



December 2009 Teacher's Guide

Table of Contents

About the Guide	3
Student Questions	4
Answers to Student Questions	6
ChemMatters Puzzle: SU-CHEM-DU	10
Answers to the ChemMatters Puzzle	11
NSES Correlation	12
Anticipation Guides	12
Hollywood's Special Effects: How Did They Do That?.....	14
The Science of Snowflakes: Crystals from the Clouds.....	15
Space Food.....	16
The Vinland Map: The Vikings' Best Kept Secret.....	17
Reading Strategies	18
Hollywood's Special Effects: How Did They Do That?.....	19
The Science of snowflakes: Crystals from the Clouds.....	20
Space Food.....	21
The Vinland Map: The Vikings' Best Kept Secret.....	22
Hollywood's Special Effects: How Did They Do That?	23
Background Information.....	23
Connections to Chemistry Concepts.....	28
Possible Student Misconceptions.....	28
Demonstrations and Lessons.....	29
Student Projects.....	32
Anticipating Student Questions.....	32
References.....	33
Web Sites for Additional Information.....	33
The Science of Snowflakes: Crystals from the Clouds	37
Background Information.....	37
Connections to Chemistry Concepts.....	40
Possible Student Misconceptions.....	40
Demonstrations and Lessons.....	41
Student Projects.....	44
Anticipating Student Questions.....	45
References.....	45
Web Sites for Additional Information.....	45
Space Food	49
Background Information.....	49
Connections to Chemistry Concepts.....	58
Possible Student Misconceptions.....	59
Demonstrations and Lessons.....	59

Student Projects.....	59
Anticipating Student Questions.....	60
References.....	60
Web Sites for Additional Information.....	60
The Vinland Map: The Vikings' Best Kept Secret.....	62
Background Information.....	62
Connections to Chemistry Concepts.....	67
Possible Student Misconceptions.....	67
Demonstrations and Lessons.....	68
Student Projects.....	71
Anticipating Student Questions.....	72
References.....	73
Web Sites for Additional Information.....	74

About the Guide

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Articles from past issues of *ChemMatters* can be accessed from a CD that is available from the American Chemical Society for \$30. The CD contains all *ChemMatters* issues from February 1983 to April 2008.

The *ChemMatters* CD includes an Index that covers all issues from February 1983 to April 2008.

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

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Student Questions

Hollywood's Special Effects: How Did They Do That?

1. List three different chemical substances used by special effects experts. Tell what each is used for.
2. Why is artificial snow better than the real thing?
3. List at least five different recipes or substances used in the past for artificial snow (11 are listed in the article).
4. What's wrong with using confetti for snow?
5. What is a polymer?
6. Explain what happens in the hydrogen bonding inside the polymer chains when sodium polyacrylate is exposed to water.
7. List the three major ingredients in latex foam.
8. Explain the role of sulfur as a curing agent for latex foam as the foam is heated.
9. Heat "cures" latex foam. What cures silicone, and how does it work?
10. What is the advantage of using miniature buildings to represent on-screen explosions?
11. What are the main ingredients of black powder?

The Science of Snowflakes: Crystals from the Clouds

1. Name the basic 3 shapes of snow crystals.
2. Who was the first person to photograph snowflakes?
3. Who grew the first man-made snow crystals?
4. What else did this man discover?
5. What two properties of water molecules are responsible for the hexagonal structure of snow crystals?
6. Why do rough surfaces grow more quickly than facet planes?
7. Why doesn't all frozen water have faceted surfaces?
8. How do branched snow stars form?
9. Why do snowflakes frequently have complex shapes?
10. What two roles does dust play in the formation of snow crystals?

Space Food

1. What happens to astronauts' nutritional requirement for iron in space?
2. Which chemical element is related to bone loss by astronauts in microgravity? How does its rate of absorption in microgravity compare to that on Earth?
3. The article provides a table that lists several categories of space food. In what way are the categories of foods on the table different from traditional food categories?
4. Freeze drying relies on what change of phase process?
5. What are the triple point values on the phase diagram for water? For a bit of a challenge, answer the question also in units of Kelvins and Pascals.
6. What electrochemical reaction takes place at the anode of the fuel cell described in the article?

7. What is the net product of the reactions that occur in fuel cells, and why is the product important on a space mission?

The Vinland Map: The Vikings' Best Kept Secret

1. Why did Norwegian explorer Helge Ingstad mount an archeological expedition to the northeastern coast of Newfoundland? What did he discover?
2. What is the Vinland Map? When did it come to light?
3. How do the ancient documents the *Tartar Relation* and *Speculum Historiale* relate to the Vinland Map?
4. How was the connection made that, although found in the *Tartar Relation*, the Vinland Map may have originally been a part of the *Speculum Historiale*?
5. What were the results of the initial analysis of the ink used to draw the map?
6. How did further analysis refute claims made by McCrone?
7. What results were reported from the testing of the medium used to thin the ink and to make it flow more easily?
8. What date did the testing of the parchment for C-14 show?
9. Did the C-14 testing finally prove the authenticity of the Vinland Map?

Answers to Student Questions

Hollywood's Special Effects: How Did They Do That?

1. **List three different chemical substances used by special effects experts. Tell what each is used for.**

Chemicals used by special effects experts include:

- a) *wood or paper pulp to mimic a blanket of snow*
- b) *ash or foam representing falling snow*
- c) *liquid latex for leathery skin*
- d) *silicone for soft, wrinkly skin*
- e) *miniature models for burning or exploding to represent real objects*

2. **Why is artificial snow better than the real thing?**

Artificial snow is not cold or wet, and it doesn't pack down after one "take".

3. **List at least five different recipes or substances used in the past for artificial snow (11 are listed in the article).**

- a) *wood or paper pulp*
- b) *ash or foam*
- c) *gypsum shavings and cornflakes*
- d) *rice or potato starch*
- e) *plastics*
- f) *Epsom salts*
- g) *cotton wadding*
- h) *detergent suds*
- i) *asbestos dust*
- j) *corrosive salt*
- k) *cellulose powder*

4. **What's wrong with using confetti for snow?**

Confetti won't work to simulate snow because it has straight edges, and these cause the small pieces of paper to fall differently from snow, and it blows about like dry leaves, instead of clumping and drifting like regular snow.

