous chef, used copper bowls and copper pans. |
|  |  | 1. During baking, air bubbles in angel food cake batter grow to three or four times their room-temperature size. |

## Fermentable Foods: Trouble in Your Diet

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Carbohydrates store energy. |
|  |  | 1. Gluten intolerance and FODMAPs sensitivity are related. |
|  |  | 1. Carbohydrates include sugars, starch, and cellulose. |
|  |  | 1. The main function of the small intestine is to absorb nutrients and minerals from food. |
|  |  | 1. The enzyme amylase works to break down all small sugars. |
|  |  | 1. Some common monosaccharides are glucose, galactose, and fructose. |
|  |  | 1. Only about 10% of adults are lactose-intolerant. |
|  |  | 1. Polyols are added to foods because they taste sweet. |
|  |  | 1. Fermentation in our small intestines produces hydrogen, carbon dioxide, and methane. |
|  |  | 1. Rice contains the compounds that people with FODMAP intolerance should avoid. |

## 3D Printers: The Next Print Revolution

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Typical home workshop 3D printers are the size of a large refrigerator. |
|  |  | 1. A 3D printer prints one-dimensional lines one at a time. |
|  |  | 1. Typical 3D printers use plastics. |
|  |  | 1. All plastics come from compounds obtained from petroleum. |
|  |  | 1. Polymers are large chain-like molecules composed of many repeating subunits of monomers. |
|  |  | 1. All of the monomers in a given polymer must be the same compound. |
|  |  | 1. Polylactic acid (PLA) is a polymer containing only carbon, hydrogen, and oxygen. |
|  |  | 1. 3D printers require thermoplastic because it is soft and malleable when heated. |
|  |  | 1. Most plastics we use every day are thermoplastics. |
|  |  | 1. 3D printers are often used by engineers to produce prototypes. |

## Air Travel: Separating Fact from Fiction

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. You are more likely to die in a car crash on the way to the airport than during an airplane flight. |
|  |  | 1. Fewer than 50% of those involved in plane crashes survive. |
|  |  | 1. The air pressure inside a flying airplane is the same as the air pressure on the ground below the plane. |
|  |  | 1. Air pressure at the top of Mount Everest is about half as much as air pressure at sea level. |
|  |  | 1. Your Eustachian tube is normally closed. |
|  |  | 1. Your ears pop when your Eustachian tube opens. |
|  |  | 1. It is physically impossible for the world’s strongest human being to open an airplane door during flight. |
|  |  | 1. Airplane windows are made of glass that is one inch thick. |
|  |  | 1. Skydivers jump from pressurized airplane cabins. |
|  |  | 1. Soft drinks go flat faster on an airplane. |

Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading and writing strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

***Teaching Strategies:***

1. Links to **Common Core Standards for Reading**:\
   * ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
   * ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
2. Links to **Common Core Standards for Writing**:
   * ELA-Literacy.WHST.9-10.2F: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
   * ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.
3. **Vocabulary** and **concepts** that are reinforced in this issue:
   * Skepticism
   * Amino acid
   * Protein
   * Enzyme
   * Organic molecular structures
   * Polymer
4. To help students engage with the text, ask students which article engaged them most and why, or what **questions** they still have about the articles. The Background Information in the *ChemMatters* Teacher’s Guide has suggestions for further research.

## ChemDemos Demystified

**Directions**: As you read, complete the graphic organizer below to explain the phenomena described in the article.

|  |  |  |  |
| --- | --- | --- | --- |
| **Phenomenon** | **Observations** | **Incorrect explanation** | **Correct explanation, with evidence** |
| **Burning candle** |  |  |  |
| **Deflected stream of water** |  |  |  |
| **Greenhouse effect demonstration** |  |  |  |

## From Liquid to Foam: How Egg Whites Change Texture

**Directions**: As you read the article, complete the graphic organizer below to describe each chemical involved in creating a stable egg white foam.

|  |  |  |
| --- | --- | --- |
| **Chemical** | **What is it?** | **How it helps create stable egg white foam, and precautions (if any) to take when using.** |
| Protein |  |  |
| Amino acid |  |  |
| Cream of tartar *or* lemon juice |  |  |
| Copper bowl |  |  |
| Iron (III) chloride |  |  |
| Conalbumin |  |  |
| Disulfide bond |  |  |

**On the back of this paper, use your knowledge of chemistry to write three steps you would take to create stable egg white foam for an angel food cake or meringue.**

## Fermentable Foods: Trouble in Your Diet

**Directions:** As you read the article, complete the graphic organizer below to explain how each of the substances represented in the acronym FODMAP contributes to digestive problems for people with FODMAP sensitivity.

|  |  |  |  |
| --- | --- | --- | --- |
| **Substance** | **Foods containing the problematic substance** | **Examples of the chemical** | **Chemical explanation of the problem** |
| **Oligosaccharides** |  |  |  |
| **Disaccharides** |  |  |  |
| **Monosaccharides** |  |  |  |
| **Polyols** |  |  |  |
| **How fermentation contributes to the problem** |  |  |  |

***Connect: On the back of this paper, write a statement about whether you think you have some FODMAP sensitivity, providing evidence for your ideas.***

3D Printers: The Next Print Revolution

**Directions:** As you read the article, complete the graphic organizer below to describe your understanding of 3D printers.

|  |  |  |
| --- | --- | --- |
| **3** | New things you learned about 3D printers | 1.  2.  3. |
| **2** | Describe 2 types of plastic polymers used in 3D printing |  |
| **1** | Name one use for 3D printers not mentioned in the article |  |
| **Contact!** | What would you use a 3D printer for if you had one? |  |

## Air Travel: Separating Fact from Fiction

**Directions**: As you read the article, complete the graphic organizer below using your own words to explain the answer to each question in the article, and provide an interesting fact you learned as you read the explanation for each question.

|  |  |  |
| --- | --- | --- |
| **Question** | **Explanation** | **Interesting Fact** |
| Are you really more likely to die in a car crash on the way to the airport than during an airplane flight? |  |  |
| Is the air pressure inside a flying airplane the same as the air pressure on the ground? |  |  |
| Why do ears pop during takeoffs and landings? |  |  |
| If someone decides to open the airplane door or break a window during a flight, wouldn’t everyone be quickly sucked out of the airplane? |  |  |
| Do carbonated beverages go flat faster on an airplane? |  |  |

# ChemDemos Demystified

## Background Information (teacher information)

**More on why teachers do demonstrations**

Here are a few quotes about the use of demonstrations by famous chemistry educators:

*“To approach demonstrations simply as chances to show off dramatic chemical changes or only to impress students with the ‘magic’ of chemistry is to fail to appreciate the opportunity they provide to teach scientific concepts and descriptive properties of chemical systems… In planning a lecture demonstration, I always begin by analyzing the reasons for presenting it.”*

~ Bassam Shakhashiri (1984)

(excerpted from “Using lecture demonstrations to promote the refinement of concepts: the case of teaching solvent miscibility”, <http://www.rsc.org/images/Ashkenazi%20paper1%20final_tcm18-85041.pdf>).

*“I still recall the very first time I ever saw a chemical demonstration on the overhead projector. It was more than 25 years ago, and the demonstrator was Clark Bricker from the University of Kansas. He added a few drops of ammonia to a solution containing ferric ions. The beauty, simplicity, and clear visibility of that demonstration impressed me so much that I have been doing demonstrations … ever since.”*

~ Doris Kolb

(excerpted from “The purpose of chemical demonstrations”, <http://www.nvon.nl/sites/nvon.dev.com/files/lesmateriaal/showdechemie1/A1_6_Childs_waarom%20demoproeven.pdf>)

*“The joy of chemical experimentation has been well recognized, at least from the early days of alchemy, and our appreciation of chemical charm probably dates back to the prehistoric discovery of ways to make and control fire.*

*Therefore, it seems useful to coin the term* ***exocharmic*** *reaction (from the Greek exo-, turning out) and, particularly in our role as chemistry teachers, to seek and share techniques for liberating as much charm as possible from the chemical changes our students see in the laboratory and classroom demonstrations.”*   
 ~ Richard Ramette

(excerpted from the introduction to Volume 1 of Bassam Shakhashiri's *Chemical Demonstrations: A Handbook for Teachers of Chemistry*)

**More on the history of the candle demonstration**

Michael Faraday is credited with doing the first large-scale demonstration(s) involving the burning of a candle. In 1848 he presented a series of six lecture-demonstration sessions, *The Chemical History of a Candle*, at the Royal Institution in London, U.K. This series, part of a long-running (1825–present) series of lectures at the Royal Institution is called the Christmas Lectures. Faraday presented his lecture-demonstrations to school-aged children, to popularize science, and chemistry in particular. He then (1861) had the six lectures assembled into a book by the same title. The book is still available today, both in print and online. (<https://archive.org/details/chemicalhistoryo00faraiala>)

The content of the Six Lectures included:

**Lecture 1:** A Candle: The Flame - Its Sources - Structure - Mobility - Brightness

**Lecture 2:** Brightness of the Flame - Air necessary for Combustion - Production of Water

**Lecture 3:** Products: Water from the Combustion - Nature of Water - A Compound - Hydrogen

**Lecture 4:** Hydrogen in the Candle - Burns into Water - The Other Part of Water - Oxygen

**Lecture 5:** Oxygen present in the Air - Nature of the Atmosphere - Its Properties - Other Products from the Candle - Carbonic Acid - Its Properties

**Lecture 6:** Carbon or Charcoal - Coal Gas Respiration and its Analogy to the Burning of a Candle - Conclusion

(<http://en.wikipedia.org/wiki/The_Chemical_History_of_a_Candle>)

A recent *ChemMatters* article provided a thorough description of the history and chemistry of candles (Rohrig, B. The Captivating Chemistry of Candles. *ChemMatters* **2007**, *25* (4), pp 4–7). Information from that article on the basic chemistry of candles includes:

[For all candles] the components are the same—a source of fuel and a wick. Today, nearly all candles are made from paraffin [which serves as a fuel]. Paraffin is a by-product of the distillation of petroleum, or crude oil. Paraffin is actually a mixture of several different heavier hydrocarbons. The wick is generally composed of tightly wound cotton or nylon fibers that make up a sturdy type of twine. All wicks are treated with various flame-retardant solutions. [Otherwise], the wick would be destroyed by the flames. You can think of the wick as the pipeline through which the fuel travels to the surface, making it available for combustion. …what happens when a candle is lit? Touched by a flame, the wick quickly conducts heat to the surface of the wax where melting begins. Liquid wax travels through the wick by capillary action. After the liquid wax travels to the top of the wick…it vaporizes upon contact with the burning flame. Combustion occurs as hot wax vapor combines with oxygen, producing the candle flame.

**More on criticism of the article’s greenhouse demonstration**

**“The Greenhouse Effect and Global Warming are quite real. Let's be sure the demonstrations we recommend to fellow educators are authentic, and get the science right!” This is the disclaimer at the top of this Web page from Climate Change Education.org:** <http://climatechangeeducation.org/hands-on/difficulties/heating_greenhouse_gases/problem_examples/bill_nye/index.html>**. According to this organization, “**We are a team of teachers, docents, scientists, engineers, techs, artists, students and parents providing pro bono services for thousands of climate education programs worldwide. While primarily based at science museums and the University of California, we work with hundreds of schools, programs and science institutions around the world to strengthen the climate education community.”

**Their site provides copious amounts of information about many (all?) of the variations on the greenhouse effect demonstration, like the one in the Tinnesand article. The site has lots of photos and videos showing the demonstrations, and a lot of science to explain why each of these demonstrations does NOT work as it is supposed to, or does not demonstrate the science it says it does. It provides a wealth of information on the topic.**

Many versions and variations exist of the demonstration described in the article. This 4:34 video clip from “Climate Change 101” shows one variation, with Bill Nye demonstrating “the greenhouse effect” using jars, small Earth globes, thermometers and heat lamps (0:50–1:30). (<http://player.vimeo.com/video/28991442>) Unfortunately, this demonstration suffers from some deficiencies similar to those of the article’s greenhouse demonstration—a confined space, infrared radiation that does not enter the jar, etc.—and some that are new: too much Earth, not enough air/CO2, possibly fabricated data.

And this site provides myriad evidence in a single report explaining why this simple experiment a) can’t work and b) didn’t work for Nye and Al Gore, who worked together on the full-length video. The experimenter very carefully attempted to duplicate the Nye experiment, with the expectation of obtaining the same results—which he did not realize. While the report is not without its own flaws, it does show the problems of doing a demonstration that is supposed to show something totally different from what it actually shows.

(<http://wattsupwiththat.com/climate-fail-files/gore-and-bill-nye-fail-at-doing-a-simple-co2-experiment/>)

In the experiment at Tufts University cited as a reference by author Tinnesand in the *ChemMatters* article, heat lamps indirectly warmed temperature sensors (shaded from the lamp) in open plastic containers. After an ambient (albeit elevated) temperature was reached (about 27 oC), carbon dioxide was added to one of the containers. The temperature immediately began rising in that container until it reached a maximum, approximately.7 Co higher than that of the container with air. (See graph below.)

They believed that the cause was the density of carbon dioxide suppressing air circulation around the sensor, rather than its ability to absorb and re-radiate infrared energy into the surroundings. But to test their hypothesis the experimenters tried a new approach. They evacuated the carbon dioxide container, allowed it to cool down, and began again. This time, they added argon instead of carbon dioxide. The authors explain their logic, and their results.

To determine whether the temperature rise when CO2 is added is a result of CO2’s infrared absorption rather than from density effects, we replicated the experiment in the second container using argon gas rather than carbon dioxide. Argon’s mass (40 u) is close to that of CO2, and thus its effect on the convective heat transport should be similar, but because it is a monatomic gas, it has no infrared absorption bands. Therefore, the radiative greenhouse effect does not occur for argon, and it represents a good experimental control for separating radiative and convective effects.

The curve labeled “Ar” in Fig. 2 [below] shows the response when the second container was filled with argon. The temperature rose by approximately the same amount and at the same rate as for CO2. Because Ar does not absorb infrared radiation, the temperature rise when Ar is added must be due to suppression of the convective heat transfer rather than to radiative effects, just as in the case of real greenhouses. We conclude that the experiment is a demonstration of a “greenhouse effect,” but not of the radiative phenomena responsible for climate change.

CO2

Ar

CO2 added

Ar added

35

33

**Temperature (C)**

31

29

27

25

200 400 600 800 1000 1200 1400

**Time (s)**

*Fig. 2. (Color online) Temperature variation when the containers are filled with carbon dioxide and argon, as indicated, after steady state is reached in air. The heat lamps are on throughout the time shown. When either gas is added, at the times shown by the arrows, the temperature rises toward a new steady-state value before decreasing when the gas level drops below the level of the temperature sensor. The effects of the two gases are almost identical. Because argon does not absorb infrared radiation, the temperature increase must be due to other effects.*

*(*[*http://rtobin.phy.tufts.edu/Wagoner%20AJP%202010.pdf*](http://rtobin.phy.tufts.edu/Wagoner%20AJP%202010.pdf)*)*

The authors then present mathematical models to verify their claims. Their conclusion:

Our results demonstrate that the temperature rise observed in a popular classroom demonstration1 arises not from the radiative greenhouse effect responsible for global warming but primarily from the suppression of convective heat transport between CO2 and air due to the density difference between the two. This density difference, much like the roof of a real greenhouse, suppresses gas mixing at the CO2-air interface and therefore inhibits heat transfer. The magnitude of the radiative effect is more than an order of magnitude smaller and is difficult to demonstrate convincingly. The interpretation of other similar demonstrations2–5 differs in detail, but is subject to the same considerations.

Our results apply only to the interpretation of classroom scale demonstrations; they do not call into question the effects of anthropogenic greenhouse gases on the Earth’s climate or existing models of those phenomena.

And this final paragraph applies directly to the intent of the entire Tinnesand article:

Although not an accurate demonstration of the physics of climate change, the experiment we have considered and related ones are valuable examples of the dangers of unintentional bias in science, the value of at least a rough quantitative prediction of the expected effect, the importance of considering alternative explanations, and the need for carefully designed experimental controls. Specifically, the use of argon as a test gas is an important supplement to the comparison of air and carbon dioxide because it allows effects due to the higher density of CO2 to be separated from those related to its infrared absorption.

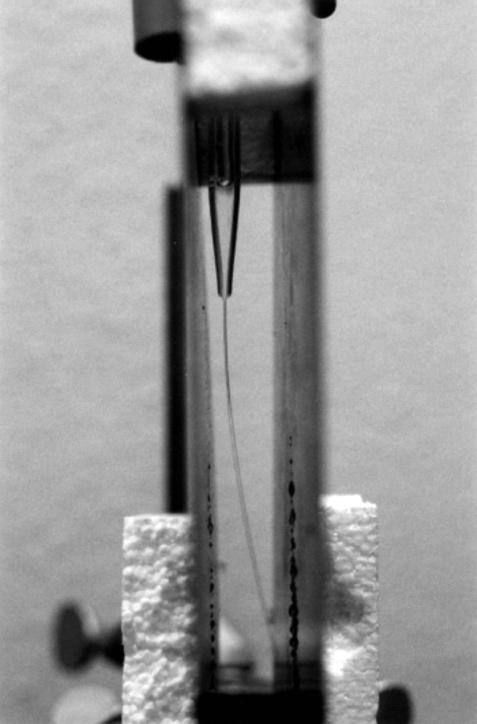
(Wagoner, P.; Chunhua, L.; Tobin, R. Climate change in a shoebox: Right result, wrong physics. *Am. J. Phys* **2010** *78*, (5), pp 536–540; <http://rtobin.phy.tufts.edu/Wagoner%20AJP%202010.pdf>)

Before leaving this study, it is interesting to note that the authors noticed the sudden decrease in temperature at the 1200 second mark for both carbon dioxide and argon and attempted to explain that apparent discrepancy (since the lamps were still lit). They tested another system by placing a small lit candle in the bottom of the container to test for carbon dioxide. As time progressed, the level of carbon dioxide decreased, presumably as some was circulating through to the top of the container and out. Mathematical calculations involving the diffusion rate of carbon dioxide led them to conclude that the 1200 second interval is the length of time needed for the carbon dioxide to escape, subsequently allowing air to circulate freely and thus reduce the temperature. The argon showed approximately the same amount of time needed for it to escape. Since both gases have approximately the same molecular mass, this is consistent with diffusion rate calculations.

**More on criticism of the article’s deflection of a polar liquid demonstration**

The article from the *Journal of Chemical Education* referenced in the Tinnesand article mentions that several groups have been successful in observing deflection of streams of nonpolar liquids in experiments similar to those done to show deflection in polar liquids.

The authors explain that

A casual interpretation of the figures [pictures showing deflection with polar liquids and none with nonpolar liquids] could give some students the impression that the mere presence of molecular dipoles gives rise to a net force on the liquid droplets in an electric field, but of course in a uniform electric field dipoles experience only a torque, and no net force.

It’s this idea of torque that most sources use as the explanation for the deflection. See this site, for instance: <https://www.youtube.com/watch?v=VhWQ-r1LYXY&feature=player_embedded>. It provides great visuals to explain how the water molecules rotate, but this alone would not cause the water stream to move toward the charged rod. Without the idea of the induced charge on the water molecules, allowing charge build-up within the stream, the explanation is woefully incomplete.

The authors continue:

Dipolar entities can only undergo deflection in a nonuniform electric field whose strength varies significantly on the length scale of the dipole. Intuition suggests that any nonuniformity in the electric field near a charged rod a few centimeters in diameter, or an electrified balloon, must be far too small to have any detectable effect on molecular dipoles.

*Figure 1. Electrical deflection of a distilled water droplet stream in a uniform electric field. The aluminum deflector plates were separated by 2-cm Styrofoam spacers (one is visible out of focus at the top of the image) and were insulated from the supporting clamp by other Styrofoam spacers visible at the bottom of the image. The plate on the left was grounded and a potential was induced on the righthand plate by a statically electrified balloon (outside the field of view to the right).*

In fact, the explanation for electrical deflection of a polar liquid droplet stream is that the polar liquid droplets carry an induced electrical charge. … The effect results from a charge separation in the water droplet as it forms, induced by the charge on the nearby deflection device. As the droplet separates, a fraction of the like charges repelled by the deflector statistically remain behind in the water reservoir so that the droplet acquires a net charge opposite to the charge on the deflector and is attracted to it.

(Williams, P.; Ziaei-Moyyaed, M.; Goodman, E. Electrical Deflection of Polar Liquid Streams: A Misunderstood Demonstration. *J. Chem. Ed.* **2000**, *77* (11), pp 1520–1523,

<http://pubs.acs.org/doi/pdfplus/10.1021/ed077p1520>, available online only to subscribers)

The authors further report that “Finally, we were able to deflect a droplet stream of a nonpolar liquid (tetrachloroethylene),” the experiments for which are explained in the rest of the article. They further report in the article:

The behavior of C2Cl4 was particularly interesting. With a vigorously electrified balloon it was just possible to detect a very weak deflection in a C2Cl4 stream even though this liquid is nonpolar. Brindle and Tomlinson reported that a strong deflection could be observed in a CCl4 stream under conditions of low humidity (*8*); Vemulapalli and Kukolich (*9*) and Shakhashiri (*10*) observed deflection of benzene and *n*-hexane, respectively (attributed in ref *9* to forces on induced dipoles and in ref *10* to dielectrophoresis, the lowering of potential energy when a dielectric material moves from a region of lower to higher electric field). Given that the electric field near our charged balloon (ca. 10 cm radius) was only slightly inhomogeneous and that no deflection was observable in a strongly inhomogeneous field even for water in our re-creation of the Vemulapalli and Kukolich experiment when the droplets formed in an electrically screened region, induced charging, even of insulating liquids, seems to be the only general explanation for all of these observations.

**More on other demonstrations that are not quite what they seem**

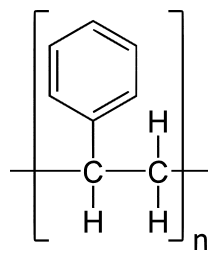
**“Dissolving” Styrofoam**™

In this demonstration, the teacher will place copious amounts of Styrofoam™ peanuts or other Styrofoam™ packaging into a beaker containing acetone. The Styrofoam™ appears to “disappear” into the acetone, with some bubbling, while closer inspection shows that some opaque viscous liquid material still exists in the acetone at the bottom of the beaker.

The usual explanation is that the acetone is “dissolving” the Styrofoam™. While this seems like a reasonable explanation, dissolving usually means the solute, the material being dissolved, truly disappears into the solvent, the material that is doing the dissolving. The fact that viscous liquid matter still remains in the mixture indicates that this is not a case of true dissolving.

Styrofoam™ is the Dow Chemical Company trade name for expanded polystyrene (EPS). (We’ll explain the expanded part shortly.) Polystyrene (PS) is a long-chain polymer composed of many styrene monomers. Styrene, (C8H8)n [at right:   
a) structural formula, b) space-filling model], is essentially a phenyl group (benzene ring) attached to an ethylene. Polystyrene is essentially a chain of ethylene reactive groups on which phenyl groups are alternately attached to the chain of carbon atoms in the ethylene groups. The polymer has the structural formula c) at right. The subscript “n” in the formula represents a large number of styrene monomers, perhaps a few thousand.

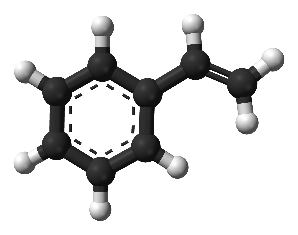
c) Polystyrene



Styrene

a) Structural b) Space-filling

formula model



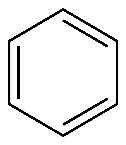
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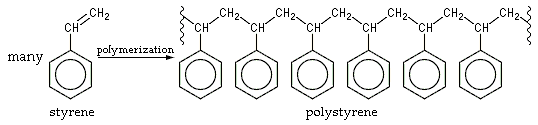
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*(Image sources: b)* [*http://en.wikipedia.org/wiki/File:Styrene-from-xtal-2001-3D-balls.png*](http://en.wikipedia.org/wiki/File:Styrene-from-xtal-2001-3D-balls.png)*, c)* [*http://upload.wikimedia.org/wikipedia/commons/6/60/Polystyrene.svg*](http://upload.wikimedia.org/wikipedia/commons/6/60/Polystyrene.svg)*)*

The diagram below shows the polymerization of styrene, where the double bond in the ethylene group is broken, and where the monomer reactive groups subsequently link together into the long chain polymer.



*(*[*http://upload.wikimedia.org/wikipedia/commons/1/10/Polystyrene\_formation.PNG*](http://upload.wikimedia.org/wikipedia/commons/1/10/Polystyrene_formation.PNG)*)*

When polystyrene is produced, many long polymer chains are formed and they become entangled with one another. These entanglements result in many attractions between the long chains, and this makes polystyrene a rigid plastic.

Expanded polystyrene (EPS) is made by adding a material called a blowing agent to already (slightly) pre-expanded polystyrene beads. The blowing agent is, or produces, a gas that expands the polystyrene further, trapping the gas inside pockets or cells within the polymer. This greatly increases the volume of the polymer, thereby vastly decreasing its density (DPS = 1.05 g/cm3, DEPS = 0.02–0.20 g/cm3).

When EPS is added to acetone, the acetone softens the polymer, working its way between the polystyrene chains, loosening the entanglements and allowing the chains more freedom of motion. As the chains loosen, the cells within the polymer structure that contain the gas soften and swell. This increases the space between the polymer strands, which allows the trapped gas within the cells to escape, so that only the original polystyrene is left; thus the *apparent* dissolution of the EPS foam as it shrivels down to almost nothing, and the macroscopic bubbling as the gas molecules escape. The PS remains as a softened mass in the acetone bath. If the bulk of the acetone is poured off and the remainder allowed to evaporate, the polystyrene lump becomes hard and brittle, as is the normal state of polystyrene.

There are many examples of this activity shown on YouTube and elsewhere on the internet. Unfortunately, almost all of these—if they offer an explanation at all—will say that the acetone “dissolves” the EPS. Here are a few examples. (More are cited in the “More Web Sites for Additional Information”, later in this Teacher’s Guide.)

In this short YouTube video clip (1:54) that nicely shows the dissolving of a large amount of expanded polystyrene in a small volume of acetone, the title is rather generic (but alright)—it just says “Acetone and Styrofoam”—but the movie clip itself has the wrong title embedded in the video—Magically *Dissolving* Styrofoam”: (<https://www.youtube.com/watch?v=h9Jx8NRkWTo&feature=player_embedded>, or this source of the same video clip (1:55), in case you can’t access YouTube at your school: <http://wn.com/styrofoam_and_acetone>)

This video clip (2:07), “Acetone Dissolving Styrofoam”, would be good to show if you want to use a video to demonstrate the phenomenon instead of actually doing the demonstration yourself in class. While it offers no talk at all, it shows a bit more controlled experiment (apparently in a lab), showing close-up video of the softening of the EPS cup and the resulting puddle of polystyrene: <https://www.youtube.com/watch?v=_7e1zljg8Oo&feature=player_embedded>.

This YouTube video news clip (3:53) with scientist Carl Nelson from “Imagination Station” provides a correct (albeit brief) interpretation of “Dissolving Styrofoam with Acetone” (Note that the title is still wrong). The video mentions that EPS is as much as “98% air”. At the end Nelson dissolves a Styrofoam head. (<https://www.youtube.com/watch?feature=player_detailpage&v=6S4zfMdjQxY>)

Finally, Flinn Scientific offers a basically correct explanation (and lab activity) in their *ChemFax* “Styrofoam Peanuts and Acetone”. Here’s what they say:

When the polystyrene peanuts are added to the acetone, the peanuts seem to dissolve. They do not really dissolve in the acetone, but go through a process called “swelling” that allows the trapped gases to escape. To put it another way, the polystyrene is “de-foamed.” If the bulk of the acetone is decanted off and the residual polystyrene/ acetone is allowed to dry, the result is a solid polystyrene disk.

(<http://www.flinnsci.com/media/620357/91075.pdf>)

**Using balloons to show that air has weight or mass**

To show that air has weight or mass, this demonstration has been used. The teacher will use a double pan balance or a balanced meter stick (hanging freely from a fulcrum at the center). Two deflated balloons of equal size are attached, one at each end. One is then detached, inflated, tied off, and reattached. The meter stick is then supposed to sag downward. This allows the teacher (and therefore, the students) to conclude that air has mass. Unfortunately, this is not quite the whole story. William Beatty explains further on his Web site, “Recurring Science Misconceptions in K-6 Textbooks”:

Unfortunately this experiment isn't very honest. When immersed in atmosphere, buoyancy causes full and empty balloons to weigh the same. One balloon shouldn't pull down the stick. But then why does the above experiment work? Usually it doesn't! In fact, the experiment will fail unless you know the trick: you must inflate the balloon near to bursting. The experiment secretly relies on the fact that the air within a high-pressure balloon is denser than air within a low pressure balloon. Of course the demonstrator never mentions this to the students, and the books which contain this demonstration don't mention density effects either. Obviously the density effects do not *directly* demonstration [sic] anything about the weight of air, so it's dishonest to tell students that this demonstration can directly weigh some air.

(<http://amasci.com/miscon/miscon4.html#balloon>)

So, using two partially-filled, appearing-to-be-inflated balloons in this demonstration won’t work the way they’re supposed to work to show that air has mass, even though the internet is replete with video clips showing the demonstration working just “as expected”. Often, though, these demonstrations are very crude and use very rough fulcrums (fulcra?) (e.g., a finger for balancing), or meter sticks that are very crudely balanced to start, so changes may not be that noticeable anyway.

The mass of air demonstration utilizes the idea of buoyancy of air to account for the way the two balloons SHOULD behave, if both balloons are just filled to maximum volume, without overfilling either one. Then, when one is popped, its (complete) remains and the other filled balloon should stay balanced, because the mass of the air inside the balloon is the same as the mass of the air it displaced before popping. And the reason it doesn’t work is because typically the two balloons are overfilled, meaning there is more air and hence, more mass in the still-filled balloon than “one balloon’s worth”—the mass of air in the atmosphere supporting it.

Another version of this demonstration is to have the two inflated balloons already attached to the meter stick so that they are balanced, one on each end. Then the teacher sticks a pin in one of the balloons to puncture it. It happens very quickly, and the punctured, now-deflated balloon typically drops and the inflated one on the other end of the stick rises. This about.com Web site provides a description of the experiment: (<http://weather.about.com/od/lessonplanselementary/ht/air_has_mass.htm>).

This video clip of four different student attempts of this experiment (using a lighter instead of the pin to puncture the balloon) shows the primary problem with this method: <https://www.youtube.com/watch?v=ENkW7yJ4rkw&feature=player_embedded>. In three of the four tests, you can see balloon pieces flying away from the balloon, and in the fourth, it is so shredded that you can’t tell if pieces are missing. So, if balloon parts that *were* there when the balloons were balanced are *not* there after the bursting, is it so surprising that the intact, inflated balloon is heavier? The whole is indeed heavier than some of its missing parts.

Flinn’s “Air Has Mass” video (15:00) shows several methods to use to demonstrate that air has mass. In the first 6 minutes the presenter shows one method: she produces some carbon dioxide with vinegar and baking soda in a 1-L plastic bottle. She masses the entire system and zeroes it out on the balance. Then she opens the cap a bit to release some of the gas (you hear the p-f-f-t). Then she masses the bottle again and it has lost mass. So, by deduction, the gas inside the bottle must have had mass that was removed when the cap was opened. It might be good for you to do the demonstration yourself for your classes, as the balance readings may be somewhat confusing to students. In the second half of the video the presenter uses buoyancy to show air has mass. This one may cloud the issue a bit because it is an indirect approach and is more difficult for students to visualize. Also note that this video is directed at a teacher audience. <https://www.youtube.com/watch?v=UKd2TwoJbzY&feature=player_embedded>

This video from “*Do* Try This at Home” shows the standard equal-arm meter stick with inflated balloons and one of them is punctured. The inflated balloon’s end of the meter stick sinks and the end with the deflated one rises, indicating to the experimenter (Mr. G) that “air has mass”. This is actually his second experiment. The first one is shown in an “oops” or blooper outtake at the end of the video, where he does the experiment and the two balloons stay balanced after one has been deflated. The experimenter concludes that he has to do the demonstration again (the “again” is the one he shows in detail in the first 80% of the video). Too bad, because he had it right the first time (the “oops”). (<https://www.youtube.com/watch?feature=player_embedded&v=Bv_tS6-qCJ4>)

**The hydrophobic effect—Water and oil don’t mix**

A mixture of vegetable oil and vinegar (as in salad dressing) is a commonly used example of the “hydrophobic effect”—“Oil and water don’t mix.” The oil floats on top of the vinegar/water mixture on the bottom. This supports the chemistry rule concerning solubility and miscibility that “likes dissolve likes”—polar substances dissolve other polar substances (vinegar and water), and non-polar substances dissolve other non-polar substances. Although this is generally true—and has lots of chemistry to back it up, an incomplete understanding of the rule may result in students believing that substances that are hydrophobic (i.e., “water-fearing”) (non-polar substances) repel or are repelled by water, or at least that they have very little attraction for water molecules.

But that is absolutely not true. Oil molecules do attract water, with much greater force of attraction than they have for other oil molecules, although this attraction may not be obvious. Dr. Kevin Lehman of the University of Virginia explains further:

We can observe the consequence of this greater attraction when we put a drop of oil on a clean surface of water. Before hitting the surface, the oil will be in the shape of a spherical droplet. This is because the oil molecules are attracted to one another and a spherical shape minimizes the number of oil molecules that are not surrounded by other molecules. When the oil hits the surface of the water, it spreads out to form a thin layer. This happens because the attractions between the oil and water molecules gained by spreading over the surface is larger than the oil-oil attraction lost in making a large oil surface on top of the water. If a sufficiently small drop of oil is put on the surface, it will spread to form a single molecular layer of oil. By measuring the area produced, one can get a simple estimate for the size of each oil molecule and thus Avogadro's number.