5. **What is a polymer?**

"A polymer is a large molecule made up of repeating small molecules known as monomers."

6. **Explain what happens in the hydrogen bonding inside the polymer chains when sodium polyacrylate is exposed to water.**

Water molecules move into the polymer to dilute the sodium ions. The hydrogen atoms in water (δ^+) are then attracted to the oxygen atoms (δ^-) in the carboxylate ions.

7. **List the three major ingredients in latex foam.**

The three major ingredients in latex foam are a) liquid latex, the sap of the rubber tree, which is an aqueous dispersion of polymer chains, b) a foaming agent to introduce air bubbles into the mix, and c) a curing agent that links the polymer chains together. Actually, a fourth ingredient, a gelling agent, is added after the whipping stage. This agent clears the foaming agent from the latex prior to curing.

8. **Explain the role of sulfur as a curing agent for latex foam as the foam is heated.**

The S_8 rings break down into shorter chains and these shorter sulfur chains bind to carbon atoms in latex molecules, with a different latex molecule at each end of the sulfur chain. This

serves to bridge latex molecules, preventing them from moving independently, resulting in a much stiffer product.

9. **Heat “cures” latex foam. What cures silicone, and how does it work?**

Silicone requires a chemical catalyst to cure it. The chemical catalyst “... hardens the silicone by linking the silicone polymer molecules together.” This builds bridges among the silicone polymer molecules, similar to those bridging the latex polymer chains.

10. **What is the advantage of using miniature buildings to represent on-screen explosions?**

The advantage to using miniature buildings to represent on-screen explosions is SAFETY.

11. **What are the main ingredients of black powder?**

The main ingredients of black powder are sulfur, potassium nitrate and charcoal.

The Science of Snowflakes: Crystals from the Clouds

1. **Name the basic 3 shapes of snow crystals.**

The three basic shapes of snow crystals are wide flat plates, long thin columns, and branched snow stars.

2. **Who was the first person to photograph snowflakes?**

The first person to photograph snowflakes was Wilson Bentley.

3. **Who grew the first man-made snow crystals?**

Ukichiro Nakaya grew the first man-made snow crystals.

4. **What else did this man discover?**

Nakaya discovered that temperature and humidity affect how crystals grow; e.g., at -2°C , crystals grow short and wide, and at -5°C , they grow tall and thin. At low humidity crystals are small; at high humidity they grow larger and form complex branches.

5. **What two properties of water molecules are responsible for the hexagonal structure of snow crystals?**

The hexagonal structure of snow crystals is due to the polarity of the water molecule—the partially negative oxygen end of the water molecule attracts the partially positive hydrogen end of other water molecules—and the bond angle of 104.5° that naturally forms hexagonal structures as the crystals grow.

6. **Why do rough surfaces grow more quickly than facet planes?**

The rough surfaces contain unbonded water molecules. Water molecules in the air are attracted to these dangling molecules, which causes the rough surfaces to grow more quickly than facet planes. The facet planes are smoother, and contain fewer unbonded water molecules.

7. **Why doesn't all frozen water have faceted surfaces?**

Faceted crystals only form from water vapor growing on a snow crystal. Ice, whether formed in your freezer or on a lake in winter, grows crystals from liquid water, not water vapor.

8. **How do branched snow stars form?**

Branched snow stars form when growing snow crystals deplete water vapor from the surrounding air. Growth stops until more water vapor molecules float by. Those new vapor molecules are more likely to attach onto an edge than a face, causing the edges to grow faster.

9. **Why do snowflakes frequently have complex shapes?**

Snowflakes have complex shapes because they travel through different levels of the atmosphere, and conditions within these levels change, resulting in different growth patterns on snowflakes.

10. **What two roles does dust play in the formation of snow crystals?**

1) Snow crystals are believed to begin with water vapor condensing and freezing on the surface of a dust particle. 2) Then later, as the snow crystal grows, dust particles may land on the snow crystal surface and impede or enhance crystal growth at that site, thus changing the shape of the crystal in unpredictable ways.

Space Food

1. **What happens to astronauts' nutritional requirement for iron in space?**

Astronauts' nutritional requirement for iron decreases because in space the body reduces the volume of blood, thus decreasing the need for iron, which is found in red blood cells.

2. **Which chemical element is related to bone loss by astronauts in microgravity? How does its rate of absorption in microgravity compare to that on Earth?**

The element related to bone loss by astronauts in microgravity is calcium, and its rate of absorption in space is less than on Earth. This decreased rate of absorption is thought to lead to bone loss during space flights. The exact mechanism is not fully understood.

3. **The article provides a table that lists several categories of space food. In what way are the categories of foods on the table different from traditional food categories?**

The categories of food listed in the table—rehydratable, freeze-dried, thermostabilized, irradiated, etc.—are not related to traditional foods groups or to nutrition. The table categorizes food based on how it is prepared and packaged for space travel.

4. **Freeze drying relies on what change of phase process?**

Freeze drying of food is accomplished by the sublimation of ice at very low pressure.

5. **What are the triple point values on the phase diagram for water? For a bit of a challenge, answer the question also in units of Kelvins and Pascals.**

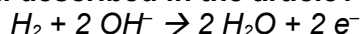
For the triple point of water, the diagram shows temperature = 0.01°C , pressure = 0.006 atm .

For the temperature in Kelvins, $0.01^{\circ}\text{C} =$ or 273.16 K ($273.15 + 0.01$); and for the pressure in Pascals, $0.006\text{ atm} = 607.8\text{ Pascals}$, or 600 or 610, depending on how you have them round it off.

$$0.006\text{ atm} \times \frac{101.3\text{ kPa}}{1.00\text{ atm}} \times \frac{1000\text{ Pa}}{1\text{ kPa}} = 607.8\text{ Pa} \sim 600\text{ Pa}$$

The actual triple point pressure for water is 611.73 Pa , but students can't get this from the calculation because the value of 0.0006 atm taken from the chart isn't precise enough.

6. **What electrochemical reaction takes place at the anode of the fuel cell described in the article?**



7. **What is the net product of the reactions that occur in fuel cells, and why is the product important on a space mission?**

The net product from reactions in the fuel cells is water. The fuel cells produce water in sufficient quantities to supply the needs of those on the space mission—for drinking, bathing and rehydrating food.