Given these strong interactions, why does not each oil molecule dive into the water solution and surround itself with the favorable water attractions? The reason is that to do so, it must come between water molecules that are already attracting each other! The strength of water-water attraction is much higher than water-oil interactions, and thus there is a net cost of energy in putting the oil molecules into a water solution. Thus the vast majority of oil molecules stay out of the water, though as many as will fit will hang on to the surface water molecules that do not have a full complement of partners.

(<http://www.faculty.virginia.edu/lehmannlab/badchemistry.html#hydrophobic>)

Essentially, the non-polar oil molecules have only van der Waal forces—

(dipole-dipole interactions) and London dispersion forces (instantaneous induced-dipole dipole interactions) of attraction—while water has these AND hydrogen bonding forces of attraction. The van der Waal forces are sufficiently strong to hold oil molecules together (after all, they *are* in the liquid state, indicating fairly strong interactions). But the hydrogen bonding holding water molecules together are far more attractive than the forces that oil molecules can bring to bear that would be required to separate water molecules from one another to allow oil molecules to intercalate between them. Thus, “oil and water don’t mix”.

Here is a table that summarizes relative strengths of the various forces of attraction between and within molecules.

**Relative strength of forces**

|  |  |  |
| --- | --- | --- |
| **Focus of force** | **Bond type** | **Dissociation energy (kcal/mol)** |
| Intramolecular | Ionic Lattice Energy | 250-4000 |
|  | Covalent Bond Energy | 30-260 |
| Intermolecular | Hydrogen Bonds | 1-12 (about 5 in water) |
|  | Dipole–Dipole | 0.5–2 |
| van der Waals | London Dispersion Forces | <1 to 15 (estimated from the enthalpies of vaporization of hydrocarbons) |

Note: this comparison is only approximate – the actual relative strengths will vary depending on the molecules involved. Ionic and covalent bonding will always be stronger than intermolecular forces in any given substance. [Ed. Note: I added the first column to clarify the areas of interaction.]

(<http://en.wikipedia.org/wiki/Intermolecular_force>)

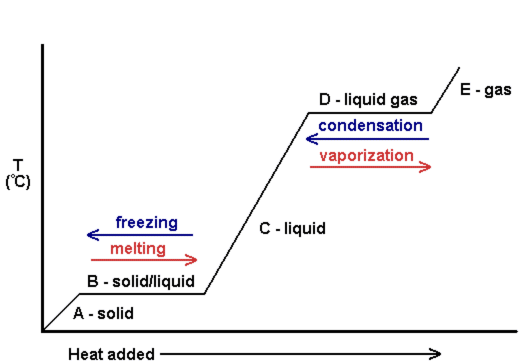
So just remember, when you discuss with students the chemistry rule that “likes dissolve likes”, their incomplete understanding of intermolecular attractive forces may lead them to believe on a simplistic level that this means “‘unlikes’ **repel** ‘unlikes’”—which is NOT true! This possible student misconception may require a bit more explanation in class when you discuss intermolecular attractions and secondary bonding. Here is a good basic Web site from Mark Ophardt’s *Virtual ChemBook* (Elmhurst College) that describes and explains the types of intermolecular forces: <http://www.elmhurst.edu/~chm/vchembook/160Aintermolec.html>.

**“You can see ‘steam’.” (NOT)**

Many a student (and even, many a teacher?) has made this statement.   
After all, if you boil water in a pot at home, or even in a beaker in the lab, you can *see* the steam billowing out of the top, right? Well, actually, no. What you see isn’t steam, but water vapor that has condensed from steam. As the hot steam (>100 oC) escapes the liquid, it immediately comes in contact with the cooler air molecules. The gaseous water molecules cool down instantly and condense into tiny droplets of liquid water. These droplets form the mist or cloud that you see as “steam”.

Heat water in a tea kettle at home or, in the lab, in a flask with a small opening, until the water is boiling vigorously. Look carefully right at the opening of the container and you will see—nothing! Actually, that’s steam you’re *not* seeing. Look at the billowing cloud and you will see—not steam, but condensed water droplets. In between the opening and the beginnings of the cloud is steam, billowing, but invisible, because it is still a gas for that brief moment before it collides with cooler air and condenses. See “In-Class Activities”, #1 for a class demonstration to show students what steam can do.

**“Steam can’t get hotter than 100oC.”**

 Many students believe this, and perhaps it’s partly our fault. We probably show them the typical phase-change diagram showing ice below 0 oC going to ice at 0 oC, to water at 0 oC, to water at 100 oC, to steam at 100 oC, and maybe even to steam above 100 oC. But we probably never do much with that last piece of information. Yet, super-heated steam is very useful, in heating large buildings in big cities and in many industrial uses—in manufacturing and in chemical processes. “In-Class Activities”, #1 below provides you with a demonstration to use to show your students the heating of steam to temperatures above 100 oC.

*(*[*http://www.kentchemistry.com/images/links/matter/HeatCool.gif*](http://www.kentchemistry.com/images/links/matter/HeatCool.gif)*)*

How many of us pursue “letter E” on the graph with our students?

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Demonstrations**—While this is not exactly a chemistry “concept”, it is an essential ingredient in many chemistry teachers’ arsenal of classroom activities. The three demonstrations in this article accentuate the negative aspects of using demonstrations in the chemistry classroom. The positive aspects may include greater student interest, greater student understanding, greater concept “staying power” in students’ minds, greater ability of students to make connections between the concept(s) central to the demonstration and other chemistry concepts, and greater familiarity with the physical and chemical properties involved in actual chemical systems, to name a few.
2. **Combustion**—the burning candle under the beaker demonstration can be used to show students one of the products of combustion, carbon dioxide; if you were to test the gas left in the beaker with limewater, it would turn cloudy, indicating the presence of CO2.
3. **Gas laws**—the rise of the water in the beaker is at least partially due to the decrease in gas temperature inside the beaker, an example of Charles’ Law (gas volume [of gas inside the beaker, shown by the rise of the water level] varies directly with temperature). Note that this would NOT be a good demonstration to use to illustrate Charles’ Law the first time it is introduced to students, as this demonstration is overly complicated by the chemical reaction that precedes the volume change; but it can be used to review Charles’ Law after you’re assured that students understand the relationship.
4. **Static electricity**—In the deflection of the stream of water demonstration, the balloon rubbed on hair or the glass rod rubbed with silk both are used to transfer charge from one object to another, causing the deflection of the stream. In a separate demonstration, they are used to display the electrical nature of matter and the relative ease with which electrons are transferred from one material to another, creating static electricity and charge potential differences.
5. **Polarity of molecules**—Although the deflected stream of water doesn’t rely on the polarity of the water molecules, the effect is much more obvious with polar molecules than with nonpolar molecules. This is because it is easier to induce a charge in molecules that already have charge separations within the molecular structure.
6. **Electronegativity**—The electronegativity differences between oxygen and hydrogen (and the asymmetric shape of the water molecule) result in water being a polar molecule.
7. The electromagnetic spectrum—In the greenhouse effect demonstration, carbon dioxide (and other gases) in the atmosphere absorb infrared radiation and re-emit it into the atmosphere and back to Earth, while most gases in the atmosphere are transparent to infrared radiation.
8. **Gas density**—The greater density of carbon dioxide in the one beaker prevents mixing of the gases which, in turn prevents the transfer of heat from inside the beaker to the air outside. Indeed, carbon dioxide is frequently used to show the density difference of various gases. An aquarium is partially filled with CO2 and large soap bubbles are floated inside the aquarium. They rest on the CO2 layer of gas (which, of course, is otherwise invisible).
9. **Light and the electromagnetic spectrum**—If you really dig into the greenhouse effect with students, they will discover that greenhouse gases absorb and re-radiate wavelengths of light based on their bonds’ natural frequencies of vibration.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“The water level rises inside the beaker because all the oxygen is being used in the burning process.”** *The article has corrected this misconception:*

T*he water level rises because*

1. S*ome of the reactant gas, oxygen, has been consumed, and much of the products have been either dissolved in the water (CO2) or condensed into the water (H2O vapor produced), leaving less gas inside the beaker at the end than at the beginning, thus lowering gas pressure inside the beaker; and*
2. *The heated air inside the beaker cools down, lowering the gas pressure inside the beaker.*

*Both these factors result in the atmospheric pressure outside the beaker forcing the water up into the beaker until gas pressure inside is once again equal to air pressure outside the beaker.*

1. **“The water deflects because the charge on the balloon attracts the opposite charge within each polar water molecule.”** *This would seem to be a logical explanation, but the article explains that it is the induced charge on the water molecules opposite to that on the charged object that causes the deflection.*
2. **“The temperature of the air inside the beaker increases because carbon dioxide is a greenhouse gas.”** *The gas inside the beaker increases in temperature solely because the carbon dioxide settles to the bottom of the beaker and inhibits circulation that prevents cooling of the inside of the beaker. It is warmed because it is in contact with the warm rocks, and that heat can’t escape the beaker.*
3. **“Demonstrations are no good because they don’t tell the truth.”** *This is only true in rare instances, and informed teachers will not purposefully deceive students just to “show them a good time”; rather, they will only use demonstrations that correctly show a specific chemical phenomena, and they will work with students to understand the chemical principles behind the demonstration.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“In the candle-under-the-jar demonstration, how do we KNOW that all the oxygen isn’t used up when the candle goes out?”** *Michael Faraday saw this one coming. He kept a mouse in his experiment and it was able to survive on the oxygen that remained in the container after the candle had gone out. OK, so we don’t want to torture mice anymore. Instead, if you redo the standard candle-under-the-jar experiment with two candles in the jar, one tall and one short, the tall one will go out first and the smaller candle will continue to burn, indicating there is still oxygen in the container. If the candles stayed lit until all the oxygen were used up, both candles would go out at the same time.*
2. **“Will the liquid level still rise if we keep the temperature high enough to prevent the water vapor from condensing?”** *This is an interesting question. The answer to the question is probably, “no”, for two reasons. First, if the temperature is hot enough   
   (>= 100 oC) such that the water vapor doesn’t condense, that means that we have all 26 moles of water, or nearly 2/3 of the original 38 moles (of oxygen) in the gaseous state, AND we probably have almost ALL of the 25 moles of carbon dioxide produced, also in the gaseous state. This is because the solubility of carbon dioxide is greatly decreased at this high temperature, as is true for all gases—gas solubility decreases with increased temperature. This means we have 51 moles of gaseous material in the same beaker where we originally had only 38 moles of gas, resulting in greater gas pressure after the combustion than originally.*

*In addition, we also have an elevated temperature inside the beaker, relative to ambient temperature (100 oC vs. perhaps 20 oC). At the higher temperature, gas pressure is also increased (Charles’ Law).*

*Both these factors will result in the greater gas pressure forcing liquid water out of the beaker, thus lowering the water level inside the beaker. However, this would be a very difficult experiment to perform, as the liquid water inside the beaker would be boiling at this elevated temperature. Thus, we would need to substitute another liquid for the water, one that would not become gaseous at the temperature at which the experiment is conducted. Of course, changing the liquid adds one more variable to the experiment, one which could affect the outcome.*

1. **“Will nonpolar liquids also be attracted to the charged rod or balloon?”** *Nonpolar liquids are also attracted to the rod or balloon, but with far less force (and therefore less than noticeable deflection). This is because, although the charged rod can still induce a charge in the nonpolar liquid, the electrons in that liquid are more evenly distributed and it is more difficult for them to be moved around. A very strong electrical field would have to be brought close to the stream of nonpolar liquid to cause a noticeable deflection.*
2. **“Are there ANY demonstrations that faithfully represent the effect of carbon dioxide on the Earth’s atmosphere?”** *The Earth atmosphere is such a huge system that it is very difficult to scale that down to a workable demonstration. The atmosphere’s huge size and complexity are two of the reasons the whole idea of global warming—or even climate change in general—is so hard to pin down. Mathematical models can come close to simulating all the variables in the atmosphere, but the devil’s in the details.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. Faraday’s “The Chemical History of a Candle” has been discussed in the “Background Information” section, above. The respected ChemStudy curriculum from the 1960s opened the year with the student experiment “Observations on a Burning Candle”, anticipating students’ following in Faraday’s footsteps. One such procedure is here: <http://boomeria.org/labschem/exper1.pdf>. It might be of interest to compare those experiments with information provided in this paper from the National Institute of Standards and Technology: Characterizations of Candle Flames.” <http://fire.nist.gov/bfrlpubs/fire05/PDF/f05141.pdf>.
2. If you want to pursue the burning-of-a-candle-under-a-jar demonstration more critically, here’s how to ignite the candle electrically—internally, after the entire set-up is ready to go. This avoids any air loss or gain prior to burning beginning. (<http://www.physics.umd.edu/deptinfo/facilities/lecdem/services/demos/demosi1/i1-64.htm>)
3. You can show this 3:07 YouTube video clip from “Mythbusters tests global warming theory” that shows a much more controlled experiment that replicates the atmosphere, using methane and carbon dioxide: <https://www.youtube.com/watch?v=pPRd5GT0v0I>. This clip shows how they controlled some of the variables in the experiment.
4. Following a discussion of the greenhouse gas demonstration, you can do a simple demonstration with carbon dioxide to verify its high density. Fill a clear container with CO2, either from a tank or from the chemical reaction between vinegar and baking soda, generated in another container and piped into the clear one. Then pour the gas only—no liquid—from the clear container over a lit candle. The flame will go out. Classroom discussion can then follow concerning the cause of the flame being extinguished.
5. You could use the 4:34 video clip from “Climate Change 101” that shows Bill Nye demonstrating “the greenhouse effect” using jars, small Earth globes, thermometers and heat lamps (0:50–1:30) and ask your students to identify the problems with the video. It is a variation on the article’s greenhouse demonstration. (<http://player.vimeo.com/video/28991442>)

Then you could show them this site that provides myriad evidence in a single report explaining why the Nye-Gore simple experiment above a) can’t work and b) didn’t work for Nye and Al Gore, who worked together on the full-length video. While the report is obviously written by a “climate change denier”, it does show the problems of doing a demonstration that is supposed to show something totally different from what it actually shows. Beware that the report is rather detailed, and itself contains a few problems (that students could be asked to search for).

(<http://wattsupwiththat.com/climate-fail-files/gore-and-bill-nye-fail-at-doing-a-simple-co2-experiment/>)

1. In case you wanted to actually *do* a greenhouse activity (similar to the one in the Tinnesand article) with your classes, here’s a good source: “Activity 12, ‘What is a greenhouse?’” from the University Corporation for Atmospheric Research. The procedure differs from that in the Tinnesand article in that no CO2 is used; instead, slots are cut in one bottle and not in the other (one allowing circulation and one, not), so if there is a difference in heating rates, it’s not going to be a density consideration. This activity contains a student version and a teacher version. The student (and teacher) version provides diagrams to show the preparation of the two systems. The teacher version is aware of problems with simplistic experiments meant to represent large Earth systems, as evidenced by the following statement:

**Cautionary Note:** The analogy between the plastic cover and the atmosphere is not a perfect one. Greenhouse covers prevent heat losses from convection (air movement carrying away the heat) as well as by radiation (direct transfer of heat energy). The atmosphere prevents only heat loss by radiation. The greenhouses used in this activity serve as a crude model of the actual atmospheric process and are only of limited use in understanding the nature and scope of the actual Greenhouse Effect.

(<http://www.ucar.edu/learn/1_3_2_12t.htm>)

For information leading up to the activity above, this page provides background information on what the greenhouse effect is: <http://www.ucar.edu/learn/1_3_1.htm>.

This page gives students a second activity, which allows for more variation in the outcome: Activity 13, “What Factors Impact a Greenhouse?” (<http://www.ucar.edu/learn/1_3_2_13t.htm>)

1. The Office of Science Education at the Jefferson Lab National Accelerator presents the phenomenon of water being deflected by a charged rod on their “Frostbite Theater” video clip (2:08). They also present a wrong explanation of the deflection, saying the water molecules rotate so that their partial charge opposite that of the charged rod moves toward the rod and their partial charge the same as the rod moves away from the rod, causing the deflection: <https://www.youtube.com/watch?v=VhWQ-r1LYXY>. Here is a correct, albeit short (1:13) explanation—induced charge: <https://www.youtube.com/watch?v=p1f6zLysilU>.
2. Here’s the polar-nonpolar charged rod deflection demonstration, done with a water stream and an oil stream. The teacher demonstrates while he explains the difference between polar and nonpolar substances. (<https://www.youtube.com/watch?v=k4AdJ2PSIco>)
3. Here’s another take on the deflection of water demonstration. A magic wand that does miraculous things to a stream of water—an old physics trick involved creating a parabola shaped spray of water by taking a finely tipped glass tube connected to a rubber hose attached to the cold water faucet and allowing the stream of droplets of water to fall into a sink. When the teacher points a black wand (a rubber rod which has been rubbed with flannel or fur) near the stream, the fine spray coalesces into larger drops and into a single stream of water. The fine spray consists or a large number of fine droplets of water carrying the same electrical charge. The water droplets repel each other resulting in the fine spray. The black rod made of ebonite and charged with static electricity by rubbing it with fur or flannel neutralizes the charge on the droplets of water as the rod is brought near the spray. The droplets no longer repel each other. They coalesce into larger drops and form a single stream of water. The flow of water and height of the stream can be controlled with a pinch cock attached to rubber hose.
4. “The “open” structure of Styrofoam™ can be dramatically demonstrated by placing a few milliliters of acetone in the bottom of a Petri dish and then setting an empty Styrofoam™ (expanded polystyrene—EPS) cup in the acetone. As the EPS “dissolves” in the acetone (for the real explanation of what occurs, see “More on other demonstrations that are not quite what they seem—Dissolving Styrofoam™”), the cup rapidly disappears. The open structure of the EPS (many cells) creates a large amount of surface area upon which the reaction takes place. Alternatively, a few centimeters of acetone can be placed in a large opaque container like a coffee can. Styrofoam™ packing “peanuts” can be added to the can. They will “disappear”. The number that can be added is rather amazing.

Care should be exercised in handling the acetone. It is very flammable, and in addition, the demonstration should probably be done in a fume hood. The product should not be flushed down the drain. The excess acetone should be allowed to evaporate in the fume hood, and the relatively dry product should then be packaged in plastic Ziploc bags and properly disposed of in the trash.” (Teacher’s Guide, *ChemMatters*, October 2000, accompanying article: “Packaging: Keeping Food Safe, Fresh, and Available”. Please explain to students that the process is not really dissolving.

1. Following a critical discussion of the air-has-mass demonstration, this is a good demonstration (or student experiment) to test students’ understanding of buoyancy of air in the atmosphere. It involves the law of conservation of mass. In a sealed zipper plastic bag, react sodium carbonate and vinegar. Put the vinegar in a small, loosely stoppered vial or test tube. Make a solution of Na2CO3, put it in another vial, stopper loosely and place both vials into the bag. Seal the bag and place it on the balance to note its initial mass. Ask students to predict what will happen to the mass of the system when the chemicals react inside the bag. Unstopper the vials through the bag, pour the contents of both into the bottom of the bag. Now put it back on the balance and watch its mass as the reaction proceeds. The mass actually decreases, due to the volume of CO2 produced by the reaction inside the bag displacing air outside the bag. The atmosphere buoys up the bag, thereby decreasing its mass. Even though the mass of the bag and contents remains constant before and after the reaction, the mass of the system *appears* to decrease. So much for students believing the Law of Conservation of Mass—UNLESS you explain the results using buoyancy. You can always try the experiment again, only this time use a glass airtight container (e.g., an Erlenmeyer flask with stopper). This time, buoyancy is constant, so the mass should not change.
2. You can’t see steam. (See “You can see ‘steam’.” In the “Background Information” section above.) You can do a classroom demonstration to show students the difference between steam and condensed water vapor, and that steam can get hotter than 100 oC. (Becker, R. “Question from the Classroom”. *ChemMatters* **2009**, 27 (3), p 2)
3. A fun activity and a good example of the actual operation of “hydrophilic” and “hydrophobic” materials is illustrated by comparing the properties of regular sand and the commercially available “Magic Sand.” Magic sand is hydrophobic. It is sand coated with a material that prevents it from attracting water (“repel” is not the proper word, but that does summarize what its observed behavior seems to be). Consequently if you cover it with water and then remove it, the sand is dry! (available at Educational Innovations, <http://www.teachersource.com/product/magic-sand/chemistry> or Steve Spangler Science, <http://www.stevespanglerscience.com/magic-sand.html>)
4. You can show students the value of skepticism in science and in their daily life in this *ChemMatters* article about a water purification device. You can probably duplicate the experiments in the article (OK, maybe not the one with the atomic absorption spectrometer). This article relates directly to the chemistry course chapter on redox. (Hesse, J. Mystery Matters:Tainted Water. *ChemMatters* **1988**, *6* (3), pp 13–15)
5. You could use this pair of video clips to show how science actually works. The first is a segment of a video by Veritasium (1:50–5:07) that shows a stream of water being deflected by a charged object, and the narrator explains the phenomenon—incorrectly, even by the old standard. The second clip follows up on that Veritasium explanation and offers its own experiments, focusing on the premise that if a prediction is made based upon a model (hypothesis) and the prediction doesn’t match what actually happens, then the model or hypothesis must be wrong, and we have to rethink our explanation. True to form, the second video leaves the question open-ended, pending further experimentation.

Veritasium video (3:57): <https://www.youtube.com/watch?v=jIMihpDmBpY>.

“When Veritasium Gets it Wrong!” (8:53): <https://www.youtube.com/watch?v=3Ev_k__U3Io>.

## Out-of-class Activities and Projects (student research, class projects)

1. A student might be interested in experimenting to find out whether adding extra CO2 dissolved in the water affects the amount of gas (water level) in the candle/jar experiment. Perhaps using club soda instead of the water would be a place to start?
2. Students can research online for other “bad” demonstrations that the teacher could then perform with them to uncover—and correct—the problem areas.
3. You could use this pair of video clips to show how science actually works. The first is a segment of the video by Veritasium (1:50–5:07) shows a stream of water being deflected by a charged object, and the narrator explains the phenomenon—incorrectly. The second clip (8:54) follows up on that Veritasium explanation and offers its own experiments, focusing on the premise that if a prediction is made based upon a model (hypothesis) and the prediction doesn’t match what actually happens, then the model or hypothesis (Veritasium’s) must be wrong, and we have to rethink our explanation. True to form, the second video leaves the question open-ended, pending further experimentation.  
   Veritasium video: <https://www.youtube.com/watch?v=jIMihpDmBpY>.  
   When Veritasium Gets it Wrong! video: <https://www.youtube.com/watch?v=3Ev_k__U3Io>.
4. Students can test a well-established “truth”. Everyone knows that shaking an unopened can of soda, and then opening it right away results in an explosion of bubbles—and soda—out of the can. And everyone *knows* that tapping the sides of the can after it’s been shaken is the way to avoid the “big splash, right? But maybe it’s not the tapping that makes things right. Students can experiment to find the truth. (Becker, R. Question from the Classroom. *ChemMatters* **2008**, *26* (1), pp 2–3)

## References (non-Web-based information sources)



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [http://ww.acs.org/chemmatters](http://www.acs.org/chemmatters)**. Scroll about half way down the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

Hesse, J. Mystery Matters:Tainted Water. *ChemMatters* **1988**, *6* (1), pp 13–15. Skepticism plays a large role in science, as perhaps it should in daily life. This article tells the story of a family considering the purchase of a water purification device being sold by a salesman. Healthy skepticism and an understanding of chemistry save the day.

Cardulla, F. Pseudoscience—Too Good to be True? *ChemMatters* **2002,** *20* (1), pp 4–5. While this article doesn’t deal with chemistry demonstrations, it does deal with the need for students to remain skeptical (or maybe, more correctly, analytical) about things they hear of or read about. Cardulla suggests “sifting through the claims” and “using science—REAL science” to find out the truth about things that sound too fantastic to be true.

Herlocker, H. Life in a Greenhouse. *ChemMatters* **2003**, *21* (3), pp 18–21. Author Herlocker describes the greenhouse effect and explains it in terms of molecular vibrations of the greenhouse gases. She compares both their effectiveness at absorbing and re-radiating infrared energy, and their relative abundances in the atmosphere. This would be a good introductory article for students who want to learn more about the actual greenhouse effect.

Becker, R. Question from the Classroom. *ChemMatters* **2005**, *23* (1), p 2. In this article, author Bob Becker discusses the student misconception that only the wick burns when a candle burns. He talks about flash point when showing that candle wax by itself doesn’t get hot enough to burn when you try to light it with a match.

Becker, R. Question from the Classroom. *ChemMatters* **2006**, *24* (2), pp 2–3. In this article, author Becker discusses the “oil and water don’t mix” or hydrophobicity demonstration, and its accompanying—possibly wrong—explanation. He addresses the misconception that oil and water have no attraction for one another, or may actually repel one another. Becker has a knack for explaining tough concepts at a level students can understand—and appreciate.

Becker, R. Question from the Classroom. *ChemMatters* **2008**, *26* (1), pp 2–3. Here’s another demonstration that we all know is true—or is it? Becker investigates the role that tapping on the sides of a can of soda plays in preventing an explosion of bubbles and soda when opening a closed, shaken can of soda.

## Web Sites for Additional Information (Web-based information sources)

**More sites on why teachers *do* demonstrations**

This document from George Bodner, Professor of Chemistry at Purdue University, published in the *Journal of the Royal Society of Chemistry*, U.K (2001), explains the benefits to teachers of doing chemistry demonstrations. (“Why Lecture Demonstrations Are ‘Exocharmic’ For Both Students and Their Instructors”, <http://chemed.chem.purdue.edu/chemed/bodnergroup/PDF_2008/71%20Demos%20UCEd.pdf>)

This paper from Elisha Swanson discusses in some detail the pros and cons of using demonstrations in the classroom: <http://bradley.bradley.edu/~campbell/elishapaper.htm>.

If you want to know more about whether or not demonstrations actually improve student understanding/retention of concepts, read this Masters’ Thesis, *The Use of Classroom Demonstrations to Improve High School Students’ Ability to Understand Concepts in Chemistry*. It discusses many research studies testing that very hypothesis. The author’s own study involved testing differences in understanding of a concept between students who merely observed the demonstration and those who were first asked to predict what would happen, observe the demonstration, and then compare their prediction to the actual outcome. As might be expected, predictions and analysis of outcome improved understanding.

(<http://etd.lsu.edu/docs/available/etd-06272013-101731/unrestricted/(shelton)thesis.pdf>)

Here’s a second, similar study with similar results, *Interactive lecture demonstrations:*

*a tool for exploring and enhancing conceptual change*, from the Department of Science Teaching, the Hebrew University of Jerusalem, Israel: <http://www.rsc.org/images/Ashkenazi%20paper2%20final_tcm18-85042.pdf>.

**More sites on teaching using demonstrations**

Hubert Alyea (1903-1996), a Princeton professor and world-renowned chemical demonstrator was recorded for posterity doing one of his world-famous chemistry demonstration sessions in this video (28:26): <https://www.youtube.com/watch?v=jSw7cHfxbu8>. The presentation here is very fast-paced, but it gives you the flavor of this master-demonstrator and why his demonstration sessions, “Lucky Accidents, Great Discoveries and the Prepared Mind”, were almost always standing-room only. He not only taught chemistry with his demonstrations, he also taught life skills and attitudes. His advice to the (primarily student) audience, “Be expert, be human and have self-confidence.” And he had stories about famous scientists to illustrate each point. For those us (old-timers) lucky enough to have actually attended his demonstration extravaganza, well, as the saying goes, we’re lucky enough.

Carleton College collaborates with many other colleges in the Interactive Lecture Demonstration (ILD) method of teaching. This site provides detailed information about the method: <http://serc.carleton.edu/introgeo/demonstrations/index.html>.

Chemistry demonstrator David Katz provides this 5-page discussion, “The Art of Effective Demonstrations: <http://www.chymist.com/Effective%20demonstrations.pdf>.

**More sites on sources of demonstrations (to learn how to do them yourself)**

This Web site offers information on the now-5-volume set of *Chemical Demonstration: A Handbook for Teachers of Chemistry* books edited by Bassam Shakhashiri. They are widely recognized as the definitive set of books on chemical demonstrations. This Web page shows the titles of all the demonstrations in each of the 5 books. (<http://scifun.chem.wisc.edu/DemoSeries/demoser.html>) The series of books is for sale on the site.

This site offers 60 demonstrations, by title, from Bob Becker, chemistry teacher and demonstrator par excellence. He specializes in simple demonstrations to illustrate a specific point. (<http://chemmovies.unl.edu/chemistry/beckerdemos/bd000.html>)

An online *Chemical Demonstrations Booklet*, by Magda Wajrak, of the School of Natural Sciences at Edith Cowan University, in Western Australia is available as a pdf document (2008 copyright). The 43-page booklet contains very detailed instructions and safety information on 21 demonstrations for 19 different topics in a typical high school chemistry course. Close-up photographs before and after the event show in detail what students are expected to see in the reaction(s). [Note that the booklet contains several demonstrations that have safety concerns here in the U.S., such as using a zinc/mercury amalgam, and using KMnO4 with 30% H2O2.] (<http://www.ecu.edu.au/__data/assets/pdf_file/0006/358557/ECU_Chemical_Demos_Booklet.pdf>)

In 1995, the Royal Society of Chemistry published a book, *Classic Chemistry Demonstrations*, compiled by Ted Lister. The book contains 100 chemistry demonstrations that cover the gamut of topics in a typical high school chemistry course. They even have correlation tables that show the reader what demonstration relates to what topic, so you can choose a demonstration based on what you are teaching that day! General safety is discussed for each chemical, all in one section of the book. Keep in mind that this book is now 20 years old, so you will need to ascertain the safety of the chemicals and the demonstration for yourself (as always). SDSs need to be reviewed for safety before you do any of these (or any) demonstrations. All the demonstrations are organized the same way, with topic, timing, level, description, apparatus, chemicals, method/alternative method, visual tips, teaching tips, theory, notes, extensions, and safety. (<http://www.rsc.org/learn-chemistry/content/filerepository/CMP/00/001/001/Classicdemos_full.pdf>)

Many sites such as this one <http://chemistry.about.com/od/chemistrydemonstrations/> from about.com provide chemistry demonstrations as well. Unfortunately, the directions and descriptions and safety precautions are often lost in the myriad advertisements that seem to cover the screen.

The Department of Chemistry and Biochemistry at James Madison University sponsors their ChemDemo Web site at <http://sites.jmu.edu/chemdemo/category/lesson-plans>. Here, seventeen (17) demonstrations are shown, complete with directions, lesson plans, student handouts, PowerPoints, etc. Forty-six (46) more are shown that have a complete set of directions (still very complete), but no PowerPoints or lesson plans. The set of tabs at the top separates the groups for you.

This Royal Society of Chemistry (U.K.) site provides a series of 19 videos of chemistry demonstrations aimed at teachers who might want to reproduce the demonstration live with their students in class. Each video is accompanied by notes or pdf files, some taken from the *Classic Chemistry Demonstrations* booklet mentioned above. (<http://www.rsc.org/Education/Teachers/Resources/Practical-Chemistry/Videos/>)

**More sites on sources of video demonstrations (in case you don’t want to do them yourself, or want to *learn how* to do them yourself)**

This series of videos showing 12 demonstrations done by Professor John Dolhun of MIT, accompanied by Professor Bassam Shakhashiri of UW-Madison, are part of the MIT Open Courseware program: <http://ocw.mit.edu/high-school/chemistry/demonstrations/videos/>. Teaching notes accompany each video to help teachers do the demonstration live in their own classroom.

Mr. Kent’s Chemistry Page provides a set of 6 Web pages containing 65 videos showing various physical and chemical demonstrations. The KentChemistry site also contains 6 HD videos on chemistry demonstrations. (<http://www.kentchemistry.com/KentsDemos6.htm>)

This Web site from Chemicum, scientists and lecturers from the University of Tartu in Estonia, is gathering/producing videos for “100+ Experiments in Chemistry”. The site, developed for high school teachers, is in the development state. Some of the videos presently appear only as video clips, with no commentary/narration (blue links—these are still under development), while others (green links) appear with commentary on the screen describing the demonstration set-up and what’s happening, and then offer explanations (which can be paused to give you time to develop those for your class. There is even a drawing tool on-screen so that you can pause the video and draw (in multiple colors) as on a SmartBoard® to emphasize a point or to give students more information. There is a bit of a learning curve to discover what all the tools on the screen border can do (they blink on and off as the video begins, but it’s too fast to actually recognize the buttons). However, this seems like it would be a very useful Web site, especially for teachers who don’t want to, or can’t, do demonstrations in their classes. (<http://www.chemicum.com/chemistry-videos/>)

**More sites on history of the burning candle demonstration**

Here is an online source of the original Faraday book *The Chemical History of a Candle*: <https://archive.org/details/chemicalhistoryo00faraiala>. The Gutenberg Project also has a text-only version available here: <http://www.gutenberg.org/ebooks/14474>.

**More sites on the burning candle demonstration**

The *Journal of Chemical Education* published an article in their January 2008 issue entitled “A Bright Spark: Open Teaching of Science Using Faraday’s Lectures on Candles”. It details how the three authors used Faraday’s candle lectures to prepare an original inquiry-based lesson on candle burning. The lesson proceeds through a series of questions posed by the teacher that eventually take students through most of the experiments Faraday did in his lecture series. (Walker, M.; Groger, M.; Schluter, K. A Bright Spark: Open Teaching of Science Using Faraday’s Lectures on Candles. J. Chem. Educ., **2008**, 85 (1), p 59, <http://pubs.acs.org/doi/abs/10.1021/ed085p59>) (abstract only—full pdf document available online only by subscription)

This 13-page document, “Candles under Jars”, provides a very detailed explanation of all of the problems associated with the burning candle demonstration: <http://misconceptions.science-book.net/wp-content/uploads/2011/09/Chap2-1.pdf>.

**More sites on the greenhouse effect demonstration**

Here’s another site for the “Climate Change 101” (4:33) video clip of the Bill Nye greenhouse gas experiment discussed previously in this Teacher’s Guide: <http://vimeo.com/28991442>.

This site contains lots of information about the greenhouse effect. It provides several charts showing how solar energy enters and leaves our Earth system. (<http://zebu.uoregon.edu/1998/es202/l13.html>)

And this site, <http://www.ems.psu.edu/~fraser/Bad/BadGreenhouse.html>, shows us many misconceptions we have about the greenhouse effect. And note, he pulls no punches!

**More sites on electrostatic deflection of liquids demonstration**

Here’s a 0:15 video clip showing the deflection of water by a glass rod. Charging is optional (must have been done off-screen). (<https://www.youtube.com/watch?v=w8Z7HuA07to&feature=player_embedded>)

This 4:12 video clip from Flinn Scientific features Irwin Talesnick, from Queen’s University, Ontario, CA. Presenting this demonstration to teachers, he discusses the difference between polar and nonpolar molecules and uses two burets with water and toluene to show deflection with water and no deflection with toluene. He shows that both negative and positive rods attract water. As these videos from Flinn are meant to be teaching tools, he offers no explanations. (<https://www.youtube.com/watch?v=KfcVf_PdXjk>)

This 2:08 video clip from Frostbite Theater (“Cold Cuts … No baloney, just science!”) from the Office of Science Education at the Jefferson Lab National Accelerator provides a great (albeit *incorrect*) explanation of the deflected water stream, based on the rotating of the polar water molecule such that the end of the molecule that moves toward the charged rod is the oppositely charged side. (<https://www.youtube.com/watch?v=VhWQ-r1LYXY&feature=player_embedded>)

This 5:12 video clip of a classroom lesson on polar and nonpolar molecules shows side-by-side demonstrations of liquid streams of oil and water as the teacher discusses why they are polar and nonpolar and why the nonpolar stream is not deflected. The explanation is the old standard, “The positive part of the stream is attracted to my negative rod.” (<https://www.youtube.com/watch?v=k4AdJ2PSIco>)

This site from the journal of the American Association of Physics Teachers, *The Physics Teacher*, (*Phys. Teach.* 52, 266 (2014)), reports on research done trying to deflect a *horizonta*l surface of a still liquid using a charged rod, and finally, using a van de Graaff generator: <http://scitation.aip.org/content/aapt/journal/tpt/52/5/10.1119/1.4872403>. Photos are included.

**More sites on other demonstrations that are not quite what they seem**

**The “Dissolving” Styrofoam™ in acetone demonstration**

About.com usually has correct explanations of chemical phenomena, but in this case, their explanation needs a bit of work as they discuss the solubility of Styrofoam in “Dissolve Styrofoam in Acetone”: <http://chemistry.about.com/od/polymers/a/Dissolve-Styrofoam-In-Acetone.htm>.

This short video clip (0:45) from Steve Spangler Science’s “Sick Science” series shows a foam cup disappearing in acetone: <https://www.youtube.com/watch?feature=player_embedded&v=Bb6-hpe2KcY>. The only explanation given on the discussion page is that, “The acetone easily dissolves the polystyrene, leaving very little residue.” Neither of the statements is exactly true; the [expanded] polystyrene doesn’t actually dissolve, and there’s lots of polystyrene “residue” (although, relative to the original amount of expanded polystyrene, the amount of “defoamed” EPS is small). The rest of the description focuses only on the various ways you can make the demonstration fun for kids to watch, not further explanation.

**The air has mass demonstration**

This video clip (1:30) shows two ways to show that air has mass. The first is the bursting balloon experiment as described previously in this Teacher’s Guide, with one change: the balloon is cut at the neck, where the balloon is relatively unstretched. That results in the slow release of air, so that the balloon doesn’t burst, shred, and send balloon shrapnel all over the room. The deflated balloon seems to weigh less than the still-inflated one. So again, both balloons must have been inflated to their maximum, putting more air in the remaining inflated balloon under pressure, meaning more air mass. The second way uses a small soccer ball weighed (massed?) on a balance, deflated, and then inflated, to show that the air pumped in actually has mass. This is a more direct way of showing the mass of air—or that air has mass. (<https://www.youtube.com/watch?v=sCqVUmoOojI&feature=player_embedded>)

Even this 4-second clip artist’s illustration of the balanced balloons changing level on the meter stick after bursting one balloon indicates pieces of “balloon shrapnel” remaining at the bottom of the screen, which would make the deflated balloon lighter, no matter what: <https://www.youtube.com/watch?v=UY1q_Jg_tiQ&feature=player_detailpage>.

This 1:45 video clip of a teacher in a classroom shows part of his lecture/demonstration to show air has mass, using a 1-L soda bottle and a “fizz-keeper”. He weighs the bottle “empty” and then pumps it up with the fizz-keeper to put more air in and weighs it again. More air, more weight. (<https://www.youtube.com/watch?feature=player_detailpage&v=kmpPh_wV0JI>)

**The hydrophobic effect demonstration**

This Wikipedia site provides a bit more detail about the reason that oil and water don’t/can’t mix: <http://en.wikipedia.org/wiki/Hydrophobic_effect>. Part of the article is suspect, but the section “The origin of hydrophobic effect” provides clear information. This link <http://en.wikipedia.org/wiki/Entropic_force#Hydrophobic_force> within the aforementioned article provides more depth.

This site from Brandeis University provides a cohesive picture (a professor’s class lecture, actually) of the entropy-driven reactions preventing mixing of hydrophobes (nonpolar molecules) with water: <http://www.bio.brandeis.edu/classes/biochem104/hydrophobic_effect.pdf>. It also clearly defines what the hydrophobic effect is and why it exists.

## General Web References (Web information not solely related to article)

We’ve cited lots of Web pages from the ChemMovies Server operated by Dave Brooks, at the University of Nebraska-Lincoln, in many past Teacher’s Guides. But the home page provides links to entire other internal database sites that cover the gamut of chemistry for high schools. Here are the major tabs: *Doing Chemistry, Microscale Experiments, Biotechnology, Becker Demo Series, Smallscale Experiments, ChemSource, Redox Project, LABS Project,* and *ChemAnimations*. Each tab takes you to a wealth of chemistry information. And it’s all free! Enjoy! (<http://dwb4.unl.edu/Chemistry/chemmovies.html>)

The 5-volume set of books *Chemical Demonstration: A Handbook for Teachers of Chemistry*, edited by Bassam Shakhashiri of the University of Wisconsin-Madison, is widely recognized as the definitive set of books on chemical demonstrations. Each book focuses on specific areas of chemistry (e.g., book 1 covers thermochemistry, chemiluminescence, and color and equilibria of metal ion precipitates and complexes, while book 3 covers acids and bases and liquids, solutions and colloids). Each demonstration provides: a brief description of the demonstration; a materials list; step-by-step procedure to do the demonstration; explanation of the hazards involved; information about storage and disposal of the chemicals used; a detailed explanation of the chemistry behind the demonstration and the principles illustrated; and a list of references. This Web page shows the titles of all the demonstrations in each of the 5 books, a total of 335 demonstrations! It also shows where the books can be purchased. More books in the set are expected in the future. (<http://scifun.chem.wisc.edu/DemoSeries/demoser.html>)

I listed this site in the “More sites on sources of video demonstrations”, but it deserves to be bookmarked as a general reference, a source of video demonstrations whenever you need one. The site from Chemicum, scientists and lecturers from the University of Tartu in Estonia, has videos for “100+ Experiments in Chemistry” (110 presently). Check it out at <http://www.chemicum.com/chemistry-videos/>.

# Liquid to Foam: How Egg Whites Change Texture

## Background Information (teacher information)

**More on** **egg chemistry**

Before we delve into egg whites it might be helpful to describe the overall makeup of a chicken egg. If we look at an egg in cross section, we would see the familiar three parts—the shell, the egg white and the yolk. They are the parts that we refer to for purposes of nutrition. But we also see other component parts that play an important role as shown in the diagram below.

A chicken egg is composed of the following substances by percent:

Water – 76.15

Protein – 12.56

Lipids – 9.51

Ash – 1.06

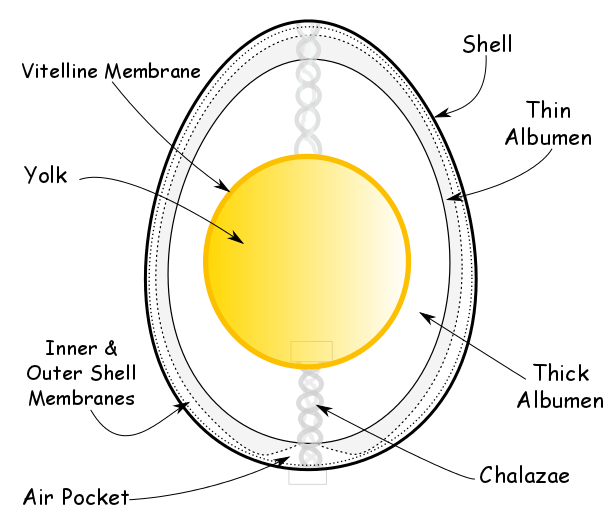
Carbohydrate – 0.73

Cholesterol – 0.372

The outer shell is made of calcium carbonate, CaCO3, and forms a rigid, semi-permeable membrane around the other components. The shell has thousands of tiny pores that allow air and water to pass through. When an egg is first laid there is a thin outer shell called the cuticle that helps to keep bacteria out of the egg. However, the cuticle is usually missing from eggs we purchase because it is washed away when eggs are processed for sale. Your students will likely know that egg shells vary in color, including white, cream, brown, blue or green. The color depends entirely on the breed of the laying hen. All eggs begin as white. As the egg moves through the hen’s oviduct chemicals are deposited on the shell to create color. In brown eggs, for example, the pigment is protoporphyrin, and in blue eggs the pigment is oocyanin.

*(*[*http://www.incredibleegg.org/egg-facts/eggcyclopedia/c/color*](http://www.incredibleegg.org/egg-facts/eggcyclopedia/c/color)*)*

Inside the outer shell are two thin membranes, outer and inner, which act as barriers to bacteria. Freshly laid eggs have a temperature of about 41 oC, but they quickly cool and, as they do, the membranes shrink, the inner membrane more so than the outer. As a result, an air pocket forms between the two, usually at the broader end of the egg.



*(*[*http://davidstable.com/2012/12/eggs-101-the-basics/*](http://davidstable.com/2012/12/eggs-101-the-basics/)*)*

Inside the membranes is the albumen or egg white, which is 90% water and 10% protein. It contains no fat or cholesterol. In fact, there are two layers of albumen, the thin layer and the thick layer.

The vitteline membrane surrounds and contains the yolk, which contains 41% of the egg’s protein and 100% of its fat and cholesterol. Also in the yolk are the minerals iron and calcium, and vitamins A and D, thiamine and riboflavin. A natural emulsifier called lecithin is also contained in the yolk.

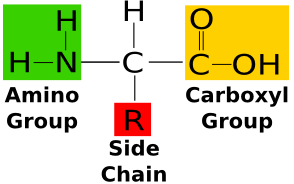
Small rope-like structures called chalazae are part of the egg whites and they anchor the yolk to the inner shell membrane to keep the yolk centered.

In the context of this article we are most interested in the albumin layer where we find the proteins that make up the foam needed for our angel food cake.

**More on** **amino acids**

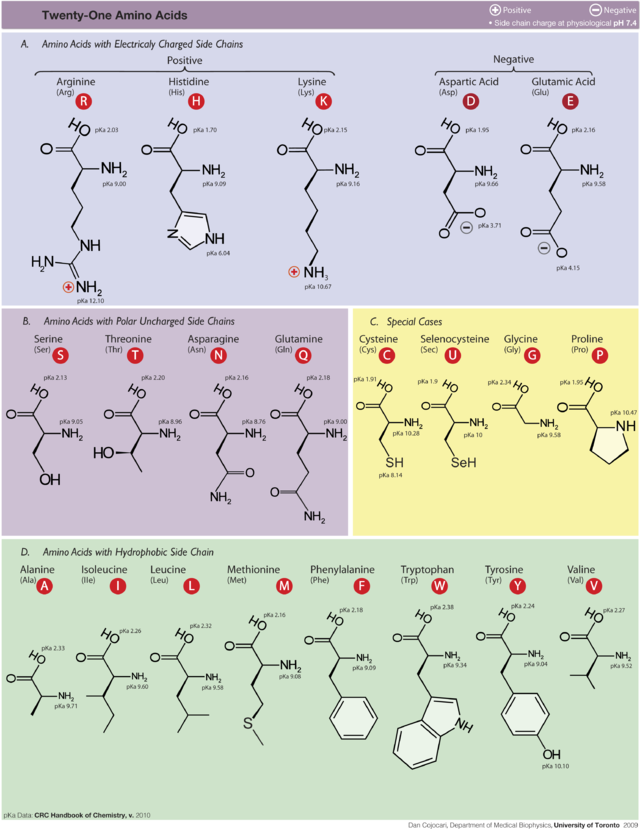
Egg white is made up of albumin, a clear alkaline solution of about 10% proteins and 90% water mixed with traces of minerals (including sodium, potassium, chorine, sulfur, iron, phosphorus, calcium and magnesium), fats, vitamin and glucose. The albumin makes up about two-thirds of the weight of the egg’s contents, not including the shell. A little more than 50% of the egg’s protein is contained in the albumin. There is no cholesterol in the albumin.

So, let’s consider the basic chemistry of amino acids. As your students will likely remember from biology class, proteins are made up of amino acids, so we need to understand a little about amino acid chemistry. All amino acids have the basic structure at left. They are a combination on an amine functional group (green in the diagram) and a carboxyl functional group (yellow) with a side chain (red) attached to the central carbon atom. The composition of the side chain determines the exact nature of the amino acid. For example, if the side chain is just one hydrogen atom then the amino acid is glycine. If the side chain is a methyl group (–CH3) then the amino acid is alanine.



*(*[*http://education-portal.com/academy/lesson/what-are-amino-acids-definition-structure-quiz.htm*](http://education-portal.com/academy/lesson/what-are-amino-acids-definition-structure-quiz.htm)*)*

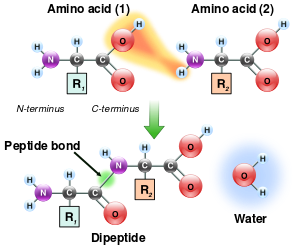
We will have more to say about the side chains later. Below is a chart of the proteins and their structures.



*(*[*http://en.wikipedia.org/wiki/Protein\_(nutrient)#mediaviewer/File:Amino\_acids.png*](http://en.wikipedia.org/wiki/Protein_(nutrient)#mediaviewer/File:Amino_acids.png)*)*

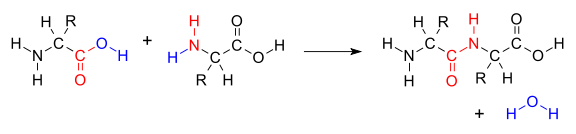
Amino acids combine to form proteins. Proteins are, then, polymers made up of protein units. The diagram at right shows the most common amino acid bonding mechanism. When two amino acid molecules approach each other and the carboxyl end of one collides with the amino end of the other the carboxyl unit loses a hydrogen atom and an oxygen atom, and the amino unit loses a hydrogen atom. The resulting molecule is called a dipeptide in which the two original amino acids are now linked by a covalent peptide bond (-CO-NH-) and a water molecule is also produced. The reaction is a condensation reaction.

*(*[*http://en.wikipedia.org/wiki/Peptide\_bond*](http://en.wikipedia.org/wiki/Peptide_bond)*)*



The reaction below is another way of looking at the reaction described above. The atoms shown in blue form the water molecule and the atoms shown in red are involved in the peptide bond.

*(*[*http://en.wikipedia.org/wiki/Peptide\_bond*](http://en.wikipedia.org/wiki/Peptide_bond)*)*



So we can think about many amino acids linking together via peptide bonds to form longer chains. Chains with molecular masses of less than 10,000 Da (Daltons) are not considered proteins but are usually referred to as oligopeptide chains. Longer protein chains may have thousands of amino acids, as noted below. In addition, the resulting protein molecules can vary greatly in size and mass. For example, keratin, a smaller protein found in human hair and nails, has a molecular mass in the 50,000-70,000 Dalton range. On the other hand, titin, the largest known protein, consists of 34,350 amino acids, with a molecular mass of approximately 3.8 million Daltons. Protein molecules are so large they are often referred to as macromolecules.

In addition to the large range in molecular size, proteins have a wide variety of properties. For example, silk is a flexible fiber, animal horn is a tough rigid solid, and the enzyme pepsin forms water soluble crystals. Given the variety of amino acid structures, there is significant diversity of proteins as illustrated by the list of proteins contained in egg white, below. It should also be no surprise that the amino acids making up proteins also vary widely in properties and function.

The list of amino acids contained in egg whites, in order of their prevalence and their general biological functions appears below. This information is adapted from <http://orthomolecular.org/nutrients/proteins.shtml>.

**Glutamic Acid** - The most common excitatory (stimulating) neurotransmitter in the central nervous system, has protective effects on the heart muscle in people with heart disease.

**Aspartic acid** - Combines with other amino acids to form compounds that absorb and remove toxins from the bloodstream.

**Leucine** - Helps with the regulation of blood-sugar levels, the growth and repair of muscle tissue (such as bones, skin and muscles), growth hormone production, and wound healing as well as energy regulation. Prevents the breakdown of muscle proteins

**Valine** - Promotes mental vigor, muscle coordination and calm emotions. Preventing muscle loss at high altitudes.

**Lysine** - Helps with the building of muscle protein, assists in fighting herpes and cold sores. It is required for growth and bone development in children, assists in calcium absorption and maintaining the correct nitrogen balance in the body and maintaining lean body mass.

**Serine** - Required for the metabolism of fat, tissue growth and the immune system as it assists in the production of immunoglobulins and antibodies.

**Alanine** - Vital for the production of protein, essential for proper function of the central nervous system and helps form neurotransmitters. An important source of energy for muscle tissue, the brain and central nervous system; strengthens the immune system by producing antibodies; helps in the metabolism of sugars and organic acids

**Phenylalanine** - Influences certain chemicals in the brain that relate to pain sensation. Helpful for some people with Parkinson’s disease and has been used to treat chronic pain. It is used in elevating the mood since it is so closely involved with the nervous system. It helps with memory and learning. It has been used as an appetite suppressant

**Isoleucine** - Helps preventing muscle protein breakdown during exercise, preventing muscle loss at high altitudes and prolonging endurance performance in the heat.

**Tyrosine** - Helps in suppressing the appetite and reducing body fat, production of skin and hair pigment, the proper functioning of the thyroid as well as the pituitary and adrenal gland

**Arginine** - Vital for the production of protein. Only the L form of amino acids are constituents of protein. Arginine crosses the blood-brain barrier, is a precursor for nitric oxide and is a responsible for the secretion of hormones such as growth hormone, glucagon and insulin. Assists in wound healing, helps remove excess ammonia from the body, stimulates immune function, and promotes secretion of several hormones, including glucagon, insulin, and growth hormone.

**Threonine** - Important for the formation of many proteins and tooth enamel, collagen, and elastrin. It metabolizes fat and prevents the buildup of fat in the liver, and is useful with intestinal disorders, and indigestion. Antiulcer.

**Proline** - Helps strengthen cardiac muscle, improves skin texture and aids collagen formation and helps contain the loss of collagen during aging.

**Glycine** - Inhibits neurotransmitter signals in the central nervous system.

**Methionine** - Supplies sulfur and other compounds required by the body for normal metabolism and growth. Improves memory recall in people with AIDS-related nervous system degeneration

**Histidine** - Neurotransmitter, stimulant of gastric secretion, vasodilator, and blood pressure regulator.

**Cystine** - Strengthens the protective lining of the stomach and intestines, which may help prevent damage caused by aspirin and similar drugs. Functions as an antioxidant and is a powerful aid to the body in protecting against radiation and pollution

**Tryptophan** - Essential for the production of the B vitamin, niacin, which is vital for the brain to manufacture the key neurotransmitter, serotonin. It enhances the release of growth hormones, and suppresses the appetite.

In summary, the amino acids listed above combine in long chains to form protein molecules. In the next section we will provide additional information on proteins.

**More on** **proteins**

The article suggests that the structure of protein molecules is the most important factor in creating foamy egg whites when baking angel food cake, meringues or soufflés. Let’s dig a little deeper into protein chemistry to see how this works.

Proteins are often described as the “workhorses” of cells. They are present in every cell in the body. They serve many different functions in organisms. They provide structure to the body in skin, cartilage, muscles, tendons and ligaments. As enzymes, hormones, antibodies, and globulins they regulate body chemistry. They serve as transport agents in the form of hemoglobin, myoglobin and various lipoproteins. Protein based antibiotics and vaccines help to fight disease, and we warm and protect our bodies with clothing that is often protein-based (e.g. wool, silk and leather).

One of the difficulties in describing protein chemical structure is that proteins are very large molecules, as noted above. For example, actin is a protein that is important for cell functioning. Its mass is about 42 kDa (12 Da is the mass of a single carbon atom). Remember that proteins are long polymers of amino acid monomers. How would that chain be represented? One way is to use the FASTA format, which is a text-based method of representing peptide sequences. Each amino acid is given a single letter abbreviation. For example, here are a few amino acids and their abbreviations:

**Amino Acid Code**

Alanine A

Aspartic acid D

Glycine G

Lysine K

Leucine L

Valine V

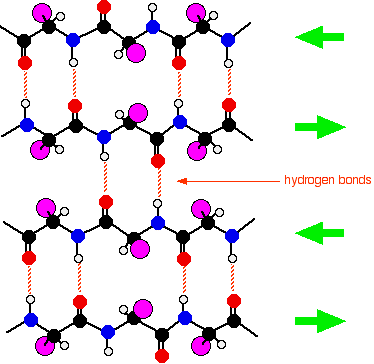
Tryptophan W

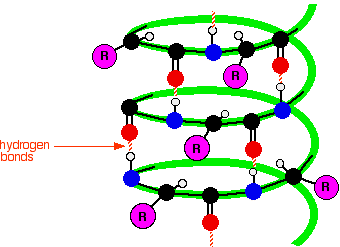
For a complete set of amino acid codes see <http://en.wikipedia.org/wiki/FASTA_form>. A protein’s structure is represented by arranging the letter abbreviations in order of the amino acids in the protein. So an example sequence might look like this:

... GKAAVDPADRCKEV .... Each letter represents an amino acid linked together by a peptide bond. This sequence is called the primary protein structure. Note that the FASTA format for an actual protein would be much longer, as indicated by the ellipses, above.

In addition to primary structures, proteins also have secondary, tertiary and in some cases quaternary structures. The secondary structure describes sub-structures of the long polymer chain that are arranged into either a helix or a sheet-like arrangement (see diagrams below). These two secondary characteristics are the result of intermolecular bonds between atoms *in the protein skeleton itself*. A note about the term “intermolecular” as it applies to macromolecules like proteins—the language is a little misleading. We usually refer to bonds like hydrogen bonds as “intermolecular” but in the case of large molecules this kind of bonding can occur between adjacent sections of the molecule, making the bonds “intra-molecular.” However, we will continue to use the conventional language.

The primary bonding of this type is hydrogen bonding, which occurs between the amide hydrogen with its partial positive charge and a non-bonding electron pair from the oxygen in the carboxyl group. In the helix structure (diagram below, left) the hydrogen atoms and the oxygen atoms face each other along the helix and the resulting hydrogen bonds hold the helix in place. In the sheet form (diagram below, right) the hydrogen atoms align alongside the oxygen atoms as the long chain doubles on itself in a single plane. As the article suggests, in a special case of intermolecular bonding in cysteine, which contains sulfur, the amino acids are bonded to each other secondarily by sulfur-sulfur bonds called disulfide bridges.





Helix secondary structure

Sheet secondary structure

*(*[*http://www.chemguide.co.uk/organicprops/aminoacids/proteinstruct.html*](http://www.chemguide.co.uk/organicprops/aminoacids/proteinstruct.html)*)*

The tertiary structure involves the way an entire polymer chain, including the helices and sheets, folds into itself to give the molecule its three-dimensional shape. Protein molecules fold into three-dimensional shapes due to intermolecular forces *between the amino acid side chains*. Many of the side chains contain units in which the hydrogen atoms set up hydrogen bonds with adjacent oxygen atoms. In the case of longer alkyl side chains temporary van der Waals dipoles can also be established, resulting in forces strong enough to hold the folded molecule in place. In some proteins there are also ionic interactions. Amino acids like aspartic acid and glutamic acid have an extra –COOH group. Other amino acids like lysine have an extra –NH2 group. If those two amino acids, each part of the same protein, were near each other in the overall structure, the –COOH could lose its H+ to the –NH2, forming a positive and a negative ion (the pair are called zwitterions), creating an ionic bond. In many proteins the tertiary structure is the final shape of the molecule.

Some proteins, however, develop a quaternary structure. These structures result from the interactions of two or more protein chains and are the result of complex intermolecular attractions. There are two general shapes into which protein molecules fold. They are globular shapes and fibrous shapes. Globular folding produces a general spherical shape. Examples of globular proteins are insulin, hemoglobin, and most enzymes. Fibrous folding presents itself as a long filamentous structure. Good examples here are keratin, mysin and actin (muscle-related proteins).

In summary, protein molecules are long polymers of amino acid monomers. Sections of the polymer take on either a helical or pleated shape and the entire backbone molecule folds itself into a general three-dimensional shape. It is important to note that the amino acid backbone also has side chains described above. As the article note, these side chains play a role in creating the protein foam for the angel food cake in question.

**More on** **egg white foam**

This article is primarily about how to create a stable foam in baking cakes, soufflés and meringues. And the article identifies beaten egg whites as the best vehicle to accomplish this feat. The foam itself is simply small air bubbles incorporated into the egg white in the whipping process. The stabilization of the foam is achieved by the egg whites. The process is summarized by the American Egg Board:

When air is incorporated into a liquid or viscous solution, the solution entraps the air bubbles, forming a foam. If the foam is stabilized by proteins, it leavens a food, increasing its height and reducing its density. The viscosity of all egg products is ideal for incorporating air cells during the whipping or beating process. As whipping or beating progresses, air bubbles decrease in size and increase in number, all the time surrounded by egg proteins. Liquid egg products have low air-liquid interfacial tension; thus, when eggs are beaten or whipped, the proteins denature, or simply, they unfold. This exposes two oppositely charged ends of the protein molecule: the hydrophobic, or water-hating end, and the hydrophilic, or water-loving ends. The proteins align themselves between the air and water, securing the air bubbles with their hydrophilic chains pointing into the water and dangling their hydrophobic chains in the air. During baking, these proteins bond with each other, forming a delicate, yet reinforced network.

Egg whites do this much better than yolks because of the unique proteins found in whites. In fact, even though the term foam technically refers to any system where there are entrapped air bubbles, in the food industry, when discussing egg products, the term tends to be exclusive to egg whites foams. This is because egg whites, unlike any other natural food ingredient, are able to create the largest possible food foam, a foam six to eight times greater in volume than unwhipped, non-aerated liquid egg white.

Whole eggs and egg yolks can also increase the volume of foods, including certain baked goods and dairy desserts such as ice cream and custard, but just not as much as egg whites alone. Visually, whipped yolks may double or triple in volume, while whipped whole eggs produce less volume than either yolks or whites whipped separately. They are also less thick than yolks alone.

There are four powerhouse proteins in egg whites that are barely present in yolks. Ovalbumin, which is about 54% of the white’s protein content, coagulates when heated, forming a solid framework around entrapped air that enables the wall structure to resist collapse. Ovalbumin does not unfold much when the egg is beaten, but without it, the foam would collapse when baked. Simply, ovalbumin allows a liquid foam to solidify. The highly elastic conalbumin, which is about 12% of the white’s protein content, together with two other proteins — ovomucin and globulins — both present in quite small amounts, stabilizes the foam at room temperature.

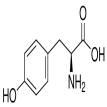
(<http://www.aeb.org/food-manufacturers/functional-properties/39-functional-properties/207-aeration-foaming-structure>)

As we think about the stability needed to create that angel food cake in the article we should focus on the side chains in amino acid molecules. These side chains can range from a single hydrogen atom in glycine, to a methyl group in alanine to more complex side chains like those in tryptophan or tyrosine (see structures below). Intermolecular forces in amino acid side chains actually hold the overall protein in its normal conformation. They also determine where the bends and folds are in the overall structure and shape of the complete molecule. And these side chains are “sticking out” on the exterior of the protein molecule and, therefore, are involved in bonding interactions of that protein.



*(*[*http://commons.wikimedia.org/wiki/File:Tryptophan\_simple.png*](http://commons.wikimedia.org/wiki/File:Tryptophan_simple.png)*)*

Tryptophan



*(*[*http://www.mpbio.com/product.php?pid=02194759&country=223*](http://www.mpbio.com/product.php?pid=02194759&country=223)*)*

Tyrosine

The article emphasizes that in order to create a stable foam from egg whites there must be a balance between protein, air and water. This stability is the result of interactions on the part of the *side chains* of the amino acids that make up the egg white protein. Based on the nature of these side chains, some amino acids are attracted to water and some are not. That is, some are hydrophilic (attracted to water) and some are hydrophobic (not attracted to water). The proteins act like a surfactant, creating an interface between the water in the protein and the air bubbles that have been incorporated into the egg white. Hydrophilic amino acids have side chains that are either charged or polar, which means that they easily interact with the polar water molecule. The side chains in hydrophobic amino acid side chains are non-polar and neutral and do not interact with water, but do interact with air. The protein also serves as a framework that encapsulates the air bubbles.

Now, most protein molecules in their normal configuration have a hydrophobic core and a polar hydrophilic surface in contact with the environment. While hydrophobic amino acid residues make up the core, polar and charged amino acids cover the surface of the folded molecule. When the egg white is whipped to create foam, the whipping process causes the protein molecules to unfold (the process is called denaturing) exposing the hydrophobic parts of the molecule as well as the hydrophilic parts. The whipping process also causes the molecules to collide at a faster rate and the result is that intermolecular bonds that give the molecule its folded shape are broken. The hydrophilic sections of the protein are attracted to water and the hydrophobic sections, especially in the protein ovomucin, are attracted to the air bubbles created by the whipping process. New bonds are formed between protein molecules, especially the protein ovalbumin which coagulates during the baking process to stabilize the foam to create the light and airy angel food which may have a volume six to eight times that of the original liquid albumin.

However, as the article notes, these side chain bonds are relatively weak and any disruptions may cause the protein framework to collapse. What are the bonds that hold the foam in place? Some bonds are, in fact, ionic in nature. The charged amino acid side chains do form ionic bonds, which in this context are called salt bridges. All of the polar side chains form hydrogen bonds with water. The non-polar side chains interact with each other and the air bubbles via van der Waals forces. And in the side chains that contain sulfur the sulfur-sulfur bonding creates covalent sulfur bridges, mentioned earlier. The polar side chains form hydrogen bonds with the water present in the foam as well. See below for more on these bonds.

In the case of these side chains in amino acids (and, therefore, proteins) polarity is a critical factor. Determining polarity in organic compounds like proteins is a little more complex than doing so in inorganic compounds, but the same basic rules apply. This will be a good opportunity to either preview or review molecular polarity basics with students. Essentially you should remind students about comparing the electronegativity of individual atoms, about finding the degree of polarity of individual bonds and about polarity of groups of atoms, either whole molecules or parts of molecules in the case of amino acid side chains. You can consult your textbook for background here.

The proteins that make up albumin include the following with the percent and a very brief description of each:

Ovalbumin - 54%

Its biological role is uncertain but it is thought to be a storage protein, supplying amino acids and metal ions to biological processes. Made up of 385 individual amino acids

Ovotransferrin (also known as conalbumin) - 12%

It is a heat shock protein that is supplied to the skin to provide protection against cold stress. It also acts as an antimicrobial agent and has role in cell maturation by transporting essential nutrients to developing embryos. Made up of 700 amino acids.

Ovomucoid - 11%

It is a trypsin inhibitor, which means it blocks digestive enzymes. It is a glycoprotein comprising 186 amino acids. Ovomucoid has antibacterial activity resulting from its ability to inhibit bacterial enzymes involved in microbial growth.

Ovoglobulin G2 - 4%

This protein is important for the foaming property of egg whites that is described in the article.

Ovoglobulin G3 - 4%

Same as Ovoglobulin G2

Ovomucin - 3.5%

This protein has a soluble component and an insoluble component. The gel-like insoluble component makes up a large portion of egg white. It supports the density and general makeup of egg white.

Lysozyme - 3.4%

It acts as an anti-bacterial agent. It is made up of 129 amino acid units.

Ovoinhibitor - 1.5%

Like ovomucoid, this protein is a trypsin inhibitor.

Ovoglycoprotein - 1%

Its function in egg white is still unclear. It is an acidic glycoprotein.

Flavoprotein - 0.8%

It binds the vitamin B that is stored in egg whites.