The Vinland Map: The Vikings' Best Kept Secret

1. Why did Norwegian explorer Helge Ingstad mount an archeological expedition to the northeastern coast of Newfoundland? What did he discover?

In 1953, Ingstad excavated the ruins of a Viking settlement in Greenland. With an interest in determining if the Vikings might also have landed in North America, he began searching and northeastern coast of Newfoundland for any signs of an ancient settlement. After spotting ridges in the grass, he mounted seven expeditions at what turned out to be a Viking settlement at L'Anse aux Meadows in Newfoundland. On the last day of the excavations a bronze pin used by Vikings to fasten their cloaks proved that the Vikings were indeed the inhabitants of the village and must have arrived in North America before Columbus.

2. What is the Vinland Map? When did it come to light?

The Vinland Map is a map that first surfaced in 1957 that purports to show that the Vikings may have been the first to sail to North America casting doubt on the universal belief that Columbus was the first European to sail to North America.

3. How do the ancient documents the *Tartar Relation* and the *Speculum Historiale* relate to the Vinland Map?

The Vinland Map was originally found bound as part of the Tartar Relation. However, further research appeared to show that the Vinland Map may originally have been a part of the Speculum Historiale.

4. How was the connection made that, although found in the *Tartar Relation*, the Vinland Map may have originally been a part of the *Speculum Historiale*?

Ancient documents, similar to the two mentioned above, are often damaged by worms eating through the parchment and creating a series of worm holes in the document. The worm holes in the Vinland Map did not match the worm holes in the Tartar Relation, but did match perfectly with the worm holes in the Speculum Historiale

5. What were the results of the initial analysis of the ink used to draw the map?

Initial results by Anna Teetsov of McCrone Associates, Inc. of Chicago, IL showed that the map was double inked—first drawn in yellow and then overdrawn in black. Preliminary examination of the yellow ink showed that anatase, a form of titanium dioxide, first available in 1917, proved that the document was a fake.

6. How did further analysis refute claims made by McCrone?

Using Proton Induced X-ray Emission (PIXE), researchers showed that one third of lines tested showed no signs of anatase and that the overdrawing of the yellow line by the black line was so perfect that it would be nearly impossible for an individual to have produced the overdrawing.

7. What results were reported from the testing of the medium use to thin the ink and to make it flow more easily?

Twenty five years after his original analysis, McCrone examined more yellow ink samples using a light microscope and an electron microscope to try and identify the medium used to thin the ancient ink. Initial tests showed that medium was a protein. Tests of the protein appeared to show that the protein was gelatin and not collagen. If true, the use of gelatin as the medium points to a date in the early 20th century.

8. What date did the testing of the parchment for C-14 show?

The radiocarbon dating of the parchment portion of the map showed that the parchment itself was ancient. The test dated the parchment to a period between 1411 and 1468.

9. Did the C-14 testing finally prove the authenticity of the Vinland Map?

The C-14 testing proved that the parchment tested did originate in the 15th century. The test did not dispute a claim that a forger might have used the ancient parchment to create the map at a much later date. The controversies concerning the age of the ink used on the map still raise doubts about the authenticity of the map.

ChemMatters Puzzle: SU-CHEM-DU

Here is a variation of a SUDOKU that needs some chemical knowledge as well as good logic to solve.

1. Instead of numbers, we are using nine letters in the grid: alphabetically, they are B, E, H, I, L, N, O, R, and S. Note that six of those letters are one-letter symbols of an element.
2. The more letters in the grid, the easier its solution. We are providing 20 of the letters directly, and 15 more come from clues below. Any box in the grid with a number has, as its letter, one of our six elements. The clue should help you zero in on the proper letter. The symmetry of the lay-out might help, too.
3. Once you've answered as many clues as you can, proceed to solve the Sudoku grid. Remember that any one letter can appear exactly ONCE in each row, column, and 3x3 square. Then, you can go back to identify any remaining clues.
4. When finished, the nine letters in the top row will yield the full name of a famous Danish physicist who made significant contributions to our understanding of the structure of the atom.

N				13				
		1		O		L		15
8	L		R		I		E	6
I			N		L		9	H
				B				
B	7		2		4			L
E	3		S		R		12	O
H		10		5		R		
				14				11

THE CLUES TO OUR SIX ELEMENTS

1. Fuses into helium in a star.
2. It contributes 88.8% to a water molecule's molar mass.
3. Smallest atom in group 13 (group IIIB on older charts).
4. As an element it's yellow in color.
5. The only halogen in our set.
6. In ground state has a half-filled 2p subshell.
7. Active metal + acid react to form this gas.
8. DNA has less of it than comparable RNA does.
9. Used in "doping" some p-type semiconductors.
10. In naming compounds, "thio" indicates presence of this element.
11. Sublimes when heated to produce purple-colored fumes.
12. Some plants have the ability to "fix" this element from air.
13. In its most stable allotrope, its molecules form a puckered 8-member ring.
14. Its boiling point is only 76 K.

15. Element #5.

Answers to the ChemMatters Puzzle

N	I	E	L	S 13	B	O	H	R
S	R	H 1	E	O	N	L	I	B 15
O 8	L	B	R	H	I	S	E	N 6
I	S	O	N	R	L	E	B 9	H
R	E	L	I	B	H	N	O	S
B	H 7	N	O 2	E	S 4	I	R	L
E	B 3	I	S 8	L	R	H	N 12	O
H	N	S 10	B	I 5	O	R	L	E
L	O	R	H	N 14	E	B	S	I 11

The Danish scientist is NIELS BOHR (top line).

NSES Correlation

National Science Education Content Standards Addressed

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	Hollywood's Special Effects	The Science of Snowflakes	Space Food	The Vinland Map
Science as Inquiry Standard A: the abilities necessary to do scientific inquiry.		✓		
Science as Inquiry Standard A: about scientific inquiry.		✓	✓	✓
Physical Science Standard B: of the structure of atoms				✓
Physical Science Standard B: of the structure and properties of matter.	✓	✓	✓	✓
Physical Science Standard B: of chemical reactions.	✓		✓	✓
Physical Science Standard B: of the interaction of energy and matter.				✓
Life Science Standard C: matter, energy and organization in living systems.			✓	
Science and Technology Standard E: about science and technology.	✓	✓	✓	✓
Science in Personal and Social Perspectives Standard F: of personal and community health.			✓	
Science in Personal and Social Perspectives Standard F: about environmental quality.	✓	✓		
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✓	✓	✓	✓
History and Nature of Science Standard G: of science as a human endeavor.		✓	✓	✓
History and Nature of Science Standard G: of the nature of scientific knowledge.		✓		✓
History and Nature of Science Standard G: of historical perspectives.			✓	✓

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.

Hollywood's Special Effects: How Did They Do That?

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.

Me	Text	Statement
		1. Snow is a very easy substance to fake in the movies.
		2. Snow on movies sets is often made of recycled materials.
		3. The polymer granules in disposable diapers can absorb 4,000 times their weight in water.
		4. The first step in making artificial skin is to make a copy of the actor's face or other body part where the artificial skin will be applied.
		5. The special effects studio described in the article now uses latex to create mythical creatures.
		6. Cross-linking in latex polymers is accomplished by adding a chemical catalyst.
		7. Safety is paramount when planning pyrotechnic special effects to create explosions or fires.
		8. The difference between a low explosive and a high explosive is the size of the explosion produced.
		9. In the future, almost all special effects will be created with computers.

The Science of Snowflakes: Crystals from the Clouds

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.

Me	Text	Statement
		1. The shapes of snowflakes depend on the temperature and humidity where they are formed.
		2. The water molecules in snowflakes always are arranged in octagons (with 8 equal sides and 8 equal angles).
		3. Water molecules attach more easily to rough surfaces than smooth surfaces.
		4. All frozen water has a faceted structure that displays symmetry.
		5. Snow stars are branched because they are formed in conditions of low humidity.
		6. Scientists have not yet figured out how to create snow crystals with the myriad of shapes found in nature.
		7. Artificial snow is created at ski resorts using supercooled water.

Space Food

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.

Me	Text	Statement
		1. Nutrients in the body behave the same way in space that they do on Earth.
		2. Astronauts have about 50 different types of foods and beverages to choose from while in space.
		3. Most astronaut food is sticky so the particles won't float around the spacecraft.
		4. Fresh fruit is not available on any space flights.
		5. Astronauts report having a reduced sense of taste while in space.
		6. No fresh fruit is ever included on spacecraft because it spoils quickly.
		7. Freeze-drying works to preserve food because most of the water that bacteria need to survive is removed.
		8. When water is restored to freeze-dried foods, the taste and texture is markedly inferior to the original food.
		9. The fuel cell that powers the space shuttle produces water for use by the astronauts as a byproduct.
		10. Freeze-dried foods have a long enough shelf-life to be used on missions to Mars.
		11. NASA's food scientists include chemists and microbiologists.

The Vinland Map: The Vikings' Best Kept Secret

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.

Me	Text	Statement
		1. An ancient Viking settlement was found in North America in the 1960s.
		2. Worm holes provide evidence regarding whether documents were bound together in the past.
		3. Medieval inks were made by crushing galls on oak trees and mixing the acid produced with an iron compound.
		4. Scientists collected just one ink sample from the alleged Vinland map for analysis.
		5. Some ink on the Vinland map was found to be made of titanium dioxide crystals called anatase which were not available in medieval times.
		6. The entire Vinland map was exposed to high-energy photons at a nuclear laboratory.
		7. The medium used to thin the ink in the Vinland map was found to have a protein base.
		8. Radiocarbon dating was not used to date the Vinland map because the process would have destroyed the map.
		9. Scientists and scholars agree that the Vinland map is authentic.

Reading Strategies

These matrices and 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 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

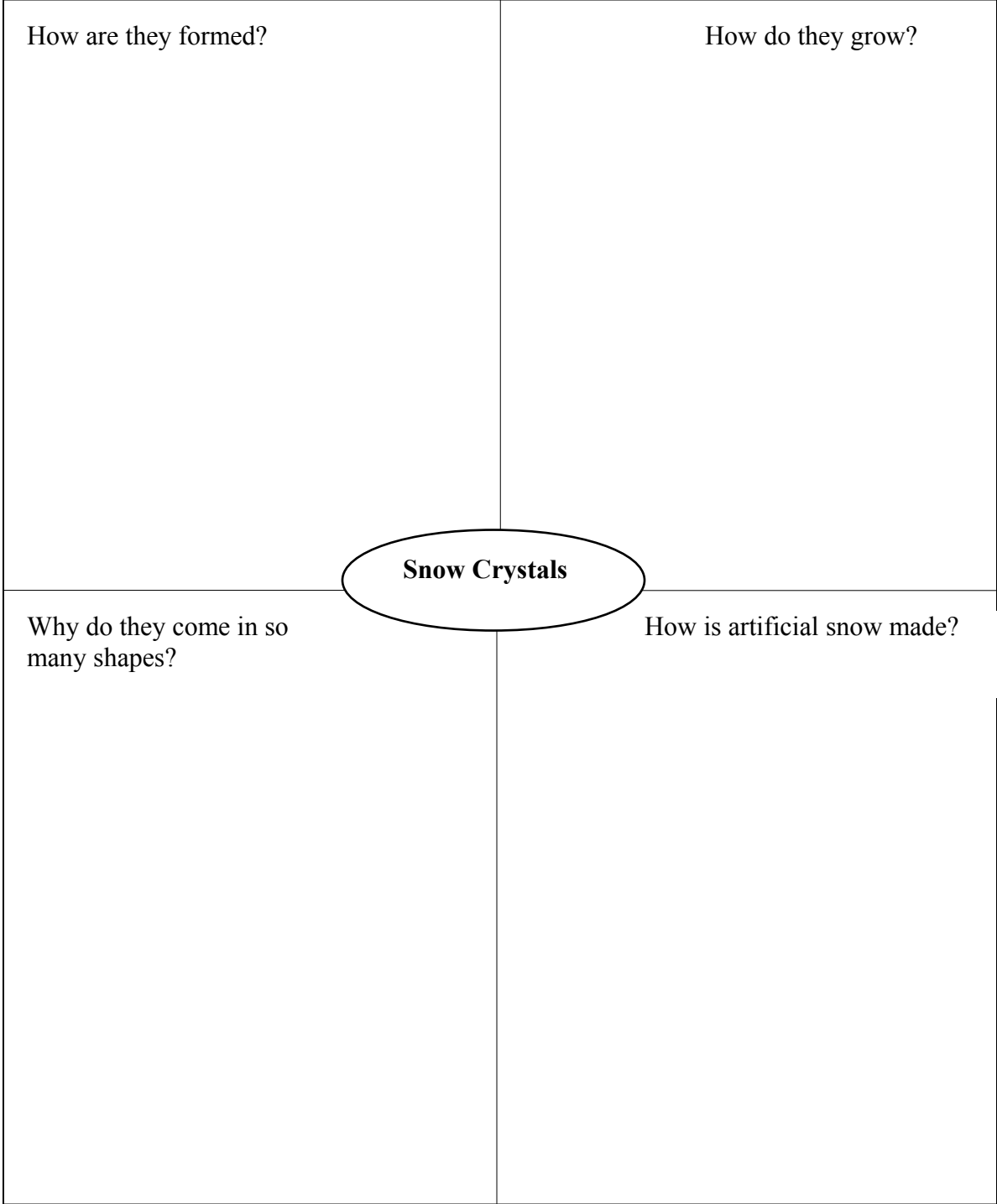
Hollywood's Special Effects: How Did They Do That?