The other minor proteins in egg white include ovomacroglobulin, avidin and cystatin.

To summarize, the foam that produces a good angel food cake is the result of air bubbles being introduced into the egg white, proteins partially unfolding and trapping the air bubbles within the water phase and intermolecular bonds holding the unfolded protein in place.

**More on** **intermolecular forces in proteins**

The material below has been adapted from the April 2005 Teacher’s Guide for the ChemMatters article, “The Amazing Drinking Bird.”

There are three types of intermolecular forces. They are (in order of increasing strength) London dispersion forces, dipole-dipole interactions, and hydrogen bonds. The relative energies of intermolecular forces are much less than covalent or ionic bonding energies. The following chart gives an approximation of the relative strengths in kJ/mol:

Covalent bonds 100–1000

Hydrogen bonds 10–40

Dipole-dipole 0.1–10

London forces 0.1–10

While covalent bond energies range from 150 to 800 kJ/mol, the energy required to overcome intermolecular attractions is usually less than 40 kJ/mol. For example, it takes 464 kJ/mol to break the H–O bonds *within* a water molecule and only 41 kJ/mol to break the bonds *between* water molecules.

London dispersion forces (one of the three forces that are, in aggregate, known as van der Waals forces) arise from instantaneous charges that arise in non-polar molecules involving atoms with larger numbers of electrons. Dipole-dipole interactions (the second type of van der Waals forces) are electrostatic forces created by the partial positive and negative charges within neighboring molecules that exhibit some degree of polarity.

Hydrogen bonds are the best known of the three and are the attractions between a polar covalently bonded hydrogen atom in one molecule and an electronegative atom with one (or more) nonbonding pair(s) of valence electrons in a neighboring molecule. Hydrogen bonding occurs most often in covalently bonded molecules involving nitrogen, oxygen, fluorine and chlorine. In proteins this occurs often between two alcohols, an alcohol and an acid, two acids, or an alcohol and an amine or amide.

**More on** **copper bowls and egg whites**

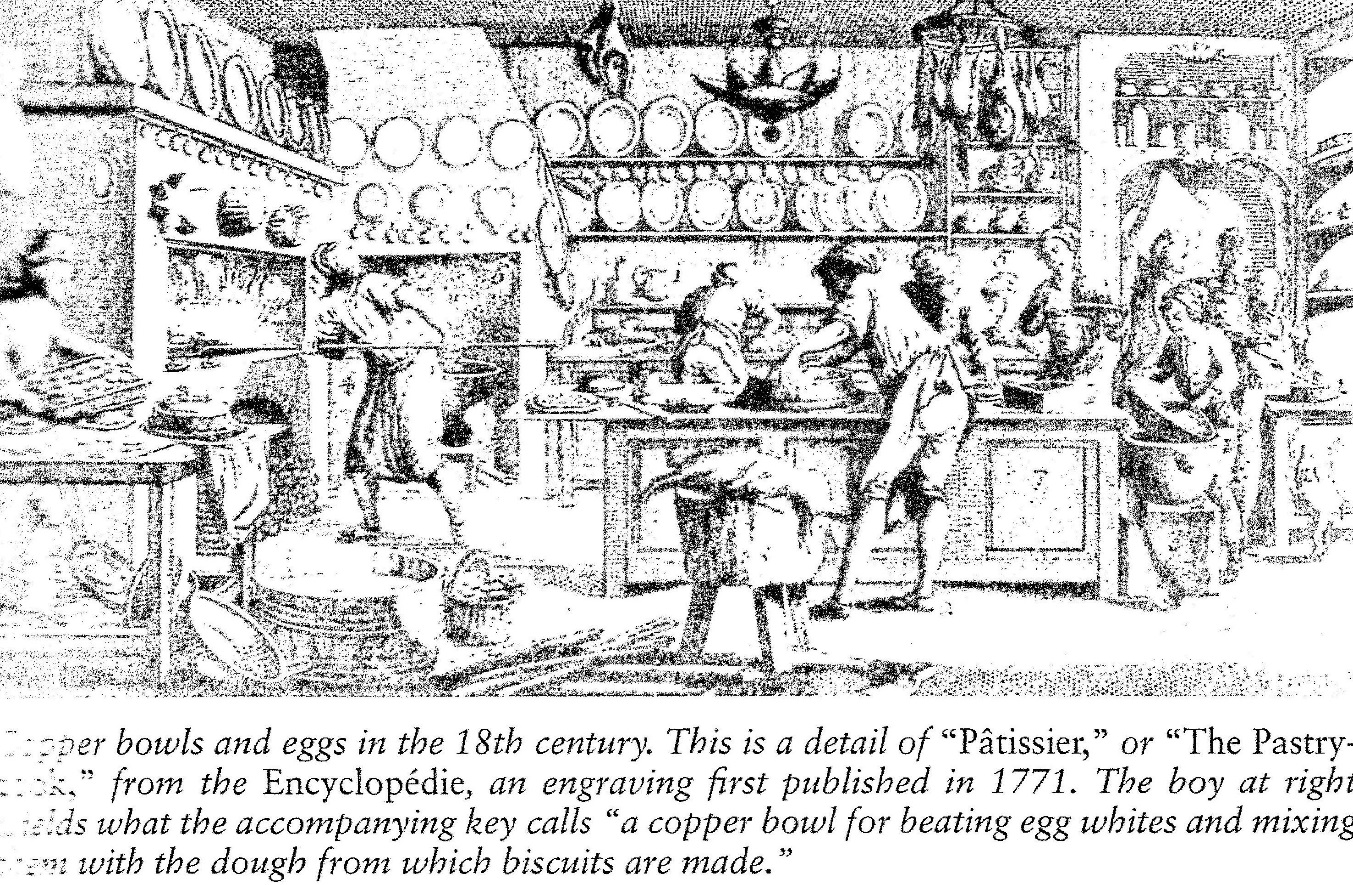
The article issues a caution about the fragility of egg white foam and suggests several remedies. The oft-cited remedy is the use of a copper bowl in which to whip the egg whites. The article cites research into why copper increases the stability of stiff egg white foam. It suggests that in the whipping process copper ions are released from the bowl, perhaps due to the acidic nature of some amino acid side chains in proteins, and these ions form ligands with conalbumin (ovotransferrin) protein in egg whites. The complex stabilizes the foam. The reaction is similar to the reaction in the biuret test for protein.

In addition, copper also reacts with sulfur in proteins. The logic here is that egg white proteins contain the amino acid cysteine, which contains a sulfur-hydrogen combination in its side chain (this sulfur when combined with hydrogen is the cause of the “rotten egg” smell when eggs go bad). The sulfur-hydrogen bond is an active site in the molecule and the hydrogen is easily lost. If one cysteine molecule loses a hydrogen and a second molecule does also, the two sulfur atoms can form a disulfide bond, as illustrated in the article. The net effect of this is that protein molecules link together excessively, making the foam grainy and sticky. However, when copper reacts with sulfur in protein it prevents the formation of sulfide bridges and limits the protein coagulation.

In his book *On Food and Cooking: The Science and Lore of the Kitchen*, Harold McGee says this about copper bowls and egg whites:

Long before anyone knew about egg proteins or their chemical bonds, cooks had come up with a way of controlling them. The French tradition has long specified the use of copper utensils for making egg foams. One early trace of this tradition is a 1771 illustration in the French *Encyclopédie* that shows a boy in a pastry kitchen working with a straw wisk [sic] and what the accompanying key identified as “a copper bowl for beating egg whites.” pp. 102-103

See illustration below, which was scanned from McGee’s book.



The more modern approach to stabilizing foam is to add an acidifying agent like cream of tartar, potassium bitartrate ([K](http://en.wikipedia.org/wiki/Potassium)[C4](http://en.wikipedia.org/wiki/Carbon)H5[O6](http://en.wikipedia.org/wiki/Oxygen)). Adding an acid—more specifically adding hydrogen ions to the mixture prevents cysteine from losing its own hydrogen ions and stabilizes the foam.

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Biochemistry—**Topics like proteins require that we look at the chemistry of a biological system like a chicken egg. Much of the study of biology today is actually biochemistry.
2. **Organic chemistry—**Most of the substances described in the article are organic compounds. Students need to understand organic nomenclature, organic structures, organic reactions, etc. in order to fully understand the content of this article.
3. **Polymers—**The article provides an opportunity for you to delve into polymers since proteins are natural polymers.
4. **Intermolecular forces**—Much of the protein structure depends on intermolecular forces, and this is a good chance to show why and how these forces are so important in explaining many of the changes we observe in chemistry.
5. **Bonding**—Bonding is not emphasized in the article, but in explaining amino acid and protein chemistry you can review covalent bonding as well as ionic bonding (to a limited extent).
6. **Acid/bases**—Acid theory, pH and the nature of organic acids are an integral part of this article.
7. **Polarity—**You will need to review polarity and polar molecules in order for your students to understand why the hydrophilic and hydrophobic nature of proteins is so important in this article.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“All polymers are man-made.”** *While many people may believe that because of all the publicity and the impact than modern plastics have had on our lives, there are important natural polymer as well. Examples of synthetic polymers include nylon, polyester, polyethylene and Teflon. Natural polymers include proteins, wool, silk, DNA and cellulose.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“The article says that proteins are ‘chains of molecules called amino acids.’ Does that mean that proteins are polymers?”** *Yes, proteins are very large natural polymers made up of amino acid monomers linked by peptide bonds.*
2. **“Is protein folding and unfolding a chemical change?”** *The folding/unfolding process is a physical change in form only. The protein molecule remains unchanged chemically.*
3. **“The article talks about hydrophilic amino acids that are attracted to water. Where does the water come from? Is it added to the egg whites as part of the recipe?”** *No, there is no need to add water to egg whites. Egg whites are 90% water to begin with.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. You can have students study eggs and osmosis using the procedure found here. (<http://everydaylife.globalpost.com/egg-osmosis-experiments-distilled-water-salt-water-32546.html>)
2. Students can observe the reaction of an egg shell with vinegar in this lab activity: <http://www.exploratorium.edu/cooking/eggs/activity-naked.html>.
3. Students can do a back titration to determine the mass of calcium carbonate in an egg shell. (<http://www.thinkib.net/chemistry/page/3117/caco3-in-egg-shells>)
4. Students learn to do tests for proteins in this lab activity and use their knowledge to solve a mystery. (<http://www.lessonplansinc.com/science.php?/biology/detail/macromolecule_mystery_lab>)
5. Students use the amino acid sequence for the protein villin in this activity: <http://web.stanford.edu/group/cpima/education/highschool.htm>.
6. This site has a series of activities including one on egg white foam: <http://www.uen.org/Lessonplan/preview.cgi?LPid=1178>.
7. Students can perform the test for proteins using this procedure: <http://www.ruf.rice.edu/~bioslabs/methods/protein/biuret.html>, or this one: <http://www.cfep.uci.edu/cspi/docs/lessons_secondary/You%20Are%20What%20You%20Eat.pdf>.
8. This activity enables students to model the structure of proteins, including tertiary structure. (<http://www.scienceteacherprogram.org/biology/SGallagher10.html>)
9. This activity allows students to create models of proteins that illustrate varying functions that proteins serve in the body. The activity also has an unusual inter-personal component. (<http://www.scienceteacherprogram.org/pdf/GiftOfProtein.pdf>)
10. By doing this very detailed lab simulation of protein structure, students will learn the factors that cause proteins to fold. (<http://www.scienceteacherprogram.org/biology/Granberry05.html>)
11. Students can do this series of lab activities to learn more about intermolecular forces”: <http://www.physics.purdue.edu/psas/docs/Intermolecular%20Forces%20Lesson%20Plan.pdf>.
12. You might try to replicate the research that discovered that copper bowls helped to stabilize egg white foam. Students can design one or more experiments using bowls made of different materials and actually try to create the best foam.

## Out-of-class Activities and Projects (student research, class projects)

1. You can assign individual students or teams of students to do research on one of the amino acids and include requirements like formula, structure, description, occurrence, uses, etc. If students construct 3D models using a uniform system for all students, students can bring their models to class and you can have students group the structures in varying ways.
2. Assign students to bring in recipes that include significant sources of proteins or protein foams. Although food in the laboratory is not a good idea, you might encourage students to bring in treats like angel food cake or meringue cookies after reading the article. A class can prepare a book of recipes to be distributed within the class or to parents.

## References (non-Web-based information sources)

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Scroll to the bottom of the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**



**30 Years of *ChemMatters***

Available Now!

Grosser, A. Egg Cookery, *ChemMatters* **1984**, *2* (4), pp 4–8. In a very simplistic way the author of this article describes the chemical structure of a chicken egg and the effect of various methods of cooking on the egg.

Baxter, R. Permanent Waves, *ChemMatters* **1993**, *11* (2), pp 8–11. Although this article is about waving hair, the chemistry of protein is featured, including the interaction of protein with water.

Vos, S. Linus Pauling: American Hero, *ChemMatters* **2007**, *25* (3), pp 7–10. Linus Pauling is credited with seminal work on the structure of proteins and so this article includes a large section on his contributions to the weak bonds—like hydrogen bonds—that give proteins their shape.

Nolte, B. Hold the Meat! Meat-free Food Takes a Seat at the Table, *ChemMatters* **2011** *29* (4), pp 9–11. This article contains an introductory section on amino acids and protein structures that may help students better understand proteins.

Hill, M. Attack of the Gluten, *ChemMatters* **2012** *30* (1), pp 9–11. Included in this article is a section on the proteins gliadin and glutenin, the proteins making up gluten. These proteins give baked products like bread their structure in a way that is similar to the proteins in egg whites that are beaten.

## Web Sites for Additional Information (Web-based information sources)

**More sites on** **eggs**

The trade association The American Egg Board supplies a lot of information about eggs. (<http://www.aeb.org/>)

This Exploratorium activity details the anatomy of a chicken egg: <https://www.exploratorium.edu/cooking/eggs/eggcomposition.html>.

National Pasteurized Eggs sponsors this site which includes a short basic course on egg chemistry: <http://www.safeeggs.com/foodservice/resources/free-ce/protein-nutrition-egg-chemistry>.

**More sites on amino acids**

The reliable *Chemguide* from the U.K. summarizes the properties of amino acids and links the page to another page on proteins. (<http://www.chemguide.co.uk/organicprops/aminoacids/background.html>)

If you want to read details about amino acids and their structures, try “The Biology Project” at the University of Arizona. Be sure to check the links on the left. (<http://www.biology.arizona.edu/biochemistry/problem_sets/aa/aa.html>)

Michigan State University’s department of chemistry gives amino acid structures and a brief background summary. (<https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/proteins.htm>)

Have a look at the amino acid pages in the *Virtual Chembook* from Elmhurst College. See the links at the top of the page. (<http://www.elmhurst.edu/~chm/vchembook/560aminoacids.html>)

The *Hyperphyics Textbook* at Georgia State University has a section on amino acids with a nice visual of peptide bonding. (<http://hyperphysics.phy-astr.gsu.edu/hbase/organic/amino.html>)

This page from New York University has multiple representations of all amino acid structures: <http://www.nyu.edu/pages/mathmol/library/life/life1.html>.

Purdue University’s amino acid page includes information on the synthesis of proteins and a section on acid/base amino acid chemistry. (<http://chemed.chem.purdue.edu/genchem/topicreview/bp/1biochem/amino2.html>)

**More sites on proteins**

This site from Lund University in Sweden has eight pages of details about proteins. **(**<http://www.proteinstructures.com/Structure/Structure/amino-acids.html>)

The Concord Consortium site highlights the hydrophobic/hydrophilic nature of proteins: <http://staff.concord.org/~btinker/workbench_web/unitV/mol_water_bg.html>. This site is rich in resources. Bookmark it.

Here’s the *Chemguide page* on proteins. It offers good explanations of secondary and tertiary structures. (<http://www.chemguide.co.uk/organicprops/aminoacids/proteinstruct.html>)

The U.K.’s Royal Society of Chemistry has a nice overview of protein chemistry: <http://www.rsc.org/Education/Teachers/Resources/cfb/proteins.htm>.

BiodotEdu from CUNY Brooklyn has good visuals as part of a complete but simple review of proteins. (<http://www.brooklyn.cuny.edu/bc/ahp/LAD/C4b/C4b_proteinShape.html>)

**More sites on** **egg white foam**

San Francisco’s Exploratorium has a section on cooking and it includes a page on eggs. Be sure to click on “Why do egg whites foam?” (<http://www.exploratorium.edu/cooking/eggs/recipe-pavlova.html>)

This site, related to the food industry, gives a very nice explanation of the factors involved in preparing egg white foam: <http://www.preparedfoods.com/articles/112210-creating-egg-white-foams>.

The American Egg Board gives its take on preparing egg white foam here: <http://www.aeb.org/food-manufacturers/functional-properties/39-functional-properties/207-aeration-foaming-structure>.

**More sites on** **intermolecular forces**

Another page from Purdue University, this one contains information on the unique characteristics of each intermolecular force: <http://chemed.chem.purdue.edu/genchem/topicreview/bp/intermol/intermol.html>.

This page from Penn State reviews intermolecular forces: <http://chemistry.bd.psu.edu/jircitano/IMforces.html>.

UC Davis provides an interesting look at intermolecular forces with good visuals. (<http://chemwiki.ucdavis.edu/Physical_Chemistry/Physical_Properties_of_Matter/Atomic_and_Molecular_Properties/Intermolecular_Forces>)

# Fermentable Foods: Trouble in Your Diet

## Background Information (teacher information)

**More on** **the basics of FODMAPs**

The issue of people having digestive tract disorders that need be analyzed in terms of cause often fall into two main categories—celiac disease (the autoimmune condition with sensitivity to gluten) and the complex issue of irritable bowel syndrome (IBS) that could have multiple causes under that umbrella of FODMAPs. The *ChemMatters* article makes clear the fact that there is somewhat reliable testing that can be done to determine if a person is suffering from celiac disease. But when it comes to determining what specific irritants in FODMAPs might be causing an irritable bowel, the sorting out of possible culprits becomes more difficult.

In our society these days, there are many people who are into gluten-free diets even though they do not have celiac disease. It is all the rage. The number of people who have celiac disease is less than 1% of the population. But recent research has shown that some people with irritable bowel syndrome are sensitive to gluten even though this is not celiac disease sensitivity. Some people would like to label this condition wheat intolerance rather than non-celiac gluten sensitivity. At the same time, it may not really be the gluten in the wheat, but rather one specific sugar category—the fructans.

The other issue about people feeling better when they cut out gluten may be the victims of the *nocebo* effect, which means that when they believe something is making them sick, it causes the sickness to happen! There are also recent studies that suggest again that the mental influences the physical. In a recent study published in the journal *Gastroenterology*, people with self-diagnosed gluten sensitivity actually didn’t feel any better when they were put unknowingly on diets without gluten. But scanning many documents related to non-celiac gluten sensitivity reveals many people giving testimony to their eliminating a variety of non- digestive tract symptoms when they have avoided wheat in their diet. Some of the symptoms were associated with various neurological problems. There is one scientific paper (government) that seems to support this particular type of reaction. But there are also many anecdotal responses by people to what they think is a reaction to eating wheat, hence gluten. But again, there is more to wheat than gluten. Things seem to revert back to the complicated situation with FODMAPs, where any one food product can contain a plethora of chemicals that an individual might be allergic to in a non-celiac way.

One interesting concern that has been expressed about non-celiac individuals going on a “gluten-free” diet is that they are missing some necessary dietary requirements including folic acid, some B vitamins, as well as adequate amounts of fiber, calcium, iron and vitamin D. However, if a person is aware of these deficiencies, he or she can provide another source of these particular nutrients. Folic acid is found in leafy green vegetables. Broccoli and dried fruit are good sources of iron. B-12 is found in meat and dairy products. Nutritional yeast is also a good source of vitamin B-12 as well as some other B vitamins. But there is much evidence to suggest that a person who wants to be gluten free by eliminating wheat products would be better served by taking on the task of evaluating foods and their possible source of the FODMAPs which many authorities believe to be the source of irritable bowel syndrome (IBS). However, trying to determine which if any of the FODMAPs is causing IBS is best done through a dietician’s help—not necessarily a convenient thing to be doing. There are sources of information about diets that eliminate FODMAPs.

**More on** **FODMAPs diets**

Various academic groups are involved in experimenting with a variety of diets that control or eliminate various FODMAP’s. One dietary program that was developed in 2005 by researchers at Monash University in Australia is an intensive treatment and should be supervised by a registered dietician. The program takes a person between two and six weeks to eliminate and reintroduce foods, in order to identify what foods contain digestive triggers for setting off a person’s reaction to a particular sugar. The first step is to eliminate foods that are high in FODMAPs such as wheat, rye, onions and legumes. Then there is lactose which is found in soft cheese, yogurt and milk. Fructose is found in high-fructose corn syrup, honey and certain fruits like apples and pears. Sorbitol, found in artificial sweeteners is another FODMAP sugar to be evaluated. Fiber is also limited as it can create digestive troubles. The next step is to re-introduce these foods one at a time to see what sets off gastrointestinal turmoil.

While going through this process, it is important that a person meet other dietary nutrients that are listed as “nutrients of concern” mentioned in the previous paragraph above. They include fiber, as mentioned previously, potassium (4700 mg from food), calcium (1000 to 1300 mg), iron, vitamin B-12, and vitamin D. A person working through the FODMAPs evaluation needs to provide these supplements through other non-FODMAP sources. An all-inclusive vitamin supplement would do the trick, except for fiber.

Here’s a sample daily menu, provided by FODMAP expert Kate Scarlata:

**Breakfast**

High-Fiber Breakfast Porridge

1/9 cup old-fashioned oatmeal

4 teaspoons red quinoa

4 teaspoons oat bran

½ cup lactose-free milk

½ cup water

1/3 tablespoon chia seeds

1/3 tablespoon chopped walnuts

Dash of cinnamon

Dash of maple syrup

1/6 cup chopped strawberries

**Lunch**

Bibb Lettuce, Feta and Pecans with Dijon Dressing

¼ head Bibb lettuce

1/8 cup Feta cheese, crumbled

¼ tablespoon red wine vinegar

¼ teaspoons Dijon mustard

¼ chopped tomato

¾ tablespoon olive oil

Dash of sea salt

Dash of pepper

½ teaspoon fresh chives, chopped

1/8 cup pecans, toasted

Blueberry Kiwifruit Smoothie

¼ cup frozen blueberries

1 small kiwifruit, peeled

1/3 cup lactose-free vanilla yogurt

Ice as desired

**Dinner**

Maple Dijon Pork and Pineapple Kabobs

3 teaspoons maple syrup

3 teaspoons Dijon mustard

1/4 pound pork tenderloin

1/2 red pepper

1/8 fresh pineapple

1/4 zucchini

Baby Kale Salad with Simple Mustardy Dressing Dash sea salt

½ tablespoon red wine vinegar

1 teaspoon fresh chives, chopped

1 teaspoon Dijon mustard - best quality like Maille

1 ½ tablespoons olive oil

1 medium-size potato

Dessert

Frozen Banana Pop

1 peeled banana

1/8 cup nonfat vanilla Greek yogurt

1/8 cup finely chopped unsalted peanuts

1/2 tablespoon mini semi-sweet chocolate chips

(<http://health.usnews.com/best-diet/low-fodmap-diet/menu>)

**Nutrition**

Here’s a breakdown of the nutritional content of a typical day on a low FODMAP diet, alongside recommendations from the U.S. Government’s “2010 Dietary Guidelines for Americans”. Diet figures were calculated by *U.S. News and World Report*, using ESHA Food Processor software.

| **Low FODMAP Diet** | | **Recommended** | |
| --- | --- | --- | --- |
| Calories | 1,417 | Women | Men |
| 21-25: 2,000 26-50: 1,800 51+: 1,600 | 21-40: 2,400 41-60: 2,200 61+: 2,000 |
| Total Fat | 44% | 20%-35% | |
| Saturated | 8% | Less than 10% | |
| Trans | 0% | N/A | |
| Total Carbohydrates | 46% | 45%-65% | |
| Sugars (total except as noted) | 18% | N/A | |
| Fiber | 24 g. | Women | Men |
| 19-30: 28 g. 31-50: 25 g. 51+: 22 g. | 19-30: 34 g. 31-50: 31 g. 51+: 28 g. |
| Protein | 15% | 10%-35% | |
| Sodium | 1,693 mg. | Under 2,300 mg., under 1,500 mg. for 51+ | |
| Potassium | 3,456 mg. | At least 4,700 mg. | |
| Calcium | 607.5 mg. | 19-50: 1,000 mg. 51+: 1,200 mg. | |
| Vitamin B-12 | 1.5 mcg. | 2.4 mcg. | |
| Vitamin D | 1.5 mcg. | 15 mcg. | |

Recommendations apply to adults 19 and older except as noted. Recommended calories assume a sedentary lifestyle. g.: grams. mg.: milligrams. mcg.: micrograms. Because of rounding, protein, fat and carbohydrate content may not add up to 100 percent.

(<http://health.usnews.com/best-diet/low-fodmap-diet/menu>)

Monash University maintains a Web site ([www.med.monash.edu/cxes/gastro/fodmap/](http://www.med.monash.edu/cxes/gastro/fodmap/)) dealing with the Low FODMAP diet for Irritable Bowel Syndrome. Available from this Web site are a number of resources and products, including smart phone apps, a blog, and frequently asked questions (FAQ).

Refer to the following Web sites for more recipes from Kate Scarlata, author of *The Complete Idiot’s Guide to Eating Well with IBS*. (<http://blog.katescarlata.com/fodmaps/> and <http://blog.katescarlata.com/low-fodmap-recipes/>)

**More on** **digestion in the gut—enzymes and bacteria**

The basic problem created by FODMAPs in the digestive system is incomplete break-down of the various sugars of FODMAPs, in order to be absorbed into the blood stream from the small and large intestine. This is due primarily because of inadequate enzyme production and utilization. Some of this is genetic, as in the case of lactose intolerance. So with inadequate absorption comes the bacterial fermentation of the sugar residues in the gut. The bacterial flora is an important and necessary component of the gut. For some people with certain infections that do not respond to antibiotics, the use of fecal bacteria has proved very effective. One particular infection from *Clostridium difficile* has a 90% cure rate when treated with fecal bacteria! The thought is not pleasant but the results are welcomed! The treatment is known as “fecal microbiota transplantation” (FMT).

Bacterial fermentation in the gut is a basic and necessary process of digestion—it is a positive rather than a negative. By means of fermentation, gastrointestinal microbes break down nutrients that cannot be hydrolyzed by mammalian enzymes. Certain bacteria break down complex carbohydrates to meet as much as 5-10% of our daily energy requirements. Without that particular fermentation, a substantial amount of energy would be lost in feces. There is also fermentation that yields short-chain fatty acids (acetic, propionic, and butyric acids) from protein; these are important because they facilitate the uptake of water and electrolytes, reducing the osmotic effect of unabsorbed carbohydrate molecules, which otherwise would produce the diarrhea associated with FODMAPs.

Some studies have shown that the ingestion of fructo-oligosaccharides increase the fecal counts of endogenous bifidobacteria by a factor of 10. You may be familiar with the term “probiotics”, particularly associated with yogurt. Yogurt contains some of these bifidobacteria, including *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. This large class of bacteria (the “bifido” refers to their Y-shape) is considered very beneficial to the health of the gut, though the specifics of their multiple functions are lacking in many instances—it is more deduction by what happens if the flora are absent!

Some Bifidobacterium strains are considered as important probiotics and used in the food industry. Different species and/or strains of bifidobacteria may exert a range of beneficial health effects, including the regulation of intestinal microbial homeostasis, the inhibition of pathogens and harmful bacteria that colonize and/or infect the gut mucosa, the modulation of local and systemic immune responses, the repression of procarcinogenic enzymatic activities within the microbiota, the production of vitamins, and the bioconversion of a number of dietary compounds into bioactive molecules.

(<http://en.wikipedia.org/wiki/Bifidobacterium>)

**More on the sugars of FODMAP**

The different categories of sugars found in FODMAP that may create problems for people whose digestive systems cannot adequately process them have some interesting properties.

**Oligosaccharides: (includes disaccharides and polysaccharides)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Oligo-saccharide** | **Description** | **Component mono-saccharides** | **Glycosidic linkage** |
| Sucrose | Common table sugar | Glucose and fructose | Glucose-1α-2-fructose |
| Maltose | Product of starch hydrolysis | Two glucose units | glucose-1α-4-glucose |
| Trehalose | Found in fungi | Two glucose units | glucose-1α-1-glucose |
| Lactose | Main sugar in milk | Galactose and glucose | galactose-1β-4-glucose |
| Meibiose | Found in legumes | Galactose and glucose | galactose-1α-6-glucose |
| Cellibiose | Building block of cellulose | Two glucose units | glucose-1β-4-glucose |
| Laltotriose | Produced by alpha amylase (common enzyme in human saliva) on amylose in starch | Three glucose units | α-1,4-glycosidic bonds |
| Raffinose | Found in beans and vegetables like cabbage, Brussels sprouts, broccoli, asparagus | Glucose, galactose and fructose | 1α-6-glycosidic linkage |
| Melibiose | Produced by hydrolysis of raffinose | Galactose and glucose residue | β(1,6) glycosidic bond |
| Maltotriose | Can be fermented by both algae and lager yeast | Three glucose units | α(1,4) glycosidic linkage |
| Maltotetralose | Cannot be fermented by algae or lager yeast | Four glucose units | α(1,4) glycosidic linkage |
| Malto-pentalose | Cannot be fermented by algae or larger yeast | Five glucose units | α(1,4) glycosidic linkage |

(<http://chemistry.tutorvista.com/organic-chemistry/oligosaccharides.html>)

Oligosaccharides are commonly found on the plasma membrane of animal cells and play a role in cell-cell recognition. Among other processes where recognition is important is in mammalian fertilization where the egg membrane verifies the “legitimacy” of a sperm cell (i.e., that it is of the same species).

Stachyose, a galactose-oligosaccharide, contains three different sugars (2 galactose molecules, one glucose and one fructose molecule). It is an active supporter of bacterial growth in the gut. Because this sugar is not readily absorbed in the large intestine and remains in the lumen, certain bacteria in the gut digest this sugar for its nutrients. In turn, the bacteria are able to multiply, keeping a good colony of these microbes active in the digestion process. These particular bacteria that flourish with stachyose have also been found to destroy two types of harmful bacteria—those that cause bacterial pneumonia, and a species that produces vaginal infections. The mechanism of their action on these harmful bacteria is not known.

Fructans, although listed as a potential FODMAP sugar that can cause problems in the gut of some people, is actually a dietary constituent in food that has been shown to have a number of protective properties in the body. A series of studies demonstrate that inulin-type fructans (plant dietary fiber that stores carbohydrates) modulate the secretion of gastrointestinal peptides involved in appetite regulation as well as lipid metabolism. Moreover, a large number of animal studies and preliminary human data show that inulin-type fructans reduce the risk of colon carcinogenesis and improve the management of inflammatory bowel diseases.

Another fructan, oligofructose, works in conjunction with the inulin-type fructan as a dietary fiber, affecting gut microflora by increasing health-promoting bacteria and reducing potentially harmful species. This is called a pre-biotic function (This term, along with probiotic, is bandied about when people are promoting healthy diets.) This oligofructose and inulin combination also induces changes in the colon’s epithelium that are constructive, rather than destructive as occurred in celiac disease and prolonged conditions of IBS from fermentation of FODMAPs.

**Polyols:**

The sugar alcohols include sorbitol, mannitol, and xylitol. Mannitol is a sugar which, when ingested, does not raise blood glucose levels as much as sucrose. Therefore it is a preferred sugar for diabetics to use. Mannitol is one of the most abundant energy- and carbon-storage molecules in nature, produced by a plethora of organisms, including bacteria, yeasts, fungi, algae, lichens, and many plants. Another unique application of mannitol is to reduce acutely-raised intracranial pressure (e.g., brain trauma), until other procedures can be applied.

Xylitol is made either from corn cobs or tree bark! The preferred source is corn cobs since they are a discard from corn harvest. If taken from trees, it means the end of the tree—

not an environmentally friendly process! The corn cob source uses a natural ion-exchange interaction of hydrogen, hydrochloric acid, and steam. The waste water from this process is used for mushroom farming adjacent to the factory itself, and the pulp is used for fuel. Xylitol has a third of the calories of sucrose which makes it a good sugar for diabetics. Interestingly enough, xylitol is toxic to dogs, should they come across some candy containing xylitol.

Sorbitol intolerance is very much genetically-based. Some statistics that relate to this principle are the following:

**Frequency in population:**

* More than 50% of adults experience significant symptoms following ingestion of more than 10 g.
* Intolerance appears more common in Asians and American blacks than in whites.
* Overall, 30 to 75% of adults malabsorbed 10g of sorbitol.
* Present in up to 70% of patients with Irritable Bowel Syndrome

(<http://www.foodintolerances.org/food-intolerances-sorbitol.aspx>)

**More on lactose intolerance**

Lactose intolerance comes in varying degrees of severity—it isn’t all or nothing. The lactase enzyme is produced in the cells of the epithelium that line the small intestine and is secreted into the lumen of the intestine. Here it catalyzes the breakdown of the lactose disaccharide into its two component sugars, glucose and galactose. Reduced enzyme production means the undigested lactose sugars are not absorbed and become fodder for bacterial fermentation with all the problems associated with irritable bowel syndrome (IBS).