Directions: As you read, please complete the chart below describing special effects used in movies.

Special Effect	Problems	Chemical solutions	Movies where this technique was used
Fake snow			
Artificial skin			
Explosions and fires			

The Science of snowflakes: Crystals from the Clouds

Directions: As you read, please complete the diagram to describe snow crystals.



Space Food

Directions: As you read, please complete the chart below describing what NASA's food scientists do to meet the needs of the space program.

Challenges	What is being done to meet challenges
Nutritional needs of astronauts	
Packaging	
Taste	
Food preparation in space	
Freeze-drying	
Food on future outposts on the moon and Mars	

The Vinland Map: The Vikings' Best Kept Secret

Directions: As you read, please complete the chart below describing the methods used to test the Vinland map. Also state whether each method supported the authenticity of the map.

Method	Scientific Explanation of Method	Evidence Found	Authentic or Forgery?
Physical examination			
Transmission Electron Microscope			
Proton Induced X-ray Emission			
Radiocarbon dating of parchment			
Viking Settlement			

Hollywood's Special Effects: How Did They Do That?

Background Information

More on the history of special effects

The earliest preparation of artificial snow probably was simply grinding up ice (think “snow cones”) into pulverized cold, white stuff. Using this technique, man could have snow even in the summer time. (This worked not only for movies, but for “real life” as well.) Later, cellulose powder or small bits of paper could pass for the white stuff. (This was pretty much for the movies only.)

Artificial snow has probably been used in movies ever since they were invented, especially for indoor scenes requiring a “winter” look. And what they used wasn't always a healthy choice. According to Asbestos.net (and other sources), the famous “Poppy Field” scene in the 1939 movie, *The Wizard of Oz*, shows Dorothy lying down in a field being covered with (artificial)snow that was 100% chrysotile (white) asbestos! (And according to the web site, the dangers of asbestos were known even then!) (<http://www.asbestos.net/asbestos-products/fake-snow.html>)

More on artificial snow

Ski slopes have been producing artificial snow for decades. Being able to produce snow at will allows the ski industry to prolong the snow season to maximize income. It's also created more snow for other types of activities, like snow tubing and snowboarding (which also maximizes income). This type of snow isn't “as fake” as some of the other types mentioned in the article and below in the Teacher's Guide, since it really is basically water, just like regular snow, but the method of producing the snow is still “fake”.

To produce this artificial snow, a snow gun is used to pump water that is cooled to just above its freezing point through a nozzle and out into the cold air. A fan or compressed air is used to help atomize the water into tiny droplets and then spread them out over a large area. The droplets freeze before they hit the ground (if all goes according to plan), producing a fairly dry snow. If the droplets land before they freeze, the snow will be too wet.

The right combination of temperature and humidity is crucial to snowmaking. The availability of nucleation sites is also critical. If the temperature is cold enough (-8°C or 18°F), water molecules themselves can serve as nucleation sites. Other materials, such as metallic ions or impurities can also serve as nucleation sites. But if the temperature is not quite cold enough (-5 to 0°C or 23 to 32°F), seed materials must be added to provide those nucleation sites. Several inorganic substances, including kaolin and soaps and detergents have been used successfully for this purpose.

More recently, microorganisms have been used to provide these nucleation sites. Currently, the most popular substance used is SnoMax, a freeze-dried protein powder. It is sold by York Snow, in Victor, NY. The additive is made from *Pseudomonas syringae*, a common bacterium commonly found on trees, grasses and vegetable crops. In the 1970s scientists at the University of Wisconsin, Madison, discovered that *P. syringae* was responsible for initializing ice crystallization on corn crops, which is a bad thing. But initializing ice crystallization on a ski slope would be a good thing. The microorganism is believed to be non-toxic.

Virginia Walker at Queen's University in Canada has done research to discover bacteria that produce the proteins that exhibit the initiation of ice crystallization. Normally this research would have to be done in extremely low-temperature climates, such as the Arctic or Antarctic, but she has taken a different approach in her own lab and has discovered a new strain of these bacteria. You can read a short article in Science Daily at <http://www.sciencedaily.com/releases/2006/09/060930094351.htm>. A brief (<2 minute) video clip about her research can be found at [http://www.sciencentral.com/articles/pop11.php3?video=quicktime&video_id=\[stn2img:2025059:stn2img\]&date10=01.23.07&article_id=218392889](http://www.sciencentral.com/articles/pop11.php3?video=quicktime&video_id=[stn2img:2025059:stn2img]&date10=01.23.07&article_id=218392889).

A newer patent has been issued that utilizes an organo-silicone surfactant to serve as the source of nucleating sites. The complete text of this patent provides a great deal of information concerning the science/technology behind snowmaking, and the problems that come with it. After discussing the problems inherent in all past snowmaking mechanisms, it explains why its system is so much better. Benefits of their new process include: slipperier snow; longer-lasting snow (when temperatures rise it doesn't melt as fast); more "intermediate" type of snow (drier, better quality) is produced at warmer temperatures than with other processes; greater "groomability" (the ability to work the snow without it sticking to the machinery) immediately after snowmaking stops; and greater flow-rate of water through the nozzles of the snow guns, providing greater snowmaking capacity, thus lowering costs.

The benefits are realized because the surfactant lowers the hydrogen-bonding in the water, reducing drag through the nozzle, and producing smaller droplets that have greater surface area and therefore freeze more quickly in the air, according to the patent. (<http://www.patentstorm.us/patents/6464148/fulltext.html>) Aquatrols, from Cherry Hill, NJ, sells this snowmaking additive as "DRIFT". (<http://www.aquatrols.com/usadrift.htm>) (Interestingly, an Aquatrols Research Summary white paper seems to show no difference in water drop size or volume through spray nozzles between plain water and water with DRIFT snowmaking additive: <http://www.aquatrols.com/Research/DRIFT/DRIFT-Spraying%20Systems%202002-2Jan07.pdf>.)

More on fake snow

Fallen snow

As the article indicates, there are many materials used for fake snow, depending on the desired appearance or purpose. More than 100 different materials can be used. Natural or machine-made snow is not desirable because it is wet and cold and messy, it melts, and it tramps down easily, so re-takes are difficult.

Several other materials can be used. Shredded plastic snow works well for small-scale scenes in a studio, and it can be recovered for re-use, but the cost is prohibitive for larger sets. Firefighting foam is also used, especially for deep snow scenes, but one can't walk on it. Mashed potato flakes also work really well. From afar, mashed potato flakes look like the real thing, but a close-up will reveal the truth. Also, disposal is a problem, especially if they get wet.

Dryslope is another type of artificial snow. Although not used for its authentic appearance, it is used by skiers for its physical properties. According to Steve Ritter, author of "Artificial Snow", from the series "What's That Stuff?"—a series of articles about the chemistry of everyday things from *Chemical and Engineering News*, dryslope

“ . . . is a group of wood, metal, or plastic materials, usually laid down as latticework with void spaces, that is used to ski on out of season or in regions where it does not snow. One downside is the hard materials can lead to a greater risk of injury.

A newer type of dryslope that aims to curb injuries is a multilayer polymer composite matting that resembles carpeting. Two products are Snowflex, made by Briton Engineering Developments, Yorkshire, England, and Powderpak, made by an Atlanta-based company with the same name.

Snowflex, for example, has a slippery polybutylene terephthalate fiber surface layer that sits atop a shock-absorbing pad that has a woven backing. Water piped through the layers exits recessed nozzles and mists the surface, which helps reduce friction even further. This new type of dryslope can be laid out like carpet and cut to fit features such as moguls. It has been used indoors and outdoors to make half pipes and short slopes for freestyle (acrobatic) or downhill skiing and snowboarding.

(<http://pubs.acs.org/cen/whatstuff/stuff/8203snow.html>) [Other information from this article was used in this section of the Teacher’s Guide.]

Falling snow

Machine-made snow isn’t typically used for falling snow because it melts quickly and doesn’t appear flaky when it falls. Paper, cellulose and starch work well for falling snow. Special effects people can sprinkle them down on a scene, and fans blowing can keep them aloft in the air. Fans can cause problems of their own, though, in terms of their noise level. This can be avoided by dubbing over the scene after it is shot.

Each of the three materials mentioned, paper, cellulose, and starch, has its own problems. Paper is good because it’s relatively weatherproof, but this benefit is a problem after the scene is shot; what to do with the paper snow after the scene has been shot. Cellulose and starch are water-soluble, which means they’re ecologically more desirable, but if the set gets wet, they will produce a slippery slushy mess to work in and then to dispose of.

Several companies’ web sites tout “dry” snow, meaning their snow making machines blow out “snow” that looks real, but it doesn’t leave a wet or sticky mess on surfaces when (if) it lands on them. The Zigmont Magic FX website says their snowflakes are really just “small clusters of tiny bubbles, like really fine soap suds”. The size of snowflakes produced can be adjusted so that the snow evaporates completely before it hits the ground, leaving no residual material. This snow is 98% water and 2% surfactant, and the microscopic surfactant particles become airborne along with the water vapor. The advantage of this type of snow is that it can be used indoors, or outdoors in areas of warmer climate, without the worry of wetting the ground or floor. This minimizes the danger of slipping on a wet floor.

(<http://www.effectspecialist.com/Everwonderwhy.htm>)

More on sodium polyacrylate

In addition to being used in disposable diapers and artificial snow, sodium polyacrylate is also used in fire control, bed pads, seed germination, hydroponics and soil conditioning, and in industrial applications as a thickening agent and an aid for dissolving soaps. It is also used as a spill absorber in laminated materials; e.g., nuclear waste cleanup and urine test kits. Its ability to absorb water is dependent upon the impurities found in the water. As the article mentioned, water molecules are attracted to the free sodium ions between the polyacrylate chains. If other

ions are in competition for the water molecules, as in hard water, for example, fewer will be trapped within the structure of the superabsorber, resulting in less water retention and a less-solid gelled mixture. Salt added to a polyacrylate gel will result in the complete de-gelling of the mixture, as the sodium ions in salt compete for the water molecules trapped inside the gelled structure. As the water molecules leave the coiled structure, the Na^+ and COO^- ions attract again and tighten the coil, squeezing out even more water molecules.

Caution students about actually extracting sodium polyacrylate from disposable diapers. The article mentions polyacrylate granules, but the material is more powdery than granular, and the powder can easily get into the nasal passages. Lots of online sites (including YouTube video clips) advise students, after cutting open a disposable diaper, to shake it onto a plastic sheet or into a clean trash can to release the polyacrylate, but that can release much of the powder into the air, where it is inhaled by the student. The online sources typically do not mention the problem of inhalation of the dry sodium polyacrylate powder.

MSDS reports say sodium polyacrylate may be harmful if swallowed or inhaled and may cause irritation. Handlers are advised to: avoid breathing the vapors, or dusts; use with adequate ventilation; avoid contact with eyes, skin, and clothes; and to wash thoroughly after handling. Sodium polyacrylate is also very slippery when wet, so there is also the potential for an accident involving a fall.

More on artificial skin

Latex is the material of choice for most special effects artists. It is soft and pliant, and it has a very small cell structure that captures the fine detail of the creases and folds in any skin. "Latex is as light as a feather. It lets sweat out and air in; there is nothing like it", says Tom McLaughlin, special effects artists and creator of Miss Piggy, Babe, Yoda and Jabba the Hutt.