Three reasons people may develop lactose intolerance are:

* The normal result of aging, which seems to occur universally! There is the thought that if you reduce or cease your intake of milk-derived products, which may be part of getting older, that your lactase production decreases. It lacks stimulus. This also suggests that you can stimulate the production of lactase by regularly using milk and milk products, gradually increasing the amount consumed so as not to set off IBS too soon.
* Result of disease or injury (secondary lactose intolerance). Such disease conditions include celiac disease, gastroenteritis, and inflammatory bowel disease such as Crohn’s disease. Surgery to the bowel can temporary interfere with lactase production.
* Congenital lactose intolerance—you are born with the condition.

Here are the factors that can make you or your child more prone to lactose intolerance, according to the Mayo Clinic**:**

* **Increasing age**. Lactose intolerance becomes more common as you age — the condition is uncommon in babies and young children.
* **Ethnicity**. Lactose intolerance is most common in black, Asian, Hispanic and American Indian people.
* **Premature birth**. Infants born prematurely may have reduced levels of lactase because this enzyme increases in the fetus late in the third trimester.
* **Diseases affecting the small intestine.** Small intestine problems that can cause lactose intolerance include bacterial overgrowth, celiac disease and Crohn's disease.
* **Certain cancer treatments.** If you have received radiation therapy for cancer in your abdomen or have intestinal complications from chemotherapy, you have an increased risk of lactose intolerance.

(<http://www.mayoclinic.org/diseases-conditions/lactose-intolerance/basics/risk-factors/con-20027906> )

The condition of lactose intolerance can be determined by several different test procedures:

* Lactose tolerance test involves drinking a liquid with high levels of lactose. Two hours after drinking the liquid, a blood sample is analyzed for the amount of glucose. Low amounts of glucose means the body is not properly digesting and absorbing the lactose-laden drink.
* Hydrogen breath test measures how much hydrogen is given off in your breath from the digestion process. Normally very little hydrogen is detectable. If lactose is not being digested, then it is fermented in the colon which produces both hydrogen and methane gases, both of which can be detected in the exhaled breath.
* Stool acidity test is done with infants and children if the other tests above cannot be done. Having been given a lactose drink, a child has a stool sample tested for lactic acid from the undigested lactose.

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic**—Almost all food is organic in the true sense of the word (not the popular term for food grown without pesticides) (i.e., it contains molecules with carbon in them). The sugars in FODMAPs are allorganic molecules.
2. **Carbohydrates**—It is the sugars in FODMAPS that are potential sources of energy for bacteria that create fermentation in the large intestine, producing the symptoms of irritable bowel syndrome (IBS).
3. **Enzymes**—These organic molecules are crucial to the chemical digestion of many FODMAP sugars, acting as catalysts.
4. **Alcohols**—Some of the FODMAPs are sugars with the molecular structure of an alcohol which means the presence of the –OH group(s).
5. **Proteins**—A category of large organic molecules, constructed from amino acids which produce a large variety of molecules.
6. **Osmosis**—This is a physical process in which water concentration is lower on one side of a cell membrane than the other side, producing a net movement of water toward the side of lower water concentration. Diarrhea in IBS is because the high concentration of undigested sugars in the gut means less water than in the cells that line the gut, resulting in a net movement of water into the gut, producing diarrhea.
7. **Rates of Reactions**—Rates of reactions in metabolism, in particular those associated with the breakdown of sugars, are dependent on enzymes.
8. **Fermentation**—This anaerobic process used by bacteria in the large intestine for producing biological energy is responsible for the bloating condition associated with IBS.
9. **Digestion**—Chemical digestion of food is the breakdown of carbohydrates, proteins, and lipids into smaller molecules that can pass through cell membranes and is often under enzymatic control.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“If you are lactose intolerant, you cannot drink milk or eat ice cream.”** *First, the condition of lactose intolerance varies in severity for different people. Some people do not suffer from the symptoms if they consume small amounts of a product containing lactose. Second, people can take pills with the lactase enzyme before eating ice cream or drinking whole milk. Otherwise, a person can purchase lactose-free milk and ice cream.*
2. **“If you develop diarrhea from eating food, simply take anti-diarrhea medicine.”** *You can take the medicine but it will not really treat the cause of the diarrhea. In fact, if the diarrhea is caused by bacteria or protozoans, it is better NOT to take the medicine but rather to allow the diarrheal condition to essentially flush the organism from the intestinal tract. This is also true for diarrhea caused by certain foods which need to be flushed by the diarrhea. Medical advice is to let the diarrhea run its course over a period of two or three days without taking any “medicine”. Eating certain foods (BRAT diet—bananas, rice, apples and toast) and keeping adequate hydration are important while suffering from diarrhea. If a person experiences a painful condition, or there is evidence of blood in the stool, or there is a fever, then medical evaluation is needed.*

For the teacher: *Some antidiarrheal medicine works on the nervous system in the intestinal area to slow down over-active neuronal responses that evacuate the gut lumen before enough water is absorbed and the residue is expelled. In the case where the diarrhea is associated with FODMAP problems, it is not so much a nerve issue but simply one of an excess amount of water in the gut (due to fermented sugars that draw in water by osmosis). The gut responds by evacuating the content volume, a watery product.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“If you start a low *FODMAP diet, do you have to be on that diet forever?*”** *Once you have identified the offending FODMAP sugars in specific food sources, you can then eat whatever is desired, avoiding those foods that you have determined to be a source of irritable bowel syndrome.*
2. **“Is a low FODMAP diet safe for vegetarians and vegans?”** *It is necessary that people who try a low FODMAP diet make sure they are getting enough protein in their diet, which can come from selected vegetables. Lacto-ovo vegetarians can meet their protein needs through eggs, hard cheeses, and lactose-free milk products. For those who do not eat eggs and dairy products, low-FODMAP nuts, seeds, milk substitutes and grains can provide some protein. Tofu, tempeh and seitan (non-celiacs only) are also allowed in all phases of the diet. Last, small amounts of well-rinsed canned lentils and chick peas have been shown to be low-FODMAP.*
3. **“How do you handle foods that do not show up on a low FODMAP diet list?”** *Keep in mind that FODMAPs are carbohydrates. Therefore, there are no FODMAPs in foods comprised of protein or fat. A person on the low-FODMAP diet can eat these foods freely. When in doubt about a food that does not show up on FODMAP food lists, one can make a guess based on the FODMAP content of similar foods.*
4. **“Is the low FODMAP diet too complicated for the average person?”** *It is recommended that people who want to succeed with a low FODMAP diet (determining what foods create a problem because of a particular FODMAP sugar), should really engage a trained nutritionist familiar with FODMAP diets and protocol.*
5. **“Are there non-food items that we consume that may contain FODMAPs?”** *In fact there are things such as medications, supplements and probiotics that may contain some of the FODMAPs. As they say, read the labels carefully or consult the medical literature or a pharmacist. Probiotics should be avoided until your elimination procedures indicate that a particular probiotic is not creating problems associated with FODMAPs!*
6. **“What fruit can I eat on a FODMAP elimination diet?”** *Fruit is the most limited group to deal with in an elimination diet.* *Fruits with more fructose than glucose are not allowed on the basic diet. Fruits with a large quantity of polyols are not allowed on the basic diet. Fruits containing fructans are not allowed on the basic diet. Fruits are allowed if the fructose and glucose in the fruit are balanced (less than .5 grams excess/100 grams of food), the total fructose per serving is not too high, and they are low in polyols and fructans.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. A lab activity that works with the amylase enzyme is found at <http://www.nuffieldfoundation.org/practical-biology/investigating-effect-ph-amylase-activity>. Though this activity deals only with the variable of pH, it does provide the prep instructions for making amylase solution (rather than having students use their saliva) and testing solutions.  
   For testing other variables including temperature effects and concentration of substrate, refer to this reference. (<http://www.odinity.com/effects-temperature-ph-enzyme-concentration-amylase/>) which includes graphed results, though students could do their own graphing. Refer to the previous Nuffield lab activity (#1) for preparing the amylase solution. A reference for an amylase experiment with good background information that could be used with either of the previous labs referred to above can be found at <http://intro.bio.umb.edu/OLLM/111F98/pdfs/Amylase.pdf>.
2. A basic lactase experiment using milk is found at <http://www.learnnc.org/lp/pages/3398>. A second lab activity that is very comprehensive is found at <http://www.towson.edu/cse/beop/mdll/Lab_Activities/looking_into_lactase_mdll_teacher_manual.pdf>. Although this lab refers to kits that are available to teachers in Maryland, the complete description of materials, their use, a schedule for conducting the activity and background material are easily obtained from the printout. There is a teacher’s guide as well.
3. This is a simulation of lactase activity with the ability to manipulate the variables (temperature, pH, substrate concentration) to show the effects on the rate of digestion through graphical analysis: <http://forio.com/simulate/jdarkow/lactase-enzyme-actions-with-data-analysis/run/>.
4. A comprehensive lab on fermentation with several fermentation activities resulting in different products is found at <http://www.accessexcellence.org/AE/AEC/AEF/1995/kolb_biotech.php>.
5. Another lab activity dealing with the fermentation of apple cider is found at <http://www.somersetmade.co.uk/oldscrump/makingcider.php>.  
   This is a fun page describing the principle stages of cider fermentation. Details are given on the following subjects: an overview of the cider making process, a discussion of the characteristics of the apple juice, the microbiology of the process, the changes in the composition of the cider during fermentation, and finally a description of how to make your own cider. A great classroom activity!
6. If your school has Vernier hardware and software, it can be used for a yeast fermentation lab exercise that investigates the rate of fermentation by yeast using different sugar substrates. This lab will determine the specificity of the enzymes in yeast for metabolizing different sugars. Refer to <http://www.vernier.com/files/sample_labs/BWV-12B-COMP-sugar_fermentation.pdf>.
7. An open lab version of this investigation into yeast fermentation is found at <http://www.vernier.com/files/sample_labs/BIO-I-10-sugar_metabolism_with_yeast.pdf>, which requires the students to do some of their own research into fermentation and devise lab procedures for investigating the process.
8. Another Vernier lab exercise deals with the action of lactase, determining the sugar product with glucose testing strips. A second part of the lab is to use yeast activity to produce CO2 from the enzyme action on several different sugars, including lactose, glucose, and galactose. Refer to two Web sites, one for the introduction to the lab activity and a second containing the lab activity details. It is recommended that you have the Vernier lab manual for experiments in both biology and chemistry, as well as the software to operate their LabPro and LabQuest data collector hardware. See <http://www.vernier.com/experiments/bwv/24a/lactase_action/> and <http://www.vernier.com/files/sample_labs/BWV-24A-COMP-lactase_action_CO2.pdf>.
9. Using a product called “Beano”, students can test the effectiveness of this gas eliminator which contains the enzyme alpha-galactosidase which breaks down the complex sugars found in gas-producing foods. For a description of the lab procedure, refer to the Web site <http://www.accessexcellence.org/AE/ATG/data/released/0167-JudyBrown/>. This lab is well written and contains background information. An information reference (Q & A’s) by the manufacturer of Beano is found at <http://www.beanogas.com/faqs/>.

## Out-of-class Activities and Projects (student research, class projects)

1. Students could research the chemistry (and microbiology) behind the process of converting milk into yogurt, then experiment with making yogurt. The process involves pH changes, physical changes that are related to chemical changes brought on by bacterial action on lactose and other sugars which students should observe and note, connecting to background information they obtained by “literature” searches (internet searches). The *ChemMatters* article cited below (“Say Cheese”) provides a good description of the changes in milk at the molecular level. A comprehensive lab activity on the subject can be found at <http://www.westminster.edu/acad/sim/documents/SMakingYogurt.pdf>.

## References (non-Web-based information sources)



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [http://ww.acs.org/chemmatters](http://www.acs.org/chemmatters)**. Scroll about half way down the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

This *ChemMatters* article explains the role of lactose in cheese making. Interesting details about the world of cheese can be found here, including the composition of a number of the more common cheeses and how they are produced. Lactose is a crucial component of the mix that is converted into cheese by bacterial action on the lactose. The article also includes a recipe for making soft cheese from whole milk, should students want to try this under adult supervision. (Baxter R, Say Cheese. *ChemMatters* **1995**, *13* (1), pp 4–7.)

For some background on how the digestive system produces a variety of gases, most of which are odorless, consult the *ChemMatters* article on flatus, listed below. In the article there is a discussion about one particular gas, methane, which is produced by certain ruminant animals (sheep, goats, and cows) and emitted into the atmosphere where it acts as a potent greenhouse gas. There is also the production of gas in people who are lactose intolerance, lactose being one of the FODMAP sugars. The Teacher’s Guide that accompanies the magazine provides additional background material and suggestions for activities related to the topic of gases in general. (Vanderborght, C. Flatus: Chemistry in the Wind. *ChemMatters* **2003,** *21* (1) pp 11–13)

For a complete description of the digestive process, including mechanical as well as chemical digestion (the role of specific enzymes and their pH requirements), see the *ChemMatters* article, Rohrig, B. 24 Hours: Your Food on the Move. *ChemMatters* **2012**, *30* (1), pp 6–8. The Teacher’s Guide for this article includes ideas for a number of in-class activities with appropriate Web sites for the details, plus additional background information.

A *ChemMatters* article that provides the details behind celiac disease, including information about the causative agent, gluten, is found here: Hill, M. Attack of the Gluten. *ChemMatters* **2013,** *30* (1), pp 9–11. Also found in this article is a simple activity of making bread in order to “feel” the role of gluten in providing “bulk” to the bread mixture.

The October 2013 Teacher’s Guide accompanying the gluten article above provides additional background information on celiac disease and some of the chemistry behind the change in the physical state of gluten as it is manipulated when kneading the bread mix of flour, water, and yeast. There is also a number of activities tied in with bread making, including the effect of yeast under different conditions of temperature.

An article from *ChemMatters* concerning lactose tolerance is found in the April 2013 issue. This two page article presents the specifics of the chemistry associated with lactose and the issues for people who cannot digest this milk sugar. Refer to: Rohrig, B. Not Milk? Living with Lactose Intolerance. *ChemMatters* **2013**, *31* (2), pp 18–19. There is also a Teacher’s Guide to complement the article with useful references and background information.

The December 2013 Teacher’s Guide that accompanies the lactose intolerance article above provides extensive background information along with suggested in-class activities related to lactose and the enzyme lactase.

## Web Sites for Additional Information (Web-based information sources)

**More sites on FODMAP diets**

The following Web site from Stanford University provides a lot of useful information on determining if a food is on the low or high end of FODMAP. There is a handy reference chart for the two categories of low and high FODMAP sources. Refer to <https://stanfordhealthcare.org/content/dam/SHC/for-patients-component/programs-services/clinical-nutrition-services/docs/pdf-lowfodmapdiet.pdf>.

A second Web site that is also rich in details about the types of food to avoid and those that are safe in terms of FODMAPs is found at <http://www.ibsdiets.org/fodmap-diet/fodmap-food-list/>. This is a very complete reference for those who need to plan meals that contain minimal FODMAPs.

**More sites on** **determining if an elimination diet for IBS is working**

For those who need to go through the process of determining what foods contain FODMAPs by the elimination process, the following Web site provides guidance: <http://www.sharecare.com/health/irritable-bowel-syndrome-ibs-treatment/how-know-fodmap-working-ibs>. People are advised that the process is best done with the help of a registered dietician.

**More sites on** **the genetics of lactose tolerance/intolerance**

A series of paper activities dealing with the genetics of lactose tolerance/intolerance is found at <http://www.hhmi.org/biointeractive/pedigrees-and-inheritance-lactose-intolerance>. This site from the Howard Hughes Medical Institute Includes teacher materials and student handouts for a number of activities including:

* “Pedigrees and the Inheritance of Lactose Intolerance”: Students explore the effects of different diets on the evolution of an enzyme that breaks down starch.
* “Diet and the Evolution of Salivary Amylase”: Students explore the genetic changes associated with lactose tolerance/intolerance and how the trait is inherited in families.
* “Milk—How Sweet Is It?” Students simulate a lactose tolerance test.
* “Got Lactase? Blood Glucose Data Analysis”: Students interpret the results of two different tests for lactase persistence.
* “Lactose Intolerance: Fact or Fiction”: Students evaluate and discuss several statements about lactose intolerance and evolution before and after watching a film.
* “The Making of the Fittest: Got Lactase? The Co-evolution of Genes and Culture” (Short Film)
* “Film Guides: Got Lactase? The Co-evolution of Genes and Culture”

A related article on “How did milk help found Western civilization?” is available at <http://www.slate.com/articles/health_and_science/human_evolution/2012/10/evolution_of_lactose_tolerance_why_do_humans_keep_drinking_milk.html>. This is a short essay that may appeal to some students. It makes for interesting reading.

**More sites on the history and uses of fermentation**

A readable document for students about the history of fermentation and its uses, old and new, can be found at <http://www.accessexcellence.org/LC/SS/ferm_background.php>. A second reference on the history of the development of wheat cultivation—the increase in gluten from plant breeding and how it became the source of gluten intolerance—might also prove enlightening to students who, for the most part, are far removed from agricultural practices. Refer to <http://www.scientificamerican.com/article/gluten-sensitivity-may-be-a-misnomer-for-distinct-illnesses-to-various-wheat-proteins/>.

**More sites on controlling or minimizing irritable bowel syndrome**

Research into explaining the benefits of eating yogurt to reduce or eliminate various digestive tract irritations and disturbances from things like FODMAPS is described in an abstract from the *American Journal of Clinical Nutrition* which again suggests that the cultivation of the right bacterial flora and fauna in the gut is central to alleviating or even preventing various intestinal “disturbances”. Refer to <http://ajcn.nutrition.org/content/80/2/245.full> for the abstract as well as the complete scientific report which describes the attempt to scientifically discern what is behind apparent anecdotal evidence for the amelioration of different irritable bowel conditions through eating yogurt.

**More sites on** **the clinical procedures for the hydrogen test**

This site, <http://www.gastrolab.com.au/hydrogen-methane-breath-testing-at-gastrolab.html>, explains the basis for the exhaled breath tests and what is involved in the examination procedure itself when testing for fermentation of undigested sugars in the FODMAP group.

A related Web site that shows quantitative data (graphical) and its interpretation concerning the hydrogen/methane breath test is found at <http://www.food-intolerance-network.com/miscellaneous-further-info-for-patients/h2-test.html>. This could be used in class when appropriate for teaching graphing and interpretation skills in the curriculum.

**More sites on** **fructose metabolism and connections to IBS**

The sugar fructose remains a controversial sugar, particularly as found in high fructose corn syrup, with its metabolism usually taking place in the liver—which means it is processed as a fat rather than a sugar. This in turn may create problems with fat deposition. However, there is the issue of malabsorption of fructose which, in turn, can create the problems associated with FODMAPs and irritable bowel syndrome (IBS). Some ideas suggest that fructose with equal amounts of glucose can be absorbed through the intestine rather than remaining in the gut to create the IBS problem. A good discussion of this issue as well as the role of fructans is found at the Web site <http://www.foodsmatter.com/allergy_intolerance/fructose_intolerance/articles/fructose_good_bad_malabsorbed.html>.

# 3D Printers: The Next Print Revolution

## Background Information (teacher information)

3Ders, those who print in 3D, say, “If you can draw it, you can make it.” Your students may ask how this is possible. First, we’ll look at the history of 3D printing, then the process, the products, and some future ideas. Remind your students that complicated models may require professional 3D files and printing machines.

The beginning of 3D printing can be traced back to 19th century attempts to create three dimensional models with cameras. Later, layering was used to produce topographical maps. In 1981, Hideo Kodama used a photopolymer liquid that turns to solid when exposed to UV light to produce an object by layering the polymer. Chuck Hull, considered the “Father of 3D Printing”, produced the first working 3D printer in 1984. 3D printing was not well known beyond the fields of engineering, architecture, and manufacturing until the 1990s.

**More on** **the history of 3D printing**

The British firm AV Plastics prepared a timeline of “3D Printing History”:

**1860 -** The photosculpture method of François Willème captures an object in 3 dimensions using cameras surrounding the subject.

**1892 -** Blanther proposes a layering method of producing topographical maps.

**1972 -** Mastubara of Mitsbushi motors proposes that photo-hardened materials (photopolymers) are used to produce layered parts.

**1981 -** Hideo Kodama of Nagoya Municipal Industrial Research Institute publishes the first account of a working photopolymer rapid prototyping system.

**1984 -** Charles Hull (founder of 3D systems) invents [stereolithography](http://en.wikipedia.org/wiki/Stereolithography) (SLA) – which is patented in 1987. The technology allows you to take a 3D model and use a laser to etch it into a special liquid (photopolymer).

**1991 -** Stratasys produces the world’s first [FDM (fused deposition modeling)](http://en.wikipedia.org/wiki/Fused_deposition_modeling) machine. This technology uses plastic and an extruder to deposit layers on a print bed.

**1992 -** 3D systems produce the first SLA 3D Printer machine.

**1992 -** DTM produces first [SLS (selective laser sintering)](http://en.wikipedia.org/wiki/Selective_laser_sintering) machine. This machine is similar to SLA technology but uses a powder (and laser) instead of a liquid.

**1994 -** Model Maker’s wax printer is released.

**1997 -** Aeromet invents laser additive manufacturing.

**1999 -** Scientists manage to grow organs from patient’s cells and use a 3D printed scaffold to support them.

**2000 -** The first 3D inkjet printer produced by Object Geometries.

**2000 -** The first multicolor 3D printer made by Z Corp.

**2001 -** The first desktop 3D printer made by Solidimension.

**2002 -** A 3D printed miniature kidney is manufactured. Scientists aim to produce full-sized, working organs.

**2005 -** The [Reprap project](http://reprap.org/) is founded by Dr. Adrian Bowyer at the University of Bath. The project was intended as a democratization of 3D printing technology.

**2008 -** The Reprap Darwin is the first 3D printer to be able to produce many of its own parts.

**2008 -** The first biocompatible FDM material produced by Stratasys.

**2008 -** The first 3D prosthetic leg is produced.

**2008 -** Shapeways – a website market for 3D models – launches.

**2008 -** Makerbot’s [Thingiverse](http://www.thingiverse.com/) launches – a website for free 3D (and other models) file sharing.

**2009 -** Makerbot produces a Reprap evolved kit for a wider audience.

**2009 -** The first 3D printed blood vessel is produced by Organovo.

**2011 -** The first 3D printed car (Urbee by Kor Ecologic).

**2012 -** The first 3D printed jaw is produced in Holland by LayerWise.

**2013 -** Cody Wilson of [Defense Distributed](http://defdist.org/) is asked to remove designs for the world’s first 3D printed gun and the domain is seized.

(<http://www.avplastics.co.uk/3d-printing-history>)

**More on Charles Hull, “the father of 3D printing”**

In 1982 Charles (Chuck) Hull made the first 3D printed object, a small, blue eye cup. *3D Printer & 3D Printing News* (June 11, 2014) published a brief biography of his work where they cited the case of twins conjoined at the leg. A 3D model of the twins’ upper leg bone showed that it was large enough to split forming two legs. As recounted by *3D Printer & 3D Printing News* following an interview with Chuck Hull:

“I think the first one that impacted me was surgical planning”, declared Hull. Talking about the recent uses of 3D printing in health care, he said that the fact that doctors are now able to scan patients’ bodies and use the scan in order to replicate the insides of the patient, and basically create a model of the part of the body that needs surgery, has been “amazing” to him. This allows surgeons to practice before the real surgery. “The first one that struck me was on conjoined twins”, added Hull. “That’s a very successful surgery now, with detailed planning. There are people walking around today who were born as conjoined twins, but now have normal lives.”

(<http://3dprint.com/5827/charles-hull-3d-printing-advancements/>)

*The Guardian*, June 22, 2014, published a nice biography of “Chuck Hull, the father of 3D printing who shaped technology”:

(<http://www.theguardian.com/business/2014/jun/22/chuck-hull-father-3d-printing-shaped-technology>).

**More on** **how 3D printers work: additive manufacturing**

3D printing is an additive process. Additive processes build products composed of stacked (or added) layers. In 3D printing, the bottom layer is formed first; a second layer is then stacked (“added”) on top of the first. Stacking continues until the top of the object has been created. Finally, the support material around the object is removed by brushing or washing it away. Three major additive techniques are used to solidify the material that forms the object: stereolithography (STL) uses a photo-reactive liquid resin that is hardened by a laser as it traces the product’s pattern layer after layer; fused deposition modeling (FDM) (the type described in the *ChemMatters* article) heats thermoplastics fed by spools which solidify as they cool; and selective laser sintering (SLS) uses a laser to fuse powdered materials such as metals, nylon, and ceramics. An excellent video shows and describes each of these manufacturing processes and the types of products produced. At this Web site (<http://www.solidconcepts.com/technologies>), click on a labeled box and watch from beginning to final product production as the relevant process is described.

The types of additive process (described below) differ in terms of the type of materials used and the method of fusing these materials together to produce the desired product. More information on additive processes can be found at <http://taktikz.com/products-services/industrial-manufacturing/manufacturing-technology/additive-processes/>.

* **stereolithography (SLA) or (STL)**

Both acronyms (SLA and STL) are often used to describe the same process. Actually, SLA is the rapid prototyping process. The .STL file, consisting of x, y, z coordinates, is an industry standard interface that forms a bridge between computer aided design (CAD) designs and the 3D printer hardware. This is described as a rapid prototyping system, a technique used to quickly fabricate a scale model of the product using 3D CAD data.

Starting from a 3D image, a part is built slice by slice from bottom to top in a vessel of liquid polymer that hardens when struck by a laser beam. The .STL file See full definition provides the 3D printing machine with the precise design data needed to divide the object into horizontal slices to create production paths. The file programs this information into the stereolithography 3D printing machine. A computer-controlled laser draws the bottom cross section onto the surface of a liquid polymer composed of photo-reactive resin that hardens where struck by the laser. The next cross section is then drawn and hardened directly on top of the previous one. The process is repeated by stacking the layers until the part is finished.

(<http://computer.howstuffworks.com/stereolith.htm>)

* **fused deposition modeling (FDM)**

FDM is the process described in the Wetterschneider article. Spools of polymer threads are fed into the dual printer heads, heated to melting, and extruded onto the surface of the machine where they cool and harden. Successive layers are added according to directions from the computer program.

(<http://www.livescience.com/39810-fused-deposition-modeling.html>)

* **selective laser sintering (SLS)**

In this process, a laser is used to fuse together finely powdered solids. This process works with plastics such as nylon, metals, ceramic, or glass powders. So, it can be used to form metal machinery parts. Since a very high-powered pulsed laser is required, SLS is too dangerous and expensive for home use. This process is generally reserved for industry or university research. (<http://www.livescience.com/38862-selective-laser-sintering.html>)

SLS technology is used in the medical field for bone tissue engineering, and bone and cartilage repair. Polycaprolactone, a bioresorbable polymer, can serve as the powdered material for the SLS 3D printer. (<http://www.sciencedirect.com/science/article/pii/S0142961204011068>)

The following URL contains a well prepared, very short, 19 second video showing the SLS process: (<http://www.buy3dprinter.org/3dprintingtechnologies/selective-laser-sintering-sls/>).

**More on the skeletal structures used in the Wetterschneider article**

The structures shown in Figures 1, 2, and 3 of the Wetterschneider 3D printer article are skeletal structures. Students may be unfamiliar with this shorthand method used to represent organic molecules. Skeletal structuring provides a quick way to draw large structures by omitting the carbon and hydrogen atoms. In addition, this type of representation is less messy so the organic chemist finds it quicker and easier to read.

Students may require help picturing that line bonds are connected by implied carbons. First, they must determine where the bonds are joined by a carbon. For example in Figure 1(a) acrylonitrile, carbon 1 (at left) joins the triple bond with nitrogen; carbon 2 (at the peak, ᴧ) single bonds to carbon 1 and double bonds to carbon 3. Once the carbons are placed, the number of implied hydrogens needed to complete the four bonds to each carbon can be counted. A good, 14-minute YouTube video shows students how to draw and interpret these structures: (<https://www.youtube.com/watch?v=RP6AS7XVIC8>).

**More on the preparation of the ABS and PLA monomers**

The dual extrusion (two nozzle) printer described in the Wetterschneider 3D printer article used ABS polymer in one feeder and PLA in the other. The three monomers that compose ABS are made from petroleum products:

* Acrylonitrile is a monomer produced from a catalyzed reaction between propylene and ammonia. The Sohio process combines propylene, ammonia, and air as the oxidizer:

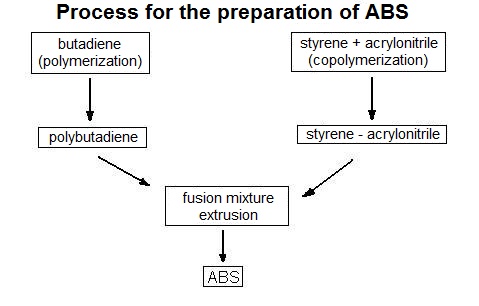
2CH3-CH=CH2 + 2NH3 + 3O2 → 2CH2=CH-C≡N + 6H2O

* 1,3-Butadiene is usually isolated from other four-carbon hydrocarbons produced in steam cracking and fractional distillation from crude oil.
* The styrene monomer is the product of dehydrogenation (removal of hydrogen atoms) from ethyl benzene, a hydrocarbon obtained from the reaction of ethylene and benzene. This reaction may be catalyzed by iron(III) oxide that is promoted by potassium oxide or potassium carbonate.

C6H5CH2CH3 → C6H5CH=CH2 + H2

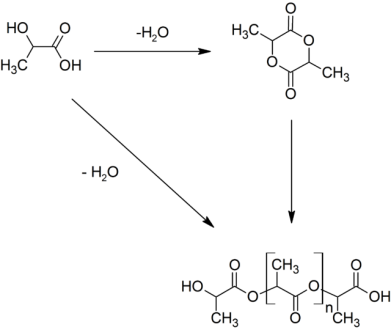
**More on preparation of the ABS polymer**

As explained in the Wetterschneider 3D printer article, ABS is formed by copolymerization of monomers of acrylonitrile, styrene, and 1,3-butadiene. First, butadiene is polymerized into polybutadiene (left reaction in flow chart at right); next, acrylonitrile is co-polymerized with styrene (first reaction on right in flow chart) to form the polymer styrene-acrylonitrile (SAN); then SAN combines with polybutadiene to form ABS, the fusion mixture that is extruded from the 3D printer nozzle (center of flow chart).



([*http://www.tudosobreplasticos.com/en/materiais/abs.asp*](http://www.tudosobreplasticos.com/en/materiais/abs.asp))

**More on preparation of the PLA polymer**



Lactic acid is a product of bacterial fermentation of crops such as sugar cane and corn. Polylactic acid, PLA, can be produced by the direct condensation of lactic acid monomers. The reaction to the right shows the condensation (removal of water) to form intermediate products (right arrow) and the final PLA polymer (down arrow). Note that the final product in the reaction is the same one shown in the Wetterschneider article, Figure 3.

*(*[*http://commons.wikimedia.org/wiki/ File:PLA\_from\_lactic\_acid\_%26\_lactide.png*](http://commons.wikimedia.org/wiki/%20File:PLA_from_lactic_acid_%26_lactide.png)*)*

**More on** **the physical and chemical properties of ABS**

ABS is a rubber-like material that is soluble in acetone and methylethylketone (2-butanone). As its name implies, 2-butanone is similar to butadiene, the linkage that holds ABS polymers together. Ketones and esters are polar protic solvents, molecules that do not have acidic hydrogen centers but which can accept hydrogen bonds. So, they are good solvents for many polymers. Nozzles clogged with ABS can be cleared with acetone and the pieces of ABS left-over from printing can be recycled by dissolving in acetone. Also, as long as there is sufficient surface area, a dilute ABS solute can bond a plastic polymer to glass. The intermolecular forces that hold ABS to glass are similar to those used by a gecko to run on glass and other surfaces.

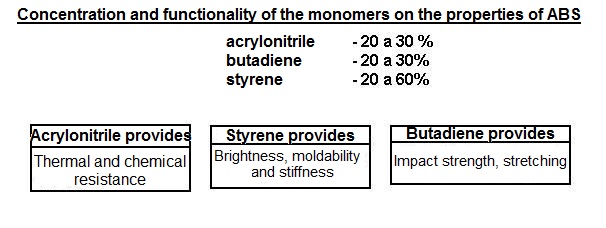
The solubility of ABS in acetone was used to produce the attractive figure on the left (below). The newly 3D-printed owl (at right) was sanded and then wiped with acetone to dissolve and smooth the outer layer, giving a glassy look. Actually, this is best done with acetone vapor rather than liquid acetone. See the directions, safety precautions, and “don’t try this at home” precautions on this Web site: <http://nicklievendag.com/filament-guide/>.



*ABS owls: Treated (Left) and untreated with acetone (by Sinkhacks)*

*(*[*http://sinkhacks.com/building-acetone-vapor-bath-smoothing-3d-printed-parts/*](http://sinkhacks.com/building-acetone-vapor-bath-smoothing-3d-printed-parts/)*)*

The properties of ABS can be varied slightly by changing the concentration of the three monomers to produce the desired characteristics for the product. For example, if the product needs to be more heat resistant, slightly increase the percentage of acrylonitrile in the mixture. See the table below for the physical characteristics of the three monomers.



*(*[*http://www.tudosobreplasticos.com/en/materiais/abs.asp*](http://www.tudosobreplasticos.com/en/materiais/abs.asp)*)*

**More on the physical and chemical properties of PLA**

PLA has a lower melting point and is not as strong and hard as ABS. Unlike ABS, PLA is not soluble in acetone; it dissolves in a strong base such as sodium hydroxide. In dual extrusion printers such as the one described in the Wetterschneider 3D printer article, PLA can serve as a dissolvable support for ABS 3D prints.