Other materials can be used to make casts. Plaster of Paris has been used for centuries to make casts, but it is relatively slow drying and quite heavy. For these reasons, it is better used to make casts of inanimate objects. For facial casts, silicone or alginate is typically used instead of latex. The one major drawback to latex foam is latex allergy. For people with this allergy, gelatin, silicone or alginate are often used as replacements.

Special effects people aren't the only ones using latex to cover real skin. Embalmers also use it in their work. They can use it to cover/mask scars or injuries sustained that lead to the death of the person.

More on latex foam

Latex foam used for creature suits is very similar to the material used in industrial foams, such as mattresses and car seats. Latex used for special effects is usually softer and more pliable, made so by adding air bubbles with soap before the latex is cured or vulcanized. McLaughlin has produced a micro-cellular foam with air cells too small to be seen with the naked eye. He has not patented the process, but keeps it tightly under wraps, so others cannot duplicate the process.

More on gelatin and silicone and alginate

Gelatin is mentioned briefly in the article. Gelatin is produced by prolonged boiling of collagen, a protein that makes up much of connective tissue, such as skin, bones and cartilage. The collagen material is obtained in bulk from the animal processing industry. The resulting powder is sold dry.

Collagen is actually a triple-helix. (DNA is a double helix.) The three strands of amino acids (polypeptide chains) are lined up and all twisted around each other. The helix is held together by hydrogen bonds between the amino acids inside the coiled strands. Boiling breaks some of the hydrogen bonds holding the triple helix together, separating either partially or completely the protein strands. The prolonged boiling hydrolyzes or breaks up the collagen proteins, severing peptide bonds between amino acids to form shortened protein chains. At the end of the process, this product, gelatin, is dried.

When water is added to gelatin, the hydrolyzed ends of the protein chains open up and tangle with other chains, trapping water in the strands in the process. The product is a gel. This gel is the basis for Jell-O® and other gelatin desserts. It is also used as a thickener in foodstuffs such as ice cream and yogurt, and it is the major ingredient in the soluble capsules containing drugs to be ingested.

In addition to being used for special effects prosthetics, gelatin is also a major ingredient in “natural” cosmetic peel-off face masks. There are many recipes online for gelatin-based facial masks.

Silicone chemistry is explained in the article. Silicone can be used by itself as an artificial skin and for prosthetics, or it can be used over a latex base, to improve appearance, since silicone is more translucent than latex and holds its color better under different lighting conditions.

Alginate is derived from brown seaweed. It is a biopolymer. Alginic acid is the salt-free form of the alginate. Sodium alginate is water-soluble, while calcium alginate is not. When alginate is used to make a face cast, it is usually reinforced with a layer of plaster tape to give it strength. Without this, the cast is prone to tearing. This adds an extra layer (no pun intended) of time to the process, as well.

More on polymers and bridges (cross-links)

All of the examples involving polymers used in the article: sodium polyacrylate, latex, silicone (and most others you use in your classroom) are already polymers in their raw ingredient state. Adding water to sodium polyacrylate forms the gel because water molecules are attracted by hydrogen bonding to the COO^- on one chain and the Na^+ on the other chain, thus cross-linking the two polymer chains. Adding sulfur to latex chains effectively does the same thing. The S_8 ring opens upon heating to form short sulfur chains. The end sulfur atoms of each of these short chains bond to carbon atoms across two latex polymer chains to link them together—another cross-linking—reducing their flexibility and making a stiffer material. (This process is essentially the same process that happens in the vulcanization of the rubber in a car tire.) Silicone is also a polymer chain, with the silicone-oxygen backbone and a small double-bonded organic group attached at intervals, as described in the article. The tin or platinum catalyst can help to break the double bond, which leads to the formation of a bond between two polysilicone chains—another cross-link.

Very few actual polymerization reactions are done in the classroom, for several reasons. First, polymerization reactions are very rapid and often hard to control (think, “runaway reaction”). Next, since so many bonds form so rapidly to make the polymer chains, these reactions are usually very exothermic (think, “too hot to handle”). And the product is frequently difficult to remove from the reaction vessel (think, “wrecked test tube”).

Connections to Chemistry Concepts

1. **Properties**—This article contains great examples of the differing properties of substances; e.g., the difference in properties between cured (vulcanized, cross-linked) and uncured latex. Special effects artists, like some scientists, need to create materials that have specific properties, and they do this on the basis of very real chemistry.
2. **Models**—Scientists use or create models to describe or represent natural phenomena, similar to those models made by special effects artists to represent real structures.
3. **Molecular structure**—Several examples are shown in the article: S_8 rings of sulfur atoms breaking down into smaller chains that cross-link latex molecules, $[-CH_2-CH(COONa)-]_n$ sodium polyacrylate polymer that absorbs water.
4. **Cross-linking of polymers**—Both sodium polyacrylate and latex are cross-linked. The latex and silicone polymers have vastly different properties before and after cross-linking.
5. **Catalysis**—Silicone rubber is cured using platinum or tin catalysts.
6. **Kinetics**—Particle size (size of bubbles trapped in latex as it is whipped) and time of reaction (duration of time spent whipping the latex foam) both affect reaction, although in this case, these two factors directly affect the properties of the product, rather than just influencing the rate of the reaction.
7. **Thermodynamics**—The S_8 rings are opened with heat.
8. **Polymers**—Sodium polyacrylate in artificial snow, latex, gelatin, silicone and arginate in fake skin are all examples of polymers with “real-life” (OK, maybe not so “real”) applications. It’s probably worth mentioning to students that none of the processes mentioned in the article are actually polymerization reactions. The materials already exist as polymers—the reactions described merely represent the cross-linking already-existing polymer chains. (See Possible Student Misconceptions #2, below.)
9. **SAFETY**—Safety is especially emphasized in the “Explosives and fires” section of the article. Joe Viskocil can serve as a role model for teachers, as he constantly emphasizes the need for safety in all his work, and he refuses to compromise safety for the sake of excitement or drama.

Possible Student Misconceptions

1. **“Special effects are all done with computer-generated images now.”** *Although many film companies are now using computer-generated images in place of real materials or events in their movies, many special effects artists still use models of real-life materials to represent actual materials or chemical materials to serve as prostheses in their films.*
2. **“When latex or silicone materials cure, they are ‘polymerizing’, they’re monomers becoming polymers.”** *The latex and silicone were already polymers in their more fluid state; curing merely cross-linked or bridged the polymer chains. Prior to curing, the polymer chains could slide past each other relatively easily, since they were not linked together (they could flow); after curing, the chains are linked to each other and thus cannot move*

independently of each other (they're more solid now). The same process is happening when water is added to sodium polyacrylate. It's not becoming a polymer-it already is a polymer. The water merely allows the cross-links to form between the polymer chains and then gets trapped inside the chains, forming the gel.

3. **“Bigger is always better!”** Joe Viskocil (and others) would vehemently oppose this statement. He believes that bigger is almost always more dangerous, but not necessarily better. That's why special effects artists use miniatures to represent structures they are going to blow up or burn, as there is less danger of injury to actors and others in the vicinity of the explosion. (See *Chemistry Conceptions #9*, above.)

4. **“A prosthetic is like an artificial arm or leg, right?”** While this is true in the real world, it is a very limited view of the term from a special effects standpoint. To a special effects artist, a prosthetic can be anything that changes the appearance of the surface (or interior) of a person, from an arm with a small scratch with fake blood, to an axe or knife protruding from a person's skull or abdomen oozing blood—and beyond.

Demonstrations and Lessons

1. The College of Education at the University of Houston, TX produced an entire curriculum of integrated physics and chemistry (IPC) lessons and student activities focused on the science in the movies (“IPC Goes to the Movies”). They collaborated with Steve Wolf, a Hollywood special effects specialist, author of *Science in the Movies* and school-assembly presenter/performer. The course consists of six major units: Motion, Properties of Matter, Energy Transformations, Changes in Matter, Waves, and Solutions Chemistry. Each unit contains student activities, teacher background, standards, assessment rubrics (“4 thumbs up”, “3 thumbs up”, etc.), safety, and video clips of Steve presenting some of the ideas to assembly groups (mostly lower middle school, although the IPC package is geared for high school science classes). Although the activities are couched in the movie scenario format, many of them are fairly typical labs and demos that are used in chemistry and physics classes. The lessons are based on the “5 Es”. You can access the entire package at <http://www.coe.uh.edu/texasipc/>. Steve's video clips show how science (chemistry especially) can be useful in careers that would seem on the surface to have little to do with science. Steve Wolf's book, *Science in the Movies*, can be purchased directly from him at <http://www.scienceinthemovies.com/book/>.

2. Many teachers use video clips of movies to use as discussion points in class to identify “bad” science. Physics teachers might start here: “Insultingly Stupid Movie Physics”, <http://www.intuitior.com/moviephysics/>. The site begins with examples of bad physics that are prevalent in many movies, and follows that discussion with specific movies, reviewed and ranked for their bad physics. Another page on the site gives ideas for how to use movie physics in the classroom. There's also a book by the same name as the web site, authored by the web master, Tom Rogers, a physics teacher.

3. Halloween might be a good time to experiment with fake skin and prosthetics. Some students may be grossed out with the thought of experimenting with these items, but it could be a lot of fun. You could have teams of students experiment with producing the same type of prosthetic (a knife wound, a gouge, etc.) using different starting materials: latex (the “real thing”, for special effects artists), white glue (a lesser substitute), and gelatin (also used for real by special effects artists). IndyMogul's web site has some good descriptions of how it's done. See the selection of videos/blogs at <http://www.indymogul.com/search?cx=008205495395035886862%3Aobhaekte5s0&cof=FORID%3A11&q=fake+skin#1078>.

Latex can be obtained from science supply stores or art supply stores; white glue can be obtained almost anywhere; gelatin can be found in grocery stores.

4. You can simulate latex foam polymerizing by using a polyurethane foam kit, sold by science supply stores. Parts “A” and “B”, both liquids, are mixed and stirred. The reaction produces CO₂ gas, which gets trapped in the viscous liquid, causing bubbles to form in the reaction mixture. This results in the expansion of the material. Then the material surrounding the bubbles of gas (now a polymer) hardens and forms cells. A video of the reaction can be seen at <http://video.google.com/videoplay?docid=-6367640639873461283#>. For the basic chemistry of polyurethane foam polymerization, see

<http://urethanestechology.blogspot.com/2007/06/basic-chemistry-of-polyurethanes.html>.

5. As an extension of the latex-simulation activity (#4, above), you could have students design and construct molds of various shapes and sizes to contain the foam, having them calculate the volume of “A” and “B” needed to fill their mold. A competition could produce a winner that most nearly matched actual and calculated output. As polyurethane is being used more and more in packaging of consumer goods (think electronics) for shipping, this activity is not just an exercise in fun—companies must do exactly the same calculations to know how much of “A” and “B” to mix to exactly fill the space around an item inside a box, without over-filling the box (the sides will bulge and the excess is waste cutting into the bottom-line) or under-filling the box (the item may not be adequately protected from outside impact and may be damaged in shipment). As they plan their mold for this activity, be sure to caution students that polyurethane foam is NOT a candidate for a life cast, as the product will stick to everything (skin included), and most solvents will have no effect on the hardened, cross-linked polymer; skin may be torn off with the mold when it is removed. (It is also important to note that liquids “A” and “B” and the product foam are irritating to skin and mucous membranes, so skin should not come in contact with the foam or its ingredients.)

6. To reinforce the role of a cross-linking agent in a polymerization reaction, check out this description of an activity involving students discovering the effect of the amount/concentration of cross-linking agent on the rigidity of the foam produced in the reaction, check out [http://www.chem.wisc.edu/~ediger/outreach\(Manual\).htm](http://www.chem.wisc.edu/~ediger/outreach(Manual).htm). This is a list of seven programs covering several weeks of class time. The one you want is “Polymers”, Program Module #2, Day 3 of 4.

7. You can show students the low solubility of calcium alginate by producing “worms” of calcium alginate in a solution containing calcium chloride to which you inject (using a micropipette) sodium alginate solution. (Gaviscon® antacid is the source of the alginate.)

The diagrams at http://members.ift.org/NR/rdonlyres/1D889FCE-7C48-4273-ABA9-3B4ED101D7D2/0/activity_alginategummie.pdf show the chemistry of the process. This Chicago Section