The melting point of PLA is 180–220 °C, a lower temperature than ABS, which melts at approximately 230 °C. It flows better than ABS so it can be printed more quickly. Quick printing produces prints with a shinier surface. PLA’s flammability is the key to “Lost PLA casting”. This is a process where a PLA printed solid is encased in a plaster-like molding. The entire structure is placed in a furnace where the PLA object is burned out leaving a hollow center. Thus, a mold for a molten metal casting of the object has been formed.

PLA filament comes in more colors than ABS. There are even sparkle and glow-in-the-dark colorings. The pictures below are shown in both white and UV light colors on the Web site.



*(*[*http://nicklievendag.com/filament-guide/*](http://nicklievendag.com/filament-guide/)*.)*

PLA breaks down into lactic acid, so it can safely be used for 3D printed medical implants. It is absorbed inside the body gradually, within six months to two years. Another note, PLA can be used to make biodegradable, disposable clothing.

**More on a comparison of the properties of PLA and ABS**

Although both PLA and ABS are thermoplastic polymers, their properties differ considerably. PLA is made from renewable resources such as corn starch or sugar cane, so it is biodegradable and considered more “green” than ABS, whose monomers are derived from crude oil.

The table below provides some basic information to help decide which material is best for use in a single nozzle 3D printer. Of course the choice will depend upon the characteristics needed for the desired product. Although there are drawbacks to either choice, basically ABS is the best plastic to use for machine parts due to its strength, resistance to impact, higher melting point and length of usable life. For an artist working at home, PLA will produce nicer, more pliable models and be easier and safer to use.

|  |  |  |  |
| --- | --- | --- | --- |
| **PLA** | | **ABS** | |
| **Pro** | **Con** | **Pro** | **Con** |
| + Can be printed on a cold surface | - Can deform because of heat (like a cassette in a car) | + Very sturdy and hard | - Made out of oil, so more damaging to the environment |
| + More environmental-friendly | - Less sturdy (than ABS) | + Suitable for machine or car parts | - Deforms when not being print on a heated surface |
| + Shinier and smoother appearance |  | + Higher melting point | - Hot plastic fumes when printing |
| + Smells sweet when being printed |  | + Longer lifespan | - Therefore, you need ventilation |
| + No harmful fumes during printing |  |  | - More difficult to print |
| + Higher 3d printer speed |  |  | - Not suitable for using with food |
| + More detail |  |  |  |

*(*[*http://www.absplastic.eu/pla-vs-abs-plastic-pros-cons/*](http://www.absplastic.eu/pla-vs-abs-plastic-pros-cons/)*)*

**More on blended filaments**

PLA can be combined with many different materials to form creative 3D printed products. The Web site <http://nicklievendag.com/filament-guide/> gives blending percentages and provides descriptions and pictures of many products composed of PLA blended with wood fibers (bamboo, pine, cherry, and coconut), brick, bronze, and copper.

Nick Lievendag is the co-founder of an animation & video marketing studio, *Captain* *Motion*, in The Netherlands. He writes about 3D printing for creative professionals. The following are just two of many examples posted on Lievendag’s Web site:

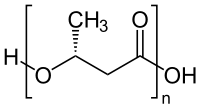
* **PLA + PHA**



Earlier I mentioned that while PLA is the easiest material for 3D Printing, it’s also very brittle. Dutch Filament manufacturer Colorfabb improved on this and developed its own unique blend of PLA/PHA which results in a tougher and less brittle PLA 3d printing filament. PHA (polyhydroxyalkanoate) is like PLA a bio-polyester, so the blend is still 100% biodegradable.

(<http://nicklievendag.com/filament-guide/>)

(*Manufactured by:* [*http://colorfabb.com/pla-pha*](http://colorfabb.com/pla-pha)*)*

 PHA is a thermoplastic like PLA and ABS. It is produced by the bacterial fermentation of sugar or lipids. Note that its structure (below) contains carbon, oxygen, and hydrogen bonded to form a polymer similar other thermoplastics.

*This is the structure of PHA.*

*(*[*http://en.wikipedia.org/wiki/Polyhydroxyalkanoates*](http://en.wikipedia.org/wiki/Polyhydroxyalkanoates)*)*

While printing in 3D is excellent for building and tweaking models, one of the major drawbacks of using this technology for mass production is the slow print speed. Now that FDM printers with multiple extruder heads are available, the process is expedited. These machines can print in multiple colors, with different polymers, and make multiple prints simultaneously. Only one machine and controller are required so speed is increased. Thus, industrial cost is reduced. (e.g., <http://3dprint.com/13310/theta-3d-printer/>)

Lievendag continues on his site:

* **PLA + Bronze**

Because this contains metal, the spool is a lot heavier than usual, but the effect is stunning!



*(Design by: (*[*http://bauermaker.tumblr.com/*](http://bauermaker.tumblr.com/)*)*

*bronzeFill by* [*ColorFabb*](http://colorfabb.com/bronzefill#.VElE8ouUfUo) *can be sanded and polished to get an actual bronze look like this beautiful print by* [*Bauermaker*](http://bauermaker.tumblr.com/)*.*

(<http://nicklievendag.com/filament-guide/>)

**More on the toxicity of the polymers used in the Wetterschneider article**

*The Soft Landing*, a team that specializes in safe, natural childproofing assessment, is particularly concerned about toxic chemicals in products for children. They found few health risks associated with ABS used in toys such as Lego building blocks.

Solid ABS resin is stable and will not leach into soil or water. But, the individual components of ABS may cause health problems. Butadiene is a known carcinogen; styrene and acrylonitrile are suspected carcinogens. While the solid polymer is not a problem, overheating ABS during 3D printing can release acrylonitrile vapors that have an unpleasant odor and carry possible health risks. In contrast, some people detect pleasant vapors released as biodegradable PLA is heated. There are no known health concerns associated with PLA fumes.

(<http://thesoftlanding.com/is-acrylonitrile-butadiene-styrene-abs-plastic-toxic/>)

**More on recycling the polymers used in 3D printing in the Wetterschneider 3D printer article**

It is possible to recycle ABS from another product to use in a 3D printer, but currently this is not very practical. An industrial strength grinder is needed to pulverize an ABS product, such as an old telephone. Then, the fine powder from the grinder is fed into an extruder to produce strands for the feeder spools. When this equipment is available at a reasonable price for home use, the cost of 3D printing will be greatly reduced. Yet, there are other concerns such as:

* Dioxins and toxic fumes being released should the consumer recycle the wrong type of plastic.
* Possible release of fumes when recycling the correct plastic.
* Maintaining uniform or near uniform filament diameter.
* Slow filament extrusion speeds.

(<http://www.quora.com/Is-it-possible-to-recycle-ABS-plastic-for-a-home-3D-printer>)

ABS products are accepted by most recycling centers. They are labeled either ABS or 07, see below:

(<http://commons.wikimedia.org/wiki/File:Plastic-recyc-abs.svg>)

(<http://www.sustainableokc.org/category/compost/>)

**More on the 3Ders news site**

In 2011, a group in the Netherlands launched the 3Ders news site (<http://www.crunchbase.com/organization/3ders>) to serve as a source of the latest in 3D printing technology. This site covers just about anything you need and want to know about 3D printing. The home page shows the latest news in 3D printing as well as a list of the basic categories. The site covers: data storage, design, scanning, software, printing (printers, accessories, and printing materials), price comparisons, and videos on 3D printing basics.

There is also a “forums” section for news discussions, questions, and an area for 3D communities to collaborate. This would be a good, comprehensive place to direct students who want to know more about 3D printing. You will see 3Ders referenced in several places in this background information section. (<http://www.3ders.org/>)

**More on purchasing a 3D printer**

When choosing a 3D printer, consider the speed, type of material to be printed, color capabilities; also research the cost of the printer, CAD program, files, and filament. In 2010–2013, commercial computer prices began at $20,000. Prices have since dropped to a level that is reasonable for some home use. *Tom’s Hardware Guide* is advertised as the “Largest independent source of cutting edge hardware information and reviews”. The London firm, founded in 1996, publishes reviews and price comparisons for 3D printers. The ““Best 3D Printers 2014” lists prices, pictures, and reviews for: “Best Budget”, $349; “Best for Beginners”, $1000. (<http://www.tomsguide.com/us/best-3d-printers,review-2236.html>)

SLS 3D printers are designed for industrial use and considered too dangerous to be used in the home. They require temperatures high enough to melt metals (over 2000 oC) and use high powered lasers. Prices range from $3,000 to $20,000 for these machines.

**More on 3D printing software**

A beginner needs to choose user-friendly software like Mario’s file, used in the Wetterschneider 3D printer article, so that the product can be printed with as little tweaking as necessary. Many files can be freely downloaded from the Internet, but these may be quite generic and require some engineering expertise for modification to personal specifications.

Non-profit MakerBot Industries was created to support early research in 3D computers. They sell kits to build your own computer. MakerBot supports Thingiverse, an on-line community for design trading and sharing of 3D printer files. (<http://www.thingiverse.com/about>)

According to their Web site: “3Ders.org provides the latest news about 3D printing technology and 3D printers.” This site lists both free and expensive commercial 3D files.

(<http://www.3ders.org/3d-software/3d-software-list.htm>)

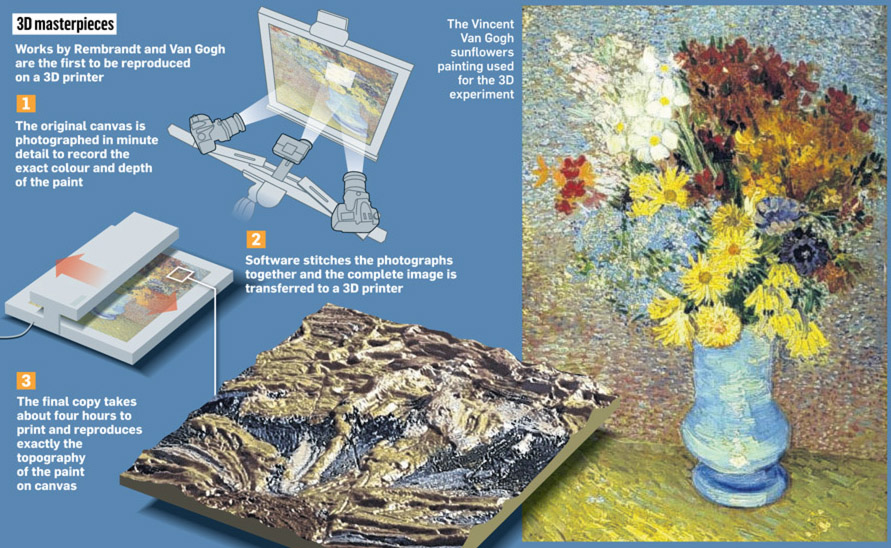
**More on scanning for 3D printer files**

 The Rijks Museum in Amsterdam’s closure for renovation provided the opportunity to scan paintings by Van Gogh and Rembrandt. During this time Tim Zaman, a Dutch researcher, used the museum collection to work on his master’s degree in biomechanical engineering. Zaman scanned slices of original paintings, then layered them with a 3D printer to produce exact replicas of the paintings such as the one shown here. This site contains three short videos showing the 3D layering process as the paintings are printed: <http://www.psfk.com/2013/09/3d-printer-paintings.html>.

*This picture shows Zaman’s 3D printing of the “Jewish Bride”*

Zaman wrote his master’s thesis on his work in 3D scanning and printing at Delft University of Technology, Netherlands: “Development of a topographical imaging device for the near-planar surfaces of paintings”. (<http://repository.tudelft.nl/search/ir/?q=zaman>) Using Zaman’s scanning procedures, researchers can study paintings at depth and propose ways to best restore, authenticate, and conserve them.

Below is an illustration of his work published in the 27 October, 2013 issue of the U.K. publication *The Sunday Times*. (<http://www.thesundaytimes.co.uk/sto/news/uk_news/Arts/article1332581.ece?CMP=OTH-gnws-standard-2013_10_26>)



*(*[*http://www.thesundaytimes.co.uk/sto/news/uk\_news/Arts/article1332581.ece?CMP=OTH-gnws-standard-2013\_10\_26*](http://www.thesundaytimes.co.uk/sto/news/uk_news/Arts/article1332581.ece?CMP=OTH-gnws-standard-2013_10_26)*)*

**More on scanners for home use**

The MakerBot® Digitizer™ Desktop 3D Scanner is designed for home use. Also, it eliminates the need for CAD files. The video shows how to calibrate and use the machine to scan up to an eight inch model. Once scanned, the file is ready to print with a 3D printer. The cost of this scanner is approximately $800. (<https://www.youtube.com/watch?v=AYq5n7jwe40>)

**More on Disney 3D printing research products**

*Disney Research* ([www.disneyresearch.com](http://www.disneyresearch.com)) is using 3D printing techniques “to advance the company’s broad media and entertainment efforts”. From the use of 3D printing techniques to produce Disney characters, the research group moves to more innovative projects such as those described below.

* **Disney characters**

Disney Researchers at ETH Zurich and MIT have developed software tools that allow a designer to load an animated Disney character model into the software. First, the points where movable joints should be placed are identified. Then, the software calculates where parts should be rigid or soft enough to allow for movement while keeping the overall appearance the same. Another type of 3D software is designed to create wobbly elastic characters that lack definite form.

(<http://www.gizmag.com/disney-research-mechanical-characters/28428/>)

* **Fluffy stuff**

Carnegie Mellon-Disney researchers have developed a 3D printer that resembles a sewing machine and extrudes a wool felt material. The machine uses an additive printing process: the first layer is a firm, flexible nylon mesh fabric designed to keep the yarn in place; flexible inner layers have embedded stiffeners; and the outer layers are soft and fluffy. The process is similar to FDM discussed above and in the Wetterschneider 3D printer article except that the printer heads feed out loose felt yarn instead of melted plastic. Each layer of yarn tangles with the layer below to form the solid, fluffy object. 3D printing also provides the opportunity to insert hardware into an inner layer to produce an articulated arm or bendable head.

Scott Hudson, who developed the 3D wool felt printer for Disney, predicts that in the future a 3D computer can be designed to produce both fabric and plastic in the same application. There are two short, excellent videos showing the process on the Web site:

<http://www.disneyresearch.com/project/printed-teddy-bears/>.

* **Printed optics**

Disney recognizes that, “Face-to-phase communication begins with the eyes, a crucial factor in the design of interactive physical characters.” So, the Disney Papillon research team used 3D printing to create interactive eyes on the characters. In response to the wave of a child’s hand, the character’s eyes will use hearts to express affection or question marks to suggest confusion. Also, with printed optics, the shapes and locations of eyes can be changed. An informative video and additional information about the Papillon project is located on the Web site. (<http://www.disneyresearch.com/project/papillon/>)

* **3D printing produces interactive speakers**

With 3D printing techniques, Disney Research Pittsburgh scientists are able to insert electrostatic loudspeakers into printed objects. In addition to adding sound to toys, embedded, inaudible ultrasound can be integrated into games and other interactive systems. Additional information is provided on their Web page. (<http://www.disneyresearch.com/wp-content/uploads/Project_3DSpeakers_CHI14_release.pdf>)

**More on 3D printing and medical applications**

* **3D printing of body parts**

*WebMD* asks, “Will 3-D Printing Revolutionize Medicine?” This site describes five pages of medical uses for 3D printing. The *WebMD* page begins with an initial five minute video featuring an art teacher who lost her fingers. The process of producing body parts is shown and described during this video.

In another, Sydney Kendall is featured. The 13 year old, who lost her arm in a boating accident, finds her pink, plastic, 3D printed arm much superior to her former prosthetic arms. With an opposable thumb, she can grip a baseball and pick up a paper cup. “It took about 7 minutes to do each finger,” says Sydney’s mother, Beth Kendall. “We were all blown away.”

Additional advancements in 3D medical printing are shown on this site. In addition, the cost of prosthetics is included. For example Sydney’s 3D printed arm cost $200 compared to the cost of traditional robotic limbs, $50,000 to $70,000. (<http://www.webmd.com/news/breaking-news/20140723/3d-printing>)

* **3D printing of knee replacements**

Traditionally knee implants were entirely generic; a recent improvement was to manufacture them gender-specific. But even more recently, they are being 3D printed! Yet, this is still the case where the surgeon adjusts the replacement to fit the patient.

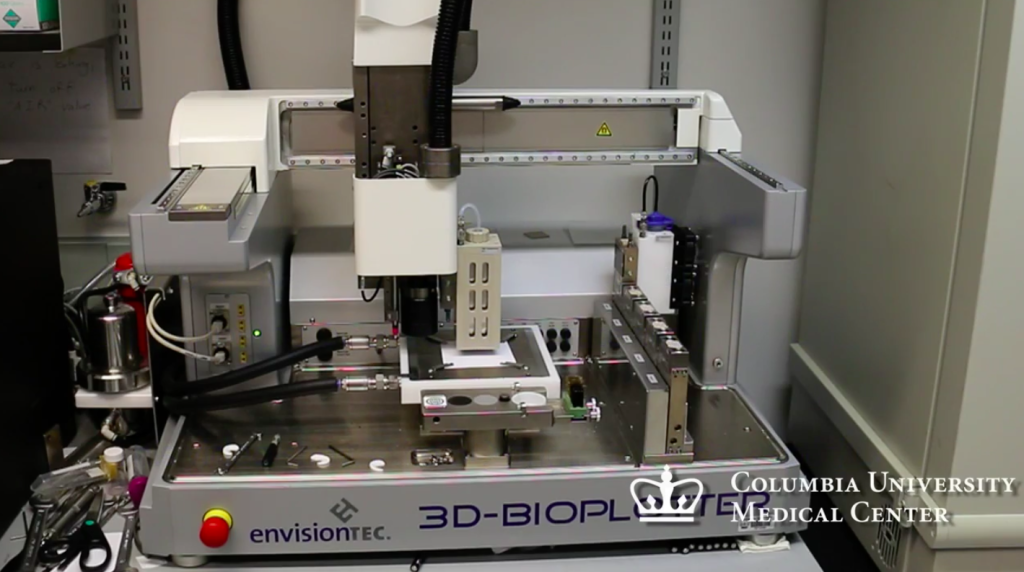
For the past year, Dr. Wallace Huff, Bluegrass Orthopaedics in Lexington, Kentucky, has been using 3D technology to print the knee replacement to fit his patient. "So rather than taking different sizes off the shelf and picking the best fit then you have the exact fit," said Dr. Huff. The 3D printed implant is the exact shape and mimics the complex forward, backward, and swivel movement of the patient’s natural knee joint. Hospital recovery time drops from three or four days to one night following surgery; pain is decreased by the perfect fit; and Dr. Huff notes that the 3D printed knee implants last longer than traditional ones. A video on this site features one of Dr. Huff’s patients. (<http://www.wkyt.com/betterliving/headlines/New-knee-replacement-surgery-in-Lexington-using-3D-printing-255540191.html>)

* **3D printing to promote tissue growth**

Recognizing the pain and possible arthritis associated with torn menisci, researchers under the direction of Dr. Jeremy Mao, department of chemistry, Columbia University Medical Center, use the 3D printing machine pictured below to print biodegradable knee scaffolds that promote tissue regeneration. The body will continue the additive process to grow new knee tissue. “We envision that personalized meniscus scaffolds, from initial MRI to 3D printing, could be completed within days,” said Dr. Mao. “The personalized scaffolds would then be shipped to clinics and hospitals within a week, to be surgically implanted in the patient’s knee.” The Columbia University Web site shows an animation of the scaffold for a knee meniscus being 3D printed. (<http://3dprintingindustry.com/2014/12/15/knee-tissue-3d-printing/>)

In the YouTube video Dr. Mao explains the process as you watch a knee meniscus scaffold being printed by the machine pictured below.

(<https://www.youtube.com/watch?v=yTDK88G2ed0#t=74>)



* **3D printing of orthopedic implants**

3D prints of biodegradable fibrous tissue can be used to promote osseointegration, by encouraging new bone growth as the printed tissue becomes integrated with the bone. Frequently, they may also have a mechanical function. For example, they may be used in a knee joint.

*Custom Cranio-Maxillofacial implant*

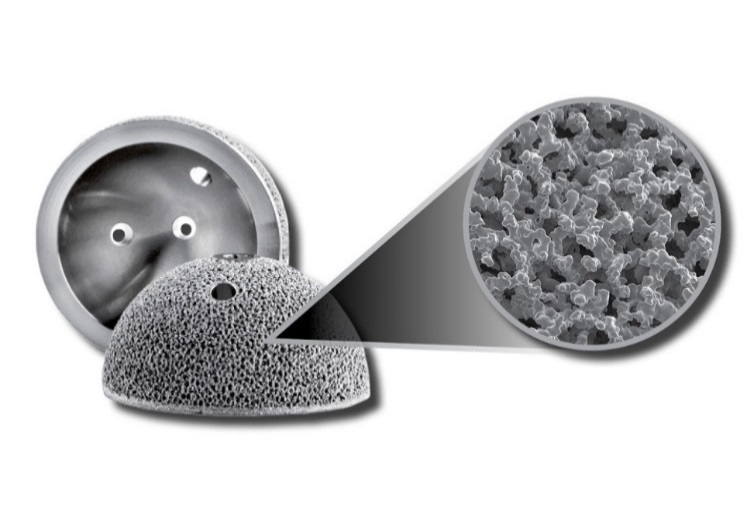
*(*[*http://www.arcam.com/wp-content/uploads/CMF\_custom\_made\_implant.jpg*](http://www.arcam.com/wp-content/uploads/CMF_custom_made_implant.jpg)*)*



The electron beam melting (EBM) technology (<http://www.arcam.com/technology/electron-beam-melting/>) can be used to produce patient-specific implants. Computer Technology (CT) scan data is used to create a Computer Assisted Design (CAD) file of the desired implant such as the “Custom Cranio-Maxillofacial implant” pictured at right.

EBM is also used to produce the trabecular structures used in reconstructive hip surgery. These structures need to be porous to provide biological ingrowth surfaces. Trabecular structures are described in an abstract posted by National Institutes of Health (NIH):

*Trabecular metal in hip reconstructive surgery* by JB Stiehl,   
Abstract: Biological ingrowth surfaces have become a standard prosthetic element in reconstructive hip surgery. A material's properties, three-dimensional architecture, and surface texture all play integral parts in its biological performance. Trabecular metal is an important new biomaterial that has been introduced to enhance the potential of biological ingrowth as well as provide a structural scaffold in cases of severe bone deficit. Initial clinical applications have focused on bone restoration in tumor and salvage cases and in primary and revision reconstructive cases where the increased biological fixation would be of clinical benefit. The bone ingrowth potential and mechanical integrity of this material offer exciting options for orthopedic reconstructive surgeons.



*Acetabular cups with integrated Trabecular Structures™   
for improved osseointegration*

*(*[*http://www.arcam.com/solutions/orthopedic-implants/*](http://www.arcam.com/solutions/orthopedic-implants/)*)*

(<http://www.ncbi.nlm.nih.gov/pubmed/16119281>)

**More on 3D printed dog legs**

Derby, the dog shown in the video cited below, was born with completely deformed front legs. With his new 3D printed legs, he is able to run faster than his owners. This three minute video will appeal to most students. It provides an excellent way for them to see the 3D printing process in action, along with an explanation. They will watch the new legs being formed and used by Derby. (<https://www.youtube.com/watch?v=uRmoowIN8aY>)

**More on 3D printed foods**

The Ford motor company uses 3D printing technology to develop four by two inch detailed plastic models of all its new vehicles. In 2014, *3D Systems* worked with *The Sugar Lab* and partnered with Ford to produce a 3D printed edible 2015 Ford mustang in white chocolate. This well prepared, short classroom video (<https://www.youtube.com/watch?v=TSAdjGGhfwo>) shows and explains the process as both the plastic and the chocolate mustangs are printed.

(<http://3dprintingindustry.com/2014/02/16/3d-printing-ford-mustang-sugar/>)

NASA is funding a Texas company to study the feasibility of using 3D printing to prepare food for astronauts during long space missions. Current space food is the shelf ready, freeze dried variety because refrigeration and/or freezing is too energy intensive. “NASA’s Advanced Food Technology program is interested in developing methods that will provide food to meet safety, acceptability, variety, and nutritional stability requirements for long exploration missions, while using the least amount of spacecraft resources and crew time.” 3D printed food could provide the opportunity for personal preferences. (<http://www.nasa.gov/directorates/spacetech/home/feature_3d_food_prt.htm>)

“A Guide to All the Food That’s Fit to 3D Print (So Far)”, *Bloomberg Business Week*, January 18, 2014, describes: the Hershey candy maker, NASA’s pizza printer, Natural Machine’s Foodini’s ravioli maker (after printing, ravioli must be baked) and vegetarian nuggets, Cornell Creative Machines Lab’s flower-shaped corn chips and hamburger patties complete with layers of ketchup and mustard, and Chefjet Pro’s custom edible cake toppers. In the article, pictures are shown and prices are provided for the 3D printers used to make these printed foods. (<http://www.businessweek.com/printer/articles/188115-a-guide-to-all-the-food-thats-fit-to-3d-print-so-far>) A video showing Chefjet’s 3D printer at work preparing decorations is located at <https://www.youtube.com/watch?v=8WWHpWgaq7I>).

**More on 3D printing for wearable jewels and clothes**

3D design software for custom jewelry saves designers the time and expense of making actual models to show and sell custom jewelry. The Gemvision site contains a video (*Create Seductive Renders*) that shows how the CAD (computer assisted design) software, Matrix 7, can be used to generate a realistic image of jewelry. This process, “rendering”, enables a computer program to make a virtual design. (<http://gemvision.com/matrix/>)

Although the primary use of 3D printing in the jewelry business has been limited to using software to generate virtual 3D images of designs, Jenny Wu is using her experience in working on 3D architectural projects to develop her own line of jewelry. She markets her 3D printed rings and necklaces under LACE. The 3Ders news site announces a show of her artwork:

Internationally celebrated architect, Jenny Wu, announced this week [November 22, 2014] the official public launch of her first 3D printed wearable designs, LACE. The collection will make its debut at Aqua Art Miami this December as a pop-up exhibition/shop in the main courtyard space.

Prompted by her success as an architect, designer and partner at the award-winning design and architecture firm, Oyler Wu Collaborative, Jenny launched her line, taking her artistic eye to the jewelry industry. The LACE by Jenny Wu collection reflects Wu's architectural aesthetic, marrying line-based geometry with intricate organic movement to create avant-garde designs that make a statement.

(<http://www.3ders.org/articles/20141122-jenny-wu-launches-lace-3d-printed-jewelry-collection.html>)

In February 2013, gold metal sprinter Michael Johnson worked with Nike designers to produce the first 3D printed football cleat. “Nike’s new 3D printed plate is contoured to allow football athletes to maintain their drive position longer and more efficiently, helping them accelerate faster through the critical first 10 yards of the 40,” said Johnson. “Translated to the game of football, mastering the Zero Step can mean the difference between a defensive lineman sacking the quarterback or getting blocked.” The cleat pictured below was printed using selective laser sintering (SLS) technology.



*(*[*http://news.nike.com/news/nike-debuts-first-ever-football-cleat-built-using-3d-printing-technology*](http://news.nike.com/news/nike-debuts-first-ever-football-cleat-built-using-3d-printing-technology)*)*



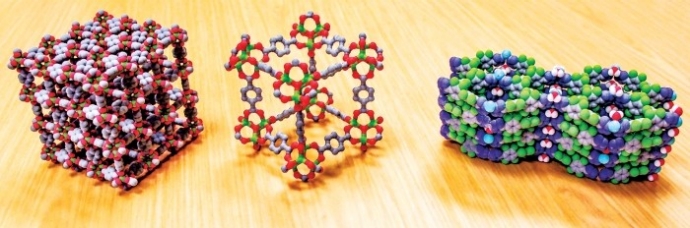
Fashion designers are experimenting with 3D printed wearable women’s shoes and dresses. Dutch designer, Iris van Herpen’s new clothing line, *Magnetic Motion*, was shown at Paris Fashion Week. The inspiration for the clothing came from the magnetic fields used by the Swiss Large Hadron Collider at CERN. She uses magnets to help 3D print her garments.

*3D printed fashion. Credit: Iris Van Herpen*

*(*[*http://www.inside3dp.com/iris-van-herpen-reveals-3d-printed-clothes-paris-fashion-week/*](http://www.inside3dp.com/iris-van-herpen-reveals-3d-printed-clothes-paris-fashion-week/)*)*

**More on printing molecular models for your classroom**

The article, *3-D Models, Without a Kit*, suggests that if you have access to a 3-D printer, you can print inexpensive custom made molecular models for your classroom.



*Credit: Ognjen Miljanic, University of Houston*

If you don’t have access to a printer, *Shapeways 3D Printing Service and Market Place* (<http://www.shapeways.com/>) will print and send your model to you. The *Shapeways* YouTube video (2 minutes) shows the 3-D printing of many other objects that people have created in addition to molecular models. (<https://www.youtube.com/watch?v=qJuTM0Y7U1k>)

(<http://cen.acs.org/articles/92/i20/3-D-Models-Without-Kit.html?h=-1610457888>)

**More on the challenges and the dark side of 3D printing technology**

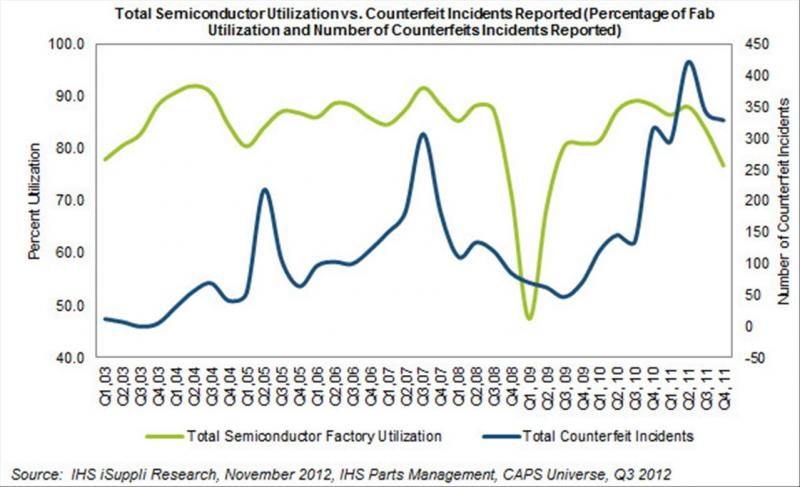
Making exact copies can be very useful. With 3D printing technology, a painting that duplicates the original can be copied down to fine brush strokes thus producing an almost perfect replicate of the original. 3D printing can provide the detail needed to authenticate and/or restore a work of art as well as to produce a copy of a famous painting or statue for home enjoyment at a reasonable price. Unfortunately, this also provides the opportunity for a 3D printed copy to be counterfeited and sold as “an original”.

*3D Printing Industry* lists six ways that counterfeiting may impact the 3D printed world:

* Professional and semi-professional pirates selling knockoffs that appear genuine
* 3D design files sold or shared peer-to-peer on the Internet, pretending to be genuine
* Genuine 3D design files sold or shared peer-to-peer on the Internet and printed not according to the specifications for the “genuine” products; the products look real but are modified or deficient, possibly dangerously so
* Consumers and prosumers printing and using products that appear genuine
* Consumers and prosumers printing and selling products that appear genuine on Craig’s List, ebay, at flea markets, etc.
* Companies, print shops, prosumers, and consumers scanning and printing replacement parts that do not satisfy OEM specs.

(<http://3dprintingindustry.com/2014/02/05/tell-whats-real-whats-fake-3d-printed-world/>)

NASA has even more serious concerns about counterfeiting, listed as one of their “biggest challenges”. 3D printed counterfeit parts that are permeating the market place can “threaten the success of its missions, the safety of its personnel and the security of the country.” Automakers and tool manufacturers face similar threats. The following graph shows the spike (blue line) of counterfeit reports in the semiconductor business during the second quarter of 2011.



*(*[*http://www.pcbdesign007.com/pages/zone.cgi?a=87719&artpg=1*](http://www.pcbdesign007.com/pages/zone.cgi?a=87719&artpg=1)*)*

In addition, problems involving intellectual property theft occur when people using 3D printers ignore copyrights to print and sell everything from toys to kitchen ware. Is there legal recourse when someone is injured because their 3D printed, counterfeit bicycle helmet falls apart? How will the victim and the company know if it is genuine?

(<http://3dprintingindustry.com/2014/02/05/tell-whats-real-whats-fake-3d-printed-world/>)

**More on anti-counterfeiting measures**

Quantum Materials Corporation (QMC) embeds unique quantum dots in products for authentication. David Doderer, Vice President for Research and Development at QMC explains,

The remarkable number of variations of semiconductor nanomaterials properties QMC can manufacture, coupled with Virginia Tech’s anticounterfeiting process design, combine to offer corporations extreme flexibility in designing physical cryptography systems to thwart counterfeiters. As 3D printing and additive manufacturing technology advances, its ubiquity allows for the easy pirating of protected designs. We are pleased to work with Virginia Tech to develop this technology’s security potential in a way that minimizes threats and maximizes 3D printing’s future impact on product design and delivery by protecting and insuring the integrity of manufactured products.

(<http://3dprintingindustry.com/2014/07/01/quantum-dots-hinder-3d-printed-counterfeits/>)

Applied DNA Sciences (ADNAS), Stony Brook, New York, marks products as genuine with plant DNA. One gram of DNA can protect 100 billion DVDs. For national security, the U.S. Defense Logistics Agency has mandated that certain electronic parts be DNA marked. The company has marked the Swedish national rail system, burglary-prone London neighborhoods, and cotton and wool fiber used by high-end carpet and textile makers. ADNAS says,

Our scientists have developed a precision-engineered mark based on botanical (plant) DNA. The engineered mark has not and cannot be broken. The conventional process used to sequence (“decode”) native DNA is not possible with the engineered mark. Additional layers of protection and complexity are added to the mark in a proprietary manner. This engineering “secret sauce” is shielded by a portfolio of 21 patents and other intellectual property protection.

(<http://3dprintingindustry.com/2014/02/05/tell-whats-real-whats-fake-3d-printed-world/>)

**More on the future of 3D printed guns**

Cody Wilson, a Texas law student, founded the non-profit organization, Defense Distributed. In May, 2013, he posted 3D printer designs for a plastic gun. The U.S. Government asked that the designs be removed. During the 2 days that the blueprints were available, there were more than 100,000 downloads. Plastic guns are not detectable by current airport screening methods.

In Japan at least eight personal computers downloaded the files. A university employee, Yoshitomo Imura, was arrested in Japan for possessing and owning five 3D printed firearms, 3D printed from files posted on the Defense Distributed Web site.

(<http://www.3ders.org/articles/20140924-new-3d-printed-revolver-dedicated-to-yoshitomo-imura-in-development.html>)

**More on the future of 3D-Printing in Medicine**

* **3D printed micro-robotic drug delivery systems**

Swiss professors, Bradley Nelson and Christofer Hierold at the department of Mechanical and Process Engineering at the Swiss Federal Institute of Technology, Zurich (ETH), have developed 3D printed helical shaped micro-robots that can carry medications or chemical sensors to specific locations in the body. They are formed with a microscopic 3D printer that incorporates magnetic nanoparticles within a light-sensitive, bio-compatible epoxy resin.

The computer program controls a laser beam that moves repeatedly in a 3D manner throughout the resin to cure it in a desired pattern. The uncured portion of the resin is washed away. By tweaking the computer program, scientists have been able to produce structures with large surface areas to enable the tiny robots to carry maximum loads. *3D Printer & 3D Printing News* quotes a student from the ETH Zurich lab:

“It is not just about swimming micro-robots,” says doctoral student Christian Peters from the group led by Professor Hierold. “The new technology can also be used when other micro-objects have to be manufactured with specific magnetic properties. Previously, these elements wobbled as they moved forward, and they were less efficient because their magnetic properties were not ideal. We have now developed a material and a fabrication technique with which we can adjust the magnetic properties independent of the object’s geometry,” said Peters.

(<http://3dprint.com/25786/micro-robots-eth-zurich/>)

* **3D printed medical-quality filaments for targeted drug delivery**

Louisiana Tech University researchers have developed methods to use 3D printers to extrude medical-quality filaments containing antibacterial and chemotherapeutic compounds to implant for targeted drug delivery. Current antibiotic implants are made of Plexiglas™ and must be removed surgically. 3D printed filaments can be made from biodegradable materials that are absorbed by the body.

“After identifying the usefulness of the 3D printers, we realized there was an opportunity for rapid prototyping using this fabrication method," said Jeffery Weisman, a doctoral student in Louisiana Tech's biomedical engineering program. "Through the addition of nanoparticles and/or other additives, this technology becomes much more viable using a common 3D printing material that is already biocompatible. The material can be loaded with antibiotics or other medicinal compounds, and the implant can be naturally broken down by the body over time.

According to Weisman, personalized medicine and patient specific medication regiments is a current trend in healthcare. He says this new method of creating medically compatible 3D printing filaments will offer hospital pharmacists and physicians a novel way to deliver drugs and treat illness. "One of the greatest benefits of this technology is that it can be done using any consumer printer and can be used anywhere in the world," Weisman said.

(<http://www.sciencedaily.com/releases/2014/08/140821090659.htm>)

**More on “How 3D Printing is changing everything”**

Bre Pettis, founding member and CEO of the 3D printer firm, MakerBot Industries describes the prototype Digitizer Desktop 3D Scanner in the *Consumer Electronics Association* (CE). (<http://www.ce.org/i3/Features/2013/May-June/How-3D-Printing-is-Changing-Everything.aspx>) A YouTube video (referenced and described above in the “*More on scanners for home use”*section) is located at (<https://www.youtube.com/watch?v=AYq5n7jwe40>). “This is something you would envision being science fiction, but in fact, it is real—and it is so cool,” Pettis says. “If something gets broken, you can just scan it and print it again.” (<http://blogs.redorbit.com/makerbot-takes-us-even-further-into-the-future-with-3d-scanning/>)

The CE.org site lists these future trends in 3D printing:

**3D Printing Trends to Watch**

**It’s all in the parts:**Expect to drive more cars and fly in more planes that are built using 3D printing. Parts that are created from this additive process will become more common, not only in heavy machinery, but also in household appliances and other devices. Lose your iPhone case? Can’t find your wrench? More households will implement 3D printers into their homes to make these smaller items.

**Let’s go shopping:** Expect to see 3D printing kiosks at the mall alongside the phone accessories hut. Not only will these destinations make 3D printing more of a household word, but they will also introduce a new generation of consumers to the technology, a lot like custom printed t-shirts and coffee mugs did a decade ago (before everyone had their own photo printers). Expect to order and pick up a 3D print the same way you order your digital photos.

**It does the body good:** The future of 3D printing isn’t just for inanimate objects anymore. It’s being used to develop products that can assist in the medical industry, including prosthetic limbs and orthodontic devices. Scientists are even experimenting with soft tissue printing that could change the way patients are treated for a variety of health needs. And 3D printing is also being used to take living cells to produce a transplantable kidney. [Surgeon Anthony Atala recently demonstrated an early-stage experiment](http://www.bbc.com/future/story/20120621-printing-a-humankidney).

**The kids are all right:** Forget the construction paper and clay, tomorrow’s students will bring home 3D prints that they make right in the classroom. Progressive schools around the country are already starting to introduce the technology in the classroom, but as the price points come down on 3D printers, a new generation of innovators will have the opportunity to experiment with the endless possibilities.

(<http://www.ce.org/i3/Features/2013/May-June/How-3D-Printing-is-Changing-Everything.aspx>)

**More on 3D printing a kidney**

To watch surgeon Anthony Atala use living cells to 3D print a kidney, see the video (with interpretation in 27 languages) located on this site.

([https://www.ted.com/talks/anthony\_atala\_printing\_a\_human\_kidney#](https://www.ted.com/talks/anthony_atala_printing_a_human_kidney))

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic Chemistry: nomenclature, structure**—The Wetterschneider 3D Printer article gives the names, chemical formulas, and the structures of monomers and the polymers. This provides the opportunity to discuss: functional groups, multiple bonds between atoms, and the omission of carbon and hydrogen in organic structural formulas.
2. **Organic Chemistry: polymerization**—The structures shown in the Wetterschneider 3D Printer article provide the opportunity to discuss how monomers, acrylonitrile, 1-3 butadiene, and styrene in Figure 1, join to form the polymer, acrylonitrile butadiene styrene (ABS), Figure 2.
3. **Reaction Mechanisms: multi-step reactions**—Step 1: butadiene monomers polymerize to form polybutadiene; Step 2: Acrylonitrile is copolymerized with styrene; Step 3: the two polymers (polybutadiene and acrylonitrile-styrene) are extruded together from the 3D printer heads to form ABS. See the background information of this teacher’s guide for additional information on this reaction.
4. **Physical Properties**—Each of the three monomers forming ABS contributes to the overall physical properties of the product. By varying the amounts of each polymer, the properties of the resulting ABS can be adjusted to form the optimal physical characteristics for the product.
5. **Physical Properties: thermoplastics**—The Wetterschneider 3D Printer article provides the opportunity to discuss how the physical properties of some thermoplastics make them suitable for smartphone cases. These materials are impact resistant and can be molded and remolded, changing from solid to liquid and back to solid again by heating or cooling. Thus, they can be reused by softening and remolding into a different shape.
6. **Chemical Bonding**: **intermolecular forces**—The polymer chains of thermoplastics are attracted by intermolecular forces which weaken to form viscous liquids as the temperature increases. As the polymers cool, the intermolecular forces increase to form the solid product.
7. **Green Chemistry: renewable resources, biodegradable**—Poly(lactic acid) (PLA) is a polymer composed of a renewable resource, lactic acid monomers. Lactic acid, formed from cornstarch or sugar cane, is biodegradable.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“What fun it will be to print a custom smartphone case with our school logo, I’ll ask my parents to buy a 3D printer today so that I can design and print like Mario.”** *Although the price of 3D printers is decreasing, they are still too expensive for most family uses. Mario’s mother is an engineer who uses the 3D printer for her business.*
2. **“My sister’s boyfriend says that pretty soon you’ll be able to print an iPhone. This will be cheaper than buying one.”** *Maybe your sister needs a smarter boyfriend! At present, home computers are not capable of printing objects with internal wiring like telephones. It will probably be a long time before you can print a personal iPhone.*
3. **“3D printing is neat but it only makes plastic objects.”** *The spools that feed a 3D printing machine can be loaded with many materials other than plastic, for example: clay, cement, silicone, and even chocolate and sugar.*
4. **“3D printing is just a fad that will soon disappear.”** *In addition to producing things for fun, in the engineering field 3D printing is becoming such a valuable asset to manufacturing that it will become a permanent part of the process. Computer designing is often less expensive than hand crafting prototypes; and tweaking the design file is simple compared to making another model by hand.*
5. **“I understand that soon human hearts can be 3D printed.”** *A replica of the human heart can be printed, but this does not mean that it will function in the human body.*
6. **“Printing in 3D is easy; Mario just tweaked his mother’s program to make the part he needed.”** *Mario was able to easily print the part he needed because the file in his mother’s 3D printer was designed to make models similar to his smartphone clip. Learning to write computer files for a 3D printer is a difficult and time consuming process. Commercial files frequently contain glitches that need to be corrected by someone with engineering skills.*
7. **“Computer assisted design (CAD) programs make 3D printing simple.”** *While 3D Printers are easy to use, CAD software is not user-friendly. To successfully run these programs you must be well trained and have engineering expertise.*
8. **“The 3D printer in the article uses plastics, another name for polymers.”** *While all plastics are polymers, NOT ALL polymers are plastic. Polymers are long chains of molecules. The chains may be composed of monomers that form plastics, but many biomolecules also polymerize to form starches (polymers of sugars), proteins (polymers of amino acids), and DNA (polymers of nucleotides). Additionally, films, paints, elastomers, fibers, gels, and adhesives are ALL polymers.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“What is the cost of a home 3D printer?”** *Prices for home 3D printers have gradually decreased from $20,000 in 2010 for a commercial 3D printer to $400 to $1,000 now for a home version.*
2. **“If I don’t know how to design, can I get files to 3D print?”** *Yes, many files that are ready for printing are available on-line and many of these are free. One community of designers willing to share files is located on the 3Ders Web site:* <http://3ders.org>.
3. **“Can I design a file to make a 3D surfboard?”** *Creating an entire surfboard using a 3D printer is possible, but not yet practical. You would need a very large, very expensive printer. Now, surfers* ***do*** *3D print small things like custom designed fins.*
4. **“With a single nozzle system, should I print with ABS or PLA?”** *ABS requires a higher temperature, which means that your printer will run hotter during printing. If you overheat it, unpleasant fumes may escape. PLA cools more quickly and sticks together better so you can usually print more quickly. If you are making a part for a dishwasher for example, ABS will withstand the higher temperature better.*
5. **“Since ABS is plastic, can it be recycled?”** *Yes, most recycling centers can handle the ABS polymer. Products of ABS are labeled with the recycling code triangle containing the number seven or ABS.*
6. **“Will everything soon be printed rather than manufactured in the traditional manner?”** *Although many things can be printed by 3D printers, current home models are not capable of printing with materials such as metals that require very high-powered, pulsed lasers and temperatures high enough to melt metals. Currently, it is usually not economically feasible to replace most industrial processes with 3D printing, a relatively slow process. In industry, 3D printing is mainly used to make prototypes and custom designed products.*
7. **“What do the formulas in Figures 1, 2, and 3 mean? I don’t understand them.”** *The diagrams in the Wetterschneider 3D Printer article are organic shortcuts called skeletal structures. They are quicker to draw and less messy than structural formulas because the carbons and hydrogens are assumed. Each intersection between lines contains a C (carbon) and the H (hydrogen) is determined by the number needed to give carbon four bonds. For example, the condensed formula for acrylonitrile is NCCHCH2.*
8. **“What is a thermoplastic polymer?”** *Thermoplastic polymers like ABS can be heated and formed over and over again. Thermoplastic monomers are often linear and have few branches and cross links so they flow under pressure when heated above their melting points. In contrast, as the name implies, a thermoset polymer forms a “set” three dimensional network when heated that cannot be reformed.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. Show the 14 minute YouTube video that teaches students how to write skeletal structures. Ask students to translate the three skeletal structures in Figure 1 of the Wetterschneider 3D printer article to structural formulas. Then, challenge students to identify the location of the three monomers, acrylonitrile, 1,3-butadience, and styrene shown polymerized in Figure 2. **(**<https://www.youtube.com/watch?v=RP6AS7XVIC8>)
2. Two suggestions for holding a class debate:
3. Watch the 36-second video that shows how to fake a master painting with a 3D printer that replicates down to fine details like brush strokes: (<https://www.youtube.com/watch?v=EXRt64HEBrk&hd=1>). and

Should museums keep original works of art hidden in light and air controlled environments? And show replicas to the public, thus reducing the cost of insurance and the possibility of theft? Student debate information is located on this site: <http://gizmodo.com/3d-printing-fine-art-fakes-is-here-to-stay-1383456733>.

1. Present a scenario about a child choking on a counterfeit toy part. The toy was sold by a major manufacturer and the part came from one of their suppliers. Who should be responsible? Who should pay for the child’s medical expenses?
2. Make a corn-based bioplastic (like PLA) in the lab. A recipe is given on page 12 of the April, 2010 *ChemMatters* article by Cynthia Washam, *Plastics Go Green.* See the section: “References (non-Web-based information sources)” for this article. The reference for this lab comes from the *Field Guide to Utah Agriculture in the Classroom, Volume 1*: The URL for the original lab activity, *Corn Starch Plastic,* can be found at: <https://utah.agclassroom.org/files/uploads/fieldguide1/plastic.pdf>.
3. Thermoplastics lab: In this chemistry lab activity, students use a hot glue gun, to investigate the properties of thermoplastics, including viscosity and the effect of heating and cooling. (<http://www.terrificscience.org/lessonpdfs/PolymerLab25.pdf>)
4. The chemistry lab activity “Bridging to Polymers” is designed for students to investigate the difference between thermoplastics and thermosets. As described in the introduction: “Students act as engineers to learn about the strengths of various epoxy-amine mixtures and observe the unique characteristics of different mixtures of epoxies and hardeners. Student groups make and optimize thermosets by combining two chemicals in exacting ratios to fabricate the strongest and/or most flexible thermoset possible.” Complete lab instructions and materials lists are located on the site. (<https://www.teachengineering.org/view_activity.php?url=collection/uoh_/activities/uoh_polymer/uoh_polymer_lesson01_activity1.xml>)
5. “Conflicts in Chemistry: The Case of Plastics, a Role-Playing Game for High School Chemistry Student” was written by Deborah Cook. This activity was developed by the Chemical Heritage Foundation to “promote increased public understanding of chemistry”. As stated in the abstract, “The activity allows students to engage in debate regarding current science policy issues linked to competing values and interests.” The complete directions and student information is located on the *Chemical Heritage* Web site.

(<http://www.chemheritage.org/discover/online-resources/conflicts-in-chemistry/the-case-of-plastics/index.aspx>) For *JCE* subscribers only: This activity was also published in the *Journal of Chemical Education*, October, 2014.

## Out-of-class Activities and Projects (student research, class projects)

1. If English is not the first language of your students, this activity about the process of solving an environmental pollution problem may be especially valuable. The accompanying interactive transcript is available in 31 languages. Ask students to select their preferred language and watch the 10-minute video, “Two young scientists break down plastics with bacteria”. Some plastics contain phthalates, as plasticizers, that easily escape to pollute the environment. In the video the scientists decide to tackle a problem in their local area. Note: ABS described in the Wetterschneider 3D printer article does not contain plasticizers.

After watching the video, ask students to take notes for a class discussion or write a report. They can be asked to focus on topics such as:

1. The problem of phthalates in the environment.
2. How mistakes may lead to discoveries (serendipity).
3. The chemistry involved in solving this problem.

(<http://www.ted.com/talks/two_young_scientists_break_down_plastics_with_bacteria>)

1. Preparation for the *Chemical Heritage* “Conflicts in Chemistry” role-playing activity can be done at home. Information for this activity is located under number 6 in the In-class activity section.
2. In 2013, one of my chemistry students attended a summer program at the University of Illinois in Materials Science. The Women in Engineering Camp for high school girls was a wonderful experience that reinforced her interest in a career in engineering. Professors lectured and graduate students ran the labs. She wrote that, “The 3D printing was really cool! We actually got to scan ourselves into a computer and then 3D print ourselves.” She returned with small 3D printed objects to show her classmates. I would highly recommend this program for female students interested in science and engineering. (<http://engineering.illinois.edu/academics/undergraduate/communities/WIE/games.html>)

## References (non-Web-based information sources)



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [http://ww.acs.org/chemmatters](http://www.acs.org/chemmatters)**. Scroll about half way down the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

The *ChemMatters* references cited below are related to the polymers used in the Wetterschneider 3D printer article.

Wood, C. Detergents. *ChemMatters* **1985**, *3* (2), pp 4–7. Surfactants such as ABS are discussed and identified as environmental pollutants, resistant to bacterial decomposition. ABS contributes to the suds found in polluted rivers.

Wood, C. Dissolving Plastic. *ChemMatters* **1987**, *5* (3), pp 12–15. This article is about another bioplastic, poly(vinyl alcohol), PVA. Hospitals put laundry in water-soluble laundry bags (made of PVA) to reduce the chance of exposure to infection. The PVA bag is tossed into the washer and as the laundry is cleaned, the bag dissolves completely in the hot water. The article discusses basic polymer chemistry including the formation of PVC. Student laboratory suggestions for solubility testing are given in the article. An envelope containing a PVA sample was included in the original magazine.

Downey, C. Biodegradable Bags. *ChemMatters* **1991**, *9* (3), pp 4–6. This article describes making polylactic acid (PLA) bags from lactic acid formed by the fermentation of potato peelings. An experiment designed to examine the biodegradable properties of these bags is included in the article.

Black. H. Putting a High Grade on Degradables. *ChemMatters* **1999,** *17* (2), pp 14–15. The process of making PLA for use as disposable garbage bags is described. These environmentally friendly bags can be decomposed by bacteria in compost heaps.

Washam, C. Plastics Go Green. *ChemMatters* **2010**, *28* (2), pp 10–12. As the title implies, this article discusses ways to “green” our lives by replacing petrochemicals with bioplastics such as PLA (used in the Wetterschneider 3D printer article) and PHA (polyhydroxyalkanoate, a biodegradable bioplastic produced by the bacterial fermentation of sugars or lipids). On page 12, there is an in-class chemistry activity: “Make Your Own Compostable Bioplastic”, using corn starch. The reference for this lab comes from the *Field Guide to Utah Agriculture in the Classroom, Volume 1*: The URL given in the *ChemMatters* article is no longer available online, but the original lab activity, *Corn Starch Plastic,* can be found at <https://utah.agclassroom.org/files/uploads/fieldguide1/plastic.pdf>.

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Selected *Chemical and Engineering News* (*C&EN*) articles address the topic of 3D printing. Some of these are available only to ACS members.

* Virginia Tech scientists have developed a process to 3D print with ionic liquids. Thus, they can print ion-conducting membranes for batteries and fuel cells, or grow tissues for bone and skin grafts. (<http://cen.acs.org/articles/92/web/2014/11/Printing-3-D-Conductive-Materials.html>) (available to all)
* A more recent article on the same research, in the December 1, 2014 issue of *C&EN*, is available to ACS members. (<http://cen.acs.org/magazine/92/09248.html>) (subscribers only)
* At Princeton University, researchers have 3D printed LEDs by stacking a layer of quantum dots on top of printed conductive polymers and between metallic contacts. This article is available to ACS members. (<http://cen.acs.org/articles/92/i45/Extending-Reach-3-D-Printing.html>) (subscribers only)
* This article addresses the business end of 3-D printing. Many people still consider the technology merely as a creative way to print and play. At the ACS National Meeting (San Francisco, August, 2014), Daniel Daly, chair of the ACS Division of Business Development & Management, spoke of the job opportunities in 3-D manufacturing such as GE’s use of 3-D printing for generating jet engine parts. <http://cen.acs.org/articles/92/i37/3-D-Printing-Steps-Toward.html> (available to all)

The *MIT Technology Review* reports that Harvard University is using 3-D technology to make objects that “sense and respond” to their environment. Princeton University researchers see the challenge to print 3-D artificial organs for drug testing or human replacement parts. They have printed eye tissue. This Web site contains a short, repeating video clip of the 3-D printing of the polymer layers to form a bionic ear. (<http://www.technologyreview.com/featuredstory/526521/microscale-3-d-printing/>)

## Web Sites for Additional Information (Web-based information sources)

**More sites on obtaining or creating files to control 3D printers**

This site sells 3D printers, but it also provides a very nice description of the types of printers and how they work: <https://bootsindustries.com/portfolio-item/3d-printers-technology-rundown/>.

**More sites on 3D printed things**

This site lists 30 things that are currently made by 3D printers. Note that they chose to omit any that referred to 3D printing of weapons. The objects printed range from “jet parts to unborn babies, icebergs to crime scenes, dolls to houses”.

(<http://www.theguardian.com/technology/2014/jan/29/3d-printing-limbs-cars-selfies>)

**More sites on putting the finishing touches on 3D printed things**

This site is for teachers to use with students to discuss solubility in depth. This will help in explaining the smoothing off of ABS plastic-3D printed objects by use of acetone. (<http://www.masterorganicchemistry.com/2012/04/27/polar-protic-polar-aprotic-nonpolar-all-about-solvents/>)

**More sites on 3D bioprinting of tissues and organs**

The ability to use biocompatible and biodegradable materials in 3D printers has opened the field of 3D printing to cells and supportive components of living systems. This research, published in *Nature Biotechnology*, December 05, 2013, provides detailed descriptions of these technologies including designing of files, types of bioprinters (inkjet, microextrusion, laser assisted), materials, scaffolds, and cell sources.

(<http://www.nature.com/nbt/journal/v32/n8/full/nbt.2958.html>)

**More sites on Disney research on tactile surfaces**

Disney Research Pittsburgh has produced 3D geometric features on touch screen surfaces. This allows a hiker to “feel” the ridges and bumps on a topography map or a blind person to detect the 3D shape of an apple. The energy produced by fingers sliding across or tapping the screen surface is sufficient to create the illusion of surface variations. The site contains an informative video and details regarding the algorithm and the calculation of the voltage requirement. (<http://www.disneyresearch.com/project/3d-touch-surfaces/>)

# Air Travel: Separating Fact from Fiction

## Background Information (teacher information)

**More on the history of the airline industry in the United States**

 One hundred years ago marked the first scheduled air service in Florida on January 1, 1914. Thomas Benoist built a seaplane, called Flying Boat #43, to transport people across Tampa Bay. The one paying customer, A.C. Phiel, won the auction for the trip by paying $400. The trip was 18 miles and took 23 minutes. The St. Petersburg-Tampa Air Boat Line continued running for four months offering 2 flights a day at a cost of $5 for a one way trip.

*The Flying Boat #43 on January 1, 1914. Percy E. Fansler, general manager of Tampa Air Boat Line at the left; Mayor A.C. Phiel and Tony Jannus, pilot*

*(*[*http://iata-production.s3.amazonaws.com/filestorage/images/13/1914%20first%20commercial%20flight%20image.jpg?width=444&height=255&quality=80&crop=0&method=ratio*](http://iata-production.s3.amazonaws.com/filestorage/images/13/1914%20first%20commercial%20flight%20image.jpg?width=444&height=255&quality=80&crop=0&method=ratio)*)*

These and other early flights were exciting and made the news, but commercial flying was not popular. People were afraid of the flying machines and the early aircraft was not much faster than the train. During World War I the airplane became a valuable asset, and major improvements, including larger motors, allowed the planes to achieve greater speeds. After the war there was an abundance of planes; therefore no new planes were being built and many aircraft builders went out of business. Many European countries began subsidizing their airline industries and offered flights over the English Channel. In the United States the aviation industry was also saved by the government using airplanes to transport mail. In 1917 the U.S. Congress appropriated $100,000 for airmail service between New York and Washington, D.C. By 1920 the airmail was being delivered across the continent, thus saving 22 hours. By the mid-1920s the Post Office mail service was booming. The U.S. Government sought the private sector to continue the service and, through the Contact Air Mail Act of 1925, gave legislative authority for the government to seek bids from the private sector. This opened the door for the creation of the private U.S. airline industry. The winners of the contracts would eventually become known as United Air Lines, Transcontinental and Western Air (TWA), American Airways (later American Airlines), Pan Am and Eastern Air Lines.

With Charles Lindbergh’s famous trip from New York to Paris in 1927 the age of air travel was solidified. In order to get people to fly instead of using the train, the planes needed to improve. They needed to be safer, faster and larger, and manufacturers went to work.

There were so many improvements to aircraft in the 1930s that many believe it was the most innovative period in aviation history. Air-cooled engines replaced water-cooled engines, reducing weight and making larger and faster planes possible. Cockpit instruments also improved, with better altimeters, airspeed indicators, rate-of-climb indicators, compasses, and the introduction of artificial horizon, which showed pilots the attitude of the aircraft relative to the ground - important for flying in reduced visibility.

(<http://www.avjobs.com/history/>)

With these improvements the first modern passenger airliner was built by Boeing in 1933, called the Boeing 247. It had a 3 person crew and room for 10 passengers. It had a cruising speed of 189 miles per hour and a range of 745 miles. Seventy five of the Boeing 247s were produced. Later in 1933, TWA contracted with Douglas Aircraft Company to produce the DC-1.

The DC-1 was very advanced for its day. Its fuselage was streamlined, as were its wings and engine cowlings. It featured all-metal construction and retractable landing gear. Variable-pitch propellers gave the plane remarkable takeoff and landing characteristics. With plush seats, a kitchen and a comfortable restroom, the DC-1 set a new standard for passenger comfort. Great efforts were made to insulate the passenger compartment from the noise of the plane's engines. The plane's passenger seats were mounted on rubber supports, while the cabin was lined with noise absorbing fabric. Carpet covered the cabin floor and even the engines were mounted on rubber insulators.

(<http://www.boeing.com/boeing/history/mdc/dc-1.page>)

With all the DC-1 advancements, only one was produced because the company improved the design to increase the number of passengers from 12 to 14 and created twenty five   
DC-2s. In 1936 Douglas produced the DC-3, which is the first plane that made air travel popular and profitable. As a result, by 1939, 90% of the airplanes were either DC-2s or DC-3s.

*Boeing DC-3*

*(*[*http://www.boeing.com/assets/images/history/mdc/images/D4E-535453\_n.jpg*](http://www.boeing.com/assets/images/history/mdc/images/D4E-535453_n.jpg)*)*

The Boeing 247, DC-2 and DC-3 made air travel popular and safe, but they had a major disadvantage. They could not go above 10,000 feet because there is insufficient air to breathe above that level. People become dizzy and would lose consciousness above that altitude. The industry wanted to be able to fly higher to avoid the rough weather at lower altitudes. Also with reduced air resistance at higher altitudes, they could fly faster and farther. The answer to these problems was solved by Boeing in 1938 by creating the Stratoliner, which was the first pressurized airplane. The pressurized cabin allowed the Stratoliner to fly to 20,000 feet carrying 5 crew and 33 passengers.

With this new industry came the need for regulations and agencies to oversee them. In 1938 the Civil Aeronautics Act created the Civil Aeronautics Board. This provided one agency to govern the airline industry. Its major functions were to determine airlines routes and to regulate prices for passenger fares. Since the airfares were regulated, the airlines competed for business by the services they offered. In 1958 the Federal Aviation Act was passed by Congress after two airplanes collided over the Grand Canyon. This legislation created the Federal Aviation Administration, which is responsible for managing all the safety issues, including air traffic control, certification of aircraft designs, airline training and maintenance programs. In the mid-1970s the need for deregulation was realized. Congress passed the Airline Deregulation Act of 1978, creating free market competition for air fares, and which disbanded the Civil Aeronautics Board shortly thereafter.

In recent history there have been setbacks to the growth of the airline industry. In 1981 the air traffic controllers went on strike. In 2001 the economic downturn decreased air travel at the same time labor and fuel costs were increasing. Then the 9/11 incidents further crippled the air industry. The industry did not really become profitable again until 2006.

**More on misconceptions about air travel**

There are numerous myths and misconceptions about air travel. Let’s look at a few others, besides those discussed in the *ChemMatters* article.

**Can lightning strikes cause an airplane to crash?** This is very unlikely. The last plane to crash in the United States due to lightning was in 1967. A bolt of lightning hit the fuel tank causing an explosion. Since then much has been learned, and the protection techniques are much improved. Airplanes actually get struck once a year on the average. Sometimes airplanes actually cause the lightning as they fly through charged regions of clouds. This lightning goes from the plane to the air and rarely causes any damage. Since 1930, engineers have worked to make planes safer to fly through lightning strikes.

And they do it by basically making sure there's a conductive path so that the lightning runs around the skin of the aircraft. It is dissipated out safely through points that have static wicks [antenna-like devices on wingtips] and so on, things that help the electricity flow around the aircraft and back out to the atmosphere.

(<http://www.cnn.com/2010/TRAVEL/08/17/planes.lightning.strikes/>)

Lightning could also affect the electronics and computers on board, so special care is taken to provide sufficient shielding, grounding and surge suppression to protect this equipment from the effects of the lightning. Likewise around the fuel tank and the fuel system there are static discharge precautions and grounding precautions to prevent sparks anywhere near the fuel. Also new fuels produce less explosive vapors and are therefore safer.

**Do airplanes dump human waste into the air?** No, all human waste is flushed to a holding tank and emptied when the plane lands. The pilot has no controls that would release the waste. The only lever to open the tank is on the outside of the plane. People routinely report that they have seen or been hit by “blue ice” which they believe is human waste mixed with the blue chemical water in the toilet and then frozen at high altitudes. The Federal Aviation Administration investigates these reports and almost always finds that it is bird droppings. There is a reason people still talk and report blue ice. The blue coloring was due to the deodorizing liquid which is also used in Port-a-Johns. Until the 1980s airplanes used electric pumps to flush away the waste and circulate fresh liquid into the bowl. Besides having to carry hundreds of gallons of deodorizing fluid, which increased fuel costs and reduced the number of passengers that could be carried, these systems tended to leak. The leaks would escape to the outside of the plane and freeze. As the plane dropped to land the “blue ice” would begin to melt and fall from the airplane. Since 1980 the design of the toilet on the airplane has changed and the blue deodorizer is no longer needed. James Kemper invented the vacuum toilet that is used today on airplanes.

Vacuum toilets rely on strong suction and slick walls to pull waste away using just a fraction of a gallon of water. Pressing the flush button opens a valve in the bottom of the bowl, exposing the contents to a pneumatic vacuum. That vac sucks the load down the plane's sewer line into a 200-gallon holding tank—vapors and all. A Teflon-like non-stick coating around the inside of the bowl assists in the transfer. Then, waste remains in the tank for the duration of the flight, and it's vacuumed out by crews on the ground. An exterior latch on the holding tank ensures that pilots don't accidentally drop a load in mid-air.

(<http://gizmodo.com/5953877/what-happens-when-you-flush-a-toilet-on-an-airplane>)

**Since the toilets now operate using a strong vacuum system is it possible to get stuck on the toilet?** In theory it is possible, but your body would have to make a perfect seal with the toilet. This is nearly impossible with the size and shape of the modern airplane toilet.

**Can cell phones bring down a plane?** There is no evidence that the electromagnetic interference from small electronic devices like cell phones have ever brought down a plane or contributed to an accident. It was shown at the Boeing’s Electromagnetic Interference Lab in Seattle that a laptop’s electrical emission could interfere with the Visual Flight Rules, VFR, radios. This would not bring down a plane but the interference could cause more work for the pilots during critical times in the flight, such as take-off and landing. The pilot’s attention could be distracted lowering the level of safety. According to a CNN report:

Cell phones and laptops with wireless network capabilities -- devices that transmit signals -- fall into a category of their own when in transmit mode. Those transmissions are banned by both the FAA, because of potential airplane interference, and the Federal Communications Commission, because of potential interference with wireless networks on the ground. And for that reason, the government industry committee reviewing portable electronic usage will not consider the airborne use of cell phones for voice communications during flight.

(<http://www.cnn.com/2013/09/23/travel/cell-phones-devices-on-airplanes/>)

The rules governing portable electronic devices (PEDs) are constantly being tested and evaluated. In October 2013 the Federal Aviation Administration announced that airplanes could safely expand the use of PEDs, and it sent guidelines to the airline industry.

Passengers will eventually be able to read e-books, play games, and watch videos on their devices during all phases of flight, with very limited exceptions. Electronic items, books and magazines, must be held or put in the seat back pocket during the actual takeoff and landing roll. Cell phones should be in airplane mode or with cellular service disabled – i.e., no signal bars displayed—and cannot be used for voice communications based on FCC regulations that prohibit any airborne calls using cell phones. If your air carrier provides Wi-Fi service during flight, you may use those services. You can also continue to use short-range Bluetooth accessories, like wireless keyboards.

(<http://www.faa.gov/news/press_releases/news_story.cfm?newsId=15254>)

The use of cell phones and laptops during take-off and landing potentially create other problems. If passengers are using cell phones during take-off, will they pay attention to the safety instructions? Laptops in use during take-off and landing could become flying projectiles if severe turbulence occurs.

**More on** **atmospheric pressure and altitude and the effects on humans**

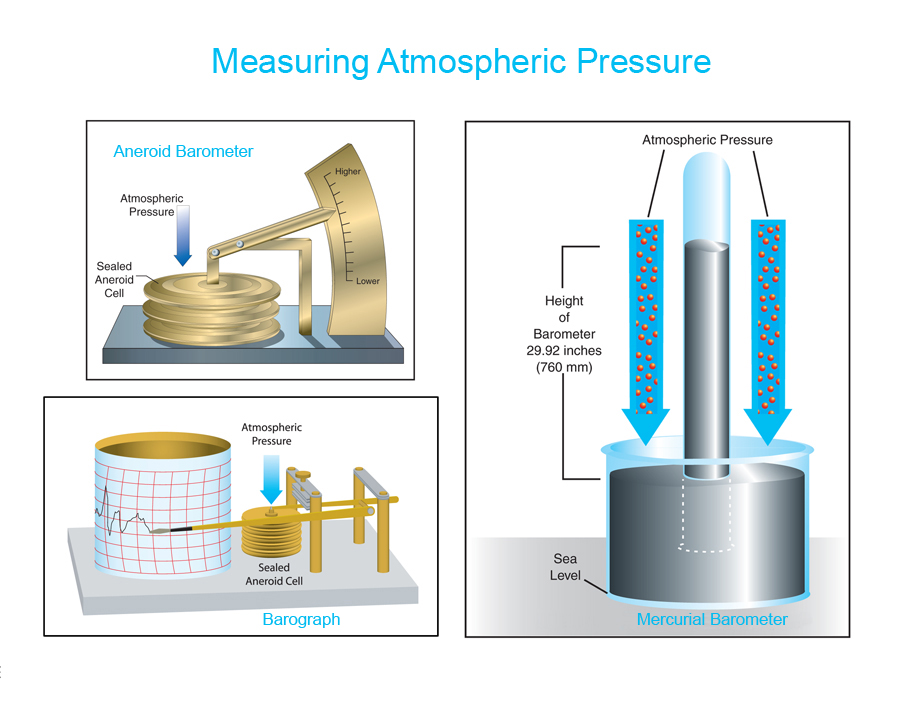
Pressure is defined as force per unit area. Atmospheric pressure is caused by the force of the air molecules exerted on Earth as gravity pulls it to the surface. The more air above you, the greater the pressure. Typically, at sea level there is the greatest amount of air above so the pressure is the greatest. As the altitude increases the column of air above decreases, so the pressure decreases.

Air pressure is measured using a barometer. There are two basic types of barometers, a mercury barometer and an aneroid barometer.

A mercurial barometer has a section of mercury exposed to the atmosphere. The atmosphere pushes downward on the mercury. If there is an increase in pressure, it forces the mercury to rise inside the glass tube and a higher measurement is shown. If atmospheric pressure lessens, downward force on the mercury lessens and the height of the mercury inside the tube lowers. A lower measurement would be shown. This type of instrument can be used in a lab or a weather station, but is not easy to move!

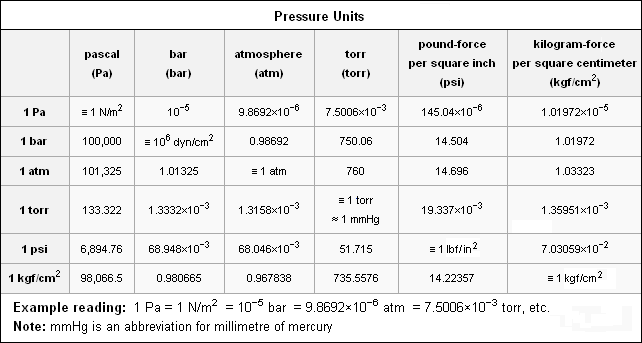
An aneroid barometer can be used in place of a mercury barometer. It is easier to move and is often easier to read. This instrument contains sealed wafers that shrink or spread out depending on changes of atmospheric pressure. If atmospheric pressure is higher, the wafers will be squished together. If atmospheric pressure lessens, it allows the wafers to grow bigger. The changes in the wafers move a mechanical arm that shows higher or lower air pressure.

(<http://www.windows2universe.org/earth/Atmosphere/measuring_press.html>)



*(*[*http://www.windows2universe.org/earth/images/measuring\_press\_big.jpg*](http://www.windows2universe.org/earth/images/measuring_press_big.jpg)*)*

There are many units used to measure atmospheric pressure. The SI unit for pressure is the pascal. The table below provides a list of atmospheric pressure units and their relationship to each other.



*(*[*http://static.trunity.net/files/185301\_185400/185312/pressurechart.png*](http://static.trunity.net/files/185301_185400/185312/pressurechart.png)*)*

As the altitude increases the number of air molecules decreases, people say the “air is thinner”, it becomes harder to breathe. Although the amount of air decreases, the percentage of oxygen and nitrogen molecules remain the same. With fewer air molecules these are fewer oxygen molecules—and they are further apart—so there is less oxygen to breathe. The reduced amount of oxygen to breathe can have many effects on the human body.

One of the most common effects is altitude sickness or mountain sickness. Not everyone is affected by this and there are no indications about who will be affected. This most commonly occurs at 8,000 ft. (2,441 meters or 1.5 miles) above sea level. At this height the pressure is only 77 kPa (574 mm or 0.76 atm) and there is only 76% of the oxygen available at sea level. The initial symptoms of altitude sickness are nonspecific and are similar to the flu or a hangover. The symptoms may include fatigue, dizziness, headache, nausea and swelling of extremities. The cause is described by the report from Princeton University.

In order to properly oxygenate the body, your breathing rate (even while at rest) has to increase. This extra ventilation increases the oxygen content in the blood, but not to sea level concentrations. Since the amount of oxygen required for activity is the same, the body must adjust to having less oxygen. In addition, for reasons not entirely understood, high altitude and lower air pressure causes fluid to leak from the capillaries which can cause fluid build-up in both the lungs and the brain. Continuing to higher altitudes without proper acclimatization can lead to potentially serious, even life-threatening illnesses.

(<http://www.princeton.edu/~oa/safety/altitude.html>)

The best treatment for attitude sickness is to return to a lower altitude. If not treated it can become life threatening.

At high altitudes and low pressure, humans also experience physical and psychological effects. The reduction in the amount of oxygen one is able to breathe reduces the amount of oxygen to muscles and the brain. Regardless of one’s physical fitness, the level of physical activity one can maintain is severely reduced at high altitudes. Likewise mental abilities are diminished, which most notably include decreased perception, memory, judgment, and attention.

High altitudes with diminished oxygen consumption may also result in sleep difficulties. The low oxygen directly affects the sleep center of the brain. Frequent awakenings, a light sleep and less total time of sleep are the main problems, and these usually improve with acclimatization after a few nights. Some persons, however, will have trouble sleeping despite acclimatization.

(<http://www.altitudemedicine.org/index.php/altitude-medicine/altitude-physiology/what-to-expect-when-you-come-to-altitude>)

The taste of food at high altitude and low pressure, like on an airplane, is also affected. Airlines have dealt with complaints of the lack of taste in their food in flight. People have always complained about airline food. It is not totally the airline’s fault, for food is less savory at 30,000 feet. In flight, not only does the pressure decrease but also the humidity decreases. Both of these changes reduce taste bud sensitivity. The taste of saltiness and sweetness is actually reduced by 30%. There is an additional effect. Flavor is a combination of both taste and smell.

“When you put something in your mouth, the vapors from this pass through the nasopharynx to reach the olfactory receptors high in the nose,” explains Dr. Tom Finger, professor at the University of Colorado School of Medicine and co-director of the Rocky Mountain Taste and Smell Center.

In addition to reduced taste bud sensitivity, cabin pressurization causes our mucus membranes to swell, blocking this pathway (remember the last stuffy nose you had and how difficult it was to enjoy your chicken noodle soup?). Cabin pressure also decreases the volatility of odor molecules, or their ability to vaporize and enter the nose.

(<http://www.nbcnews.com/health/body-odd/one-reason-airline-food-so-bad-your-own-tastebuds-f6C10823522>)

The combination of these effects makes gourmet food at sea level taste very bland on the airplane.

**More on Henry’s Law and Boyles Law**

**William Henry** was born in Manchester, England in 1775. As a physician and a chemist he developed what is known as Henry’s Law in 1803. The law states that at a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid. The mathematical relationship can be stated in a variety of ways.



*(*[*http://upload.wikimedia.org/wikipedia/commons/e/ef/William\_Henry.jpg*](http://upload.wikimedia.org/wikipedia/commons/e/ef/William_Henry.jpg)*)*

One common expression is given as: C = kHP where C is the concentration of the dissolved gas in the liquid, kH is the temperature- dependent constant, and P is the partial pressure of the gas above the solution. Others sources use the expression P = kHC (the kH is different, see below). Both forms of the law express the concept that the concentration of a gas in a liquid is directly proportional to the partial pressure of the gas above the surface of the liquid. In other words as the pressure increases the amount of gas dissolved in the liquid increases and vice versa. The difference in the forms of the equation will be the value and the units of kH.

The unit of kH is expressed in a number of different units, depending upon the units of concentration and pressure. Henry’s law is obeyed most accurately for dilute solutions and for gases that do not react with the liquid.



*(Graham, T. Unusual Sunken Treasure.* ChemMatters***2006****,* 24 *(4), pp 11*–*13)*

An application of Henry’s law is seen in the carbonation of soft drinks:

This is how soft drinks are carbonated. At the bottling plant, the beverage is placed in the can or bottle under high pressures of carbon dioxide. These high pressures force the carbon dioxide to dissolve in the liquid. When you “pop the top”, the pressure decreases and gas begins to leave the solution, forming bubbles—fizz. Eventually, most of the carbon dioxide leaves the solution, and the drink is flat.

(Kimbrough, D. Noisy Knuckles and Henry’s Law. *ChemMatters* **2000**, *18* (4), pp 12–13)

Understanding Henry’s law is critical in scuba diving. As a diver goes deeper into the ocean, the external pressure increases and he inhales more deeply to equalize the pressure. This results in more nitrogen dissolving in his blood. If the diver surfaces too rapidly, which causes the pressure to decrease rapidly, the nitrogen will come out of solution. These gas bubbles in the bloodstream block capillaries and prevent oxygen from getting to the body tissues. This is painful and causes a dangerous condition called the “bends”, which can be fatal.

**Robert Boyle** was born in Munster, Ireland in 1627. He was committed to the New Philosophy which valued observation and experimentation as much as logical thinking. Boyle’s prime interest was in chemistry, but his first published work, *New Experiments Physico-Mechanical Touching the Spring of the Air and Its Effects*, dealt with the physical nature of air. The second edition of this work, published in 1662, described the relationship between pressure and volume of a gas that we now know as Boyle’s law.



*(*[*http://images.npg.org.uk/264\_325/2/8/mw00728.jpg*](http://images.npg.org.uk/264_325/2/8/mw00728.jpg)*)*

As we know, Boyle’s law states that, for a sample of gas at constant temperature, the pressure exerted by the gas is inversely proportional to its volume. Another way of stating it is that the product of the pressure of the gas and its volume is constant. P = k/V or PV = k, where P is the pressure of the gas, V is the volume, and k is the constant for a particular gas.

Divers also have to be familiar with Boyle’s law since within the body there is air, such as in the lungs, which can be pressurized:

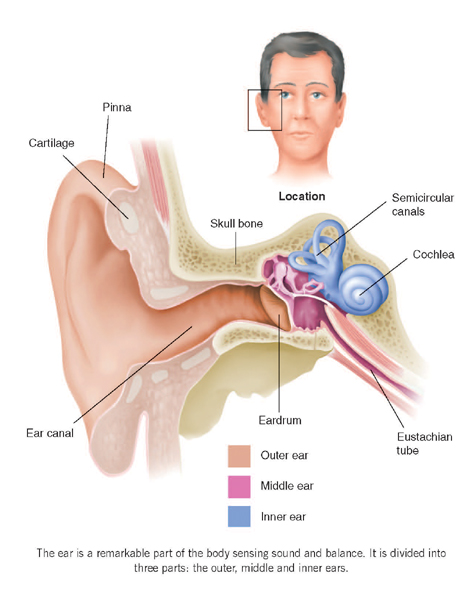
If divers descend without scuba gear, the volume of these body cavities decreases as the surrounding water pressure becomes greater. However, this effect is not experienced by divers using scuba gear because the regulator on the air tanks delivers air at the same pressure as the surroundings. But if divers must make emergency ascents from this depth, they must remember to breathe out steadily as they return to the surface. If they don’t, the pressure of the air in their lungs will cause their lungs to expand, causing rupturing of lung tissue.

(Belleman, M. Scuba: The Chemistry of an Adventure. *ChemMatters* **2001**, *19* (1),   
pp 7– 9)

Other examples of the application of Boyle’s Law are the use of a syringe. When you pull back on the plunger the volume inside the syringe increases, which decreases the pressure causing the liquid to be drawn into the syringe. You will experience Boyle’s Law if you have ever opened a plastic water bottle to take a drink on an airplane at high altitude and then closed it. When you land and return to normal atmospheric pressure the bottle will appear slightly crushed. Likewise at high altitude a sealed bag of peanuts or chips will appear greatly expanded. Let’s not forget that the popping of ears with a change in altitude, and as a result a change in pressure, is also an example of Boyle’s law.

**More on the ear and ear popping**

The ear is an amazing structure and it is not just for hearing. It is also responsible for giving us a sense of position and balance. The ear consists of three sections; outer, middle and inner ear.



*(*[*http://www.familydoctor.co.uk/wp-content/uploads/2013/10/ear-overview.jpg*](http://www.familydoctor.co.uk/wp-content/uploads/2013/10/ear-overview.jpg)*)*

**The outer ear** includes the ear lobe and the pinna. The pinna is made of ridge cartilage covered with skin. It funnels sound through the ear canal to the ear drum, the tympanic membrane. The ear drum separates the outer ear from the inner ear.

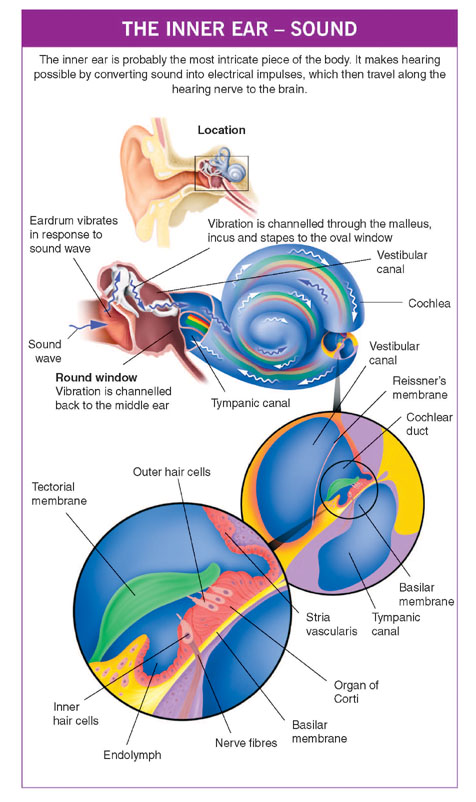
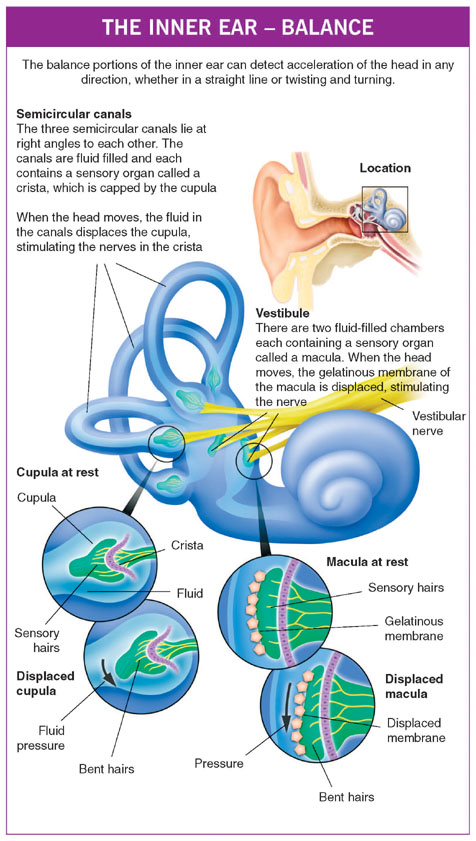
**The middle ear** is filled with air. As sound is funneled into the ear canal, it causes the ear drum to vibrate. The vibration is transmitted to the three small bones in the middle ear. These bones are called the ossicles and include the malleus (hammer), incus (anvil), and stapes (stirrup). The ossicles amplify the vibration and transmit it to the oval window which separates the middle ear from the inner ear. Also within the middle ear is the Eustachian tube, which connects the middle ear to the back of the nose and throat. It allows air in and out of the middle ear so that the air pressure on either side of the ear drum is equal and keeps the ear drum from bulging or retracting. If the ear drum is stressed then it will not transmit sounds as well and will cause pain. The Eustachian tube also allows fluid to drain from the middle ear.

**The inner ear** is composed of two major structures, the cochlea and the vestibular system. The cochlea is mainly responsible for hearing while the vestibular system is involved in maintaining balance.

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*(*[*http://www.familydoctor.co.uk/wp-content/uploads/2013/10/inner-ear.jpg*](http://www.familydoctor.co.uk/wp-content/uploads/2013/10/inner-ear.jpg)*)*

*(*[*http://www.familydoctor.co.uk/wp-content/uploads/2013/10/Inner-ear-sound.jpg*](http://www.familydoctor.co.uk/wp-content/uploads/2013/10/Inner-ear-sound.jpg)*)*



Ears pop with rapid changes in air pressure, such as when flying or scuba diving. This causes a precipitous rush of air through the Eustachian tube, causing a popping sensation. This adjustment in the middle ear is necessary to keep the eardrum vibrating normally. In an airplane it is easier for your ears to adjust during take-off than landing. During take-off the external pressure is dropping so the air in the middle ear is rushing out. During landing the external air pressure is increasing and air must go into the inner ear to balance the pressure.

But it's a lot easier to let air out of a smaller space and into a bigger space than vice versa. Think of the balloon …: inflating a balloon takes more work than letting the air out. So balancing the air pressure in your ears while you're landing usually takes more effort on your part.

(<http://sciencenetlinks.com/science-news/science-updates/popping-ears/>)

If you are flying with a cold, sinus infection or allergies, your Eustachian tube could be blocked, creating problems.

The Eustachian tube can be blocked, or obstructed, for a variety of reasons. When that occurs, the middle ear pressure cannot be equalized. The air already there is absorbed and a vacuum occurs, sucking the eardrum inward and stretching it. Such an eardrum cannot vibrate naturally, so sounds are muffled or blocked, and the stretching can be painful. If the tube remains blocked, fluid (like blood serum) will seep into the area from the membranes in an attempt to overcome the vacuum. This is called fluid in the ear, serous otitis or aero-otitis. Uncommon problems include developing a hole in the ear drum, hearing loss and dizziness.

(<http://www.entnet.org/content/ears-and-altitude>)

For that reason it is recommended to avoid air travel if possible when one has a cold or sinus infection.

**More on** **Plexiglas™**

Plexiglas™ is a synthetic polymer of methyl methacrylate. It is a thermoplastic, meaning it becomes pliable above a specific temperature and then hardens again when cooled. Plexigas™ is a trade name owned by Rohm and Haas Company. It is also known as Lucite™ and Acrylite™.



(<http://www.pslc.ws/macrog/kidsmac/images/pmma02.gif>)

Plexiglas™ is stronger and more shatter-resistant than glass. It is less dense than glass so it is lighter weight, which makes it easier to handle and reduces shipping and fuel costs. It is more transparent and less reflective than glass. Where thick windows are needed, such as in an aquarium or airplane, Plexiglas™ is the best choice because of its strength and its transparency. Plexiglas can be as thick as 13 inches and remain clear, whereas glass that thick would not.

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Risk-Benefit Analysis**—This article compares the risk of traveling by air to that of driving in a car. This provides the opportunity to discuss the importance of analyzing and comparing risks and benefits of a particular activity.
2. **Air pressure—**Air pressure is explained in this article. It explains how and why it changes with altitude. The article also discusses how air pressure affects your breathing and your ears.
3. **Force**—An understanding of force is gained in the discussion of the pressure difference between the external pressure and that of the cabin. It explains how to determine the force needed to open the airplane door while in flight.
4. **Henry’s Law**—Henry’s Law is one of the reasons carbonated beverages go flat faster on an airplane.
5. **Boyle’s Law**—Boyle’s Law is not stated by name in the article, but it is the reason the carbon dioxide bubbles in a carbonated beverage grow larger on an airplane.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“The oxygen masks are just there to get you high and calm you down.”** *This misconception was probably a result of a statement Brad Pitt made in the movie “Fight Club”. If the airplane does become depressurized you need to wear the oxygen mask. If the cabin is not pressurized then the air at high altitudes is too thin and there is not enough oxygen for your body to function normally. Without the oxygen mask, and if the airplane depressurizes, one would lose consciousness very quickly. Breathing pure oxygen does not make one inebriated.*
2. **“Air on an airplane is full of germs.”** *Studies show the air on a crowded airplane has less germs that most crowded areas. The air on an airplane is a mixture of fresh air and recirculated air. The fresh air comes off the engine compressors where it is cooled and mixed with the recirculated air. Half of the circulated air is vented and the other half is sent through filters, which are “hospital quality” and remove 94-99.9% of the airborne microbes. There is a total changeover of air every two to three minutes. So the air is not full of germs, but we cannot say that about the tray tables, arm rests and seat belts.*
3. **See also “More on misconceptions about air travel”.**

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“Why is there a little hole in each window on the airplane?”** *Many airplane windows have a small hole, less than 2 millimeters in diameter, in them. This hole is only in the innermost layer of the window and is designed to allow cabin pressure to push against the outer layer of the window, which is stronger than the inner layer.*
2. **“What is jet lag?”** *Jet lag is a temporary sleep disorder caused by travelling long distances quickly on an airplane. This disrupts one’s circadian rhythms, one’s internal clock, which tells the body when to go to sleep and when to wake up. The severity of the sleep disorder is worse the more time zones crossed. The symptoms include disturbed sleep, waking up early, daytime fatigue, difficulty in concentrating, constipation or diarrhea, and a general unwell feeling.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. An investigation of Henry’s law using a syringe, a carbonated beverage, and methyl red can be found at <http://chemmovies.unl.edu/chemistry/smallscale/SS038.html>. This includes the materials needed, procedure, time required and expected results. There are also short movie clips(less than a minute) to aid in the set up. A YouTube video of a similar investigation can be seen at <https://www.youtube.com/watch?v=gUfhvbnBWs0>. This video (2:13) is short and well done.
2. A very simple investigation of Boyle’s lab with minimal equipment is demonstrated in this YouTube video: <https://www.youtube.com/watch?v=vSFVMJQ4J7U>. This video (9:07) is designed to give the teacher instructions on how to set up and perform the investigation for their classes.
3. There are many good simulations available to demonstrate Boyle’s law. With these the students could collect and graph data and determine the relationship between pressure and volume. This could be assigned as an out of class activity as well. Three such sites are listed below:

<http://phet.colorado.edu/en/simulation/gas-properties>,

<http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law_graph.html>, and

<http://www.uccs.edu/vgcl/gas-laws/experiment-1-boyles-law.html>.

1. An excellent way to demonstrate the effect of air pressure is the collapsing soft drink can demonstration. In this demonstration a partial vacuum is produced by the rapid condensation of steam within in the can. The external air pressure causes the can to collapse. There are many references and videos available online. Here two references that are easy to follow:

<http://scifun.chem.wisc.edu/homeexpts/COLLAPSE.html> and

<http://weirdsciencekids.com/collapsingcan.html>.

1. An excellent series of experiments involving properties of gases, especially the properties of air pressure can be found in the investigation called “Properties of Gases” in *Chemistry in the Community* textbook produced by the American Chemical Society. This series of experiments, set up as 9 different lab stations, can be viewed in the video (4:36) online at <http://bcs.whfreeman.com/chemcom6e/#665402__762232__>.
2. *The Safest Journey* is an activity that analyzes the risk and benefits for various modes of travel. This is an activity in the textbook *Chemistry in the Community*. American Chemical Society. *Chemistry in the Community*, 6th ed., W. H. Freeman and Company/BFW: New York, 2012; pp 670-671. It can also be found online at <http://goo.gl/vrLmU5>.
3. “Getting a Lift” is a fun activity that investigates air pressure using straws, a plastic garbage bag and a piece of plywood. It can be found at *ChemMatters* 1983, 1 (*1*), pp 13.

## Out-of-class Activities and Projects (student research, class projects)

1. To demonstrate Boyle’s Law, students could make Cartesian Divers as an out-of-class project. There are numerous Web sites that provide instruction for making them. The following Web sites provide good instructions and explanations:

<http://chemed.chem.purdue.edu/demos/demosheets/1.2.html>,

<http://www.usc.edu/org/cosee-west/MidwaterRealm/11CartesianDiver.pdf> and

<https://www.youtube.com/watch?v=s5eIRjmor1w>.

1. Students could be assigned to watch a portion of a movie with a plane crash or disaster. They could then evaluate the movie for the science content and validity. The two Web sites listed below provide some examples of clips from movies involving airplane crashes.

<http://www.shortlist.com/entertainment/films/most-terrifying-movie-plane-crashes> and

<https://www.youtube.com/watch?v=OOrt2yXcGZk>.

1. Students could research ways in which the effects of jet lag could be minimized.
2. Students could create a barometer by following the instructions given in the following video: <https://www.youtube.com/watch?v=jmQ8FWnM0fA>.

## References (non-Web-based information sources)



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [http://ww.acs.org/chemmatters](http://www.acs.org/chemmatters)**. Scroll about half way down the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

Gas Laws and Scuba Diving. *ChemMatters* **1983**, *1* (1), pp 4–6. This is an old article but contains a well written explanation of pressure, Boyle’s Law and Henry’s Law in context with scuba diving.

Kimbrough, D. Noisy Knuckles and Henry’s Law. *ChemMatters* **2000**, *18* (4), pp 12–13. Kimbrough explains Henry’s Law and relates it to the cracking of joints as well as relating it to the need to understand Henry’s Law if scuba diving.

Graham, T. Unusual Sunken Treasure. *ChemMatters* **2006**, *24* (4), pp 11–13. Both Henry’s Law and Boyle’s Law are used to explain the difficulties in recovering bottles of champagne from a ship wrecked in 1916.

## Web Sites for Additional Information (Web-based information sources)

**More sites on** **the history of the airline industry**

This *U.S.A. Today* article provides a brief overview of the history of the airline industry: <http://traveltips.usatoday.com/history-airline-industry-100074.html>.

The following Web sites provide extensive information about the history of the airline industry:

* <http://www.avjobs.com/history/>,
* <http://www.ibtimes.com/how-airline-industry-has-evolved-100-years-commercial-air-travel-1524238>, and
* <http://james-a-watkins.hubpages.com/hub/A-History-of-Commercial-Airliners>.

The story of the first commercial airline flight is described in this article: <http://www.firstflightcentennial.org/the-first-commercial-flight/>.

This Web site has an interactive timeline describing the history of air travel: <http://www.timetoast.com/timelines/90215>.

**More sites on** **misconceptions about air travel**

An interactive quiz about the facts and myths of airplane travel can be found at this Web site. (<http://science.howstuffworks.com/transport/flight/modern/airplane-myths-and-facts-quiz.htm>)

Ten myths commonly heard about airplane travel are briefly discussed here: <http://www.businessinsider.com/10-airplane-myths-debunked-2013-9>.

Facts about airplane travel are discussed from a pilot’s perspective. (<http://www.skyscanner.net/news/secret-pilot-21-air-travel-truths-revealed>)

Myths about airplanes that come from movies are discussed in this article. It also includes some video clips from movies. (<http://www.cracked.com/article_15421_5-myths-about-flying-everyone-believes-thanks-to-movies.html>)

This *U.S. News and World Report* discusses the use of cell phones during flight: <http://www.usnews.com/opinion/articles/2013/12/12/the-fcc-should-allow-cell-phones-on-planes>.

More myths and facts about airplane and air travel can be found at these two Web sites:

* <http://www.boston.com/community/blogs/askthepilot/2013/03/the_five_most_annoying_myths_a.html> and
* <http://travel.cnn.com/explorations/life/flight-mysteries-explained-085800>.

An explanation of the effects of a lightning strike on an airplane is given at <http://www.scientificamerican.com/article/what-happens-when-lightni/>.

Information about the oxygen and oxygen masks used on airplanes is given in this article: <http://scaredflightless.com/2012/08/06/the-truth-and-myths-about-oxygen-masks-on-airplanes/>.

**More sites on** **atmospheric pressure, altitude and the effects on humans**

The following Web sites give clear, basic explanations of atmospheric pressure:

* <http://usatoday30.usatoday.com/weather/wbarocx.htm>,
* <http://education.nationalgeographic.com/education/encyclopedia/atmospheric-pressure/?ar_a=1>, and
* <http://kids.earth.nasa.gov/archive/air_pressure/>.

A great interactive Web site that calculates the air pressure and oxygen levels at various altitudes can be found here: <http://www.altitude.org/air_pressure.php>.

A table of atmospheric pressure at various altitudes is given at <https://www.avs.org/AVS/files/c7/c7edaedb-95b2-438f-adfb-36de54f87b9e.pdf>.

The physiological effects of high altitudes are describes in this article: <http://adventure.howstuffworks.com/outdoor-activities/climbing/altitude-sickness1.htm>.

The U.S. Army medical department briefly describes some altitude effects on the human body here: <http://phc.amedd.army.mil/topics/discond/ai/Pages/AltitudeEffects.aspx>.

This extensive article from Princeton University thoroughly explains altitude sickness, its prevention and acclimation: <http://www.princeton.edu/~oa/safety/altitude.html>.

The following two videos provide information about atmospheric pressure and include demonstrations of the effects of air pressure. They are both short and could easily be shown to a class. (<https://www.youtube.com/watch?v=xJHJsA7bYGc> and

<https://www.youtube.com/watch?v=jmQ8FWnM0fA>)

**More sites on Henry’s Law and Boyle’s Law**

A brief but interesting biography of William Henry can be found at <http://www.thornber.net/cheshire/ideasmen/henry.html#_ftn7>.

William Henry’s original paper, “Experiments on the Quantity of Gases Absorbed by Water, at Different Temperatures, and at Different Pressures”, can be found at this Web site: <http://rstl.royalsocietypublishing.org/content/93/29.full.pdf+html>.

This site contains a very basic description of Henry’s Law, as well as some sample calculations: <http://chemwiki.ucdavis.edu/Physical_Chemistry/Physical_Properties_of_Matter/Solutions_and_Mixtures/Ideal_Solutions/Dissolving_Gases_In_Liquids%2C_Henry's_Law>.

A Kahn video gives a nice explanation of Henry’s law: <https://www.khanacademy.org/science/health-and-medicine/respiratory-system/gas_exchange/v/henry-s-law>.

The Chemical Heritage Foundation provides this biography of Robert Boyle: <http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/early-chemistry-and-gases/boyle.aspx>.

A brief history of Robert Boyle, a definition of Boyle’s Law and some real world examples of Boyle’s Law are given at <http://chemteacher.chemeddl.org/services/chemteacher/index.php?option=com_content&view=article&id=1>.

More real world example of Boyle’s Law are given at <http://hubpages.com/hub/Examples-of-Boyles-Law>.

The actual data Robert Boyle collected as well as a brief description of his experiment can be found at <http://www.chemteam.info/GasLaw/Gas-Boyle-Data.html>.

The “Soda Pop Geyser” is demonstrated in this video by Lee Marek. It is a demonstration of both Henry’s Law and Boyle’s Law. (<http://www2.chem.uic.edu/marek/cgi-bin/vid7b.cgi>)

**More sites on the structure of the ear and the popping of the ear]**

The anatomy of the ear and its function are described well in this Web site: <http://www.familydoctor.co.uk/unassigned-articles/the-structure-of-the-ear/>.

The following three articles explain why ears pop and how to minimize the effects from it:

* <http://www.entnet.org/content/ears-and-altitude>,
* <http://www.patient.co.uk/health/ears-and-flying>, and
* <http://gizmodo.com/why-your-ears-pop-and-what-to-do-if-they-dont-505598950>.

**More sites on** **Plexiglas™**

This Web site gives a brief explanation of poly(methyl methacrylate) and some of its uses: <http://www.pslc.ws/macrog/kidsmac/pmma.htm>.

An extensive discussion of Plexiglas™ can be found at <http://en.wikipedia.org/wiki/Poly%28methyl_methacrylate%29>.

Some of the advantages of using Plexiglas™ instead of glass can be found at <http://www.ehow.com/about_6690313_acrylic-windows-vs_-glass-windows.html>.

## More Web Sites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

The *ChemSource* module on gases has a wealth of teacher information dealing with gas laws and air pressure. It includes laboratory activities, demonstrations, discussion topics, and relevancy to the modern world. Hubert, J., Miller, J., Sherman, M. “Gases.” In *SourceBook*, Version 3.0, edited by Orna, M.V.; Smith, P.J.V. ChemSource, Inc.: New Rochelle, NY, 2010. (<http://dwb.unl.edu/ChemSource/SourceBook/117GASS.pdf>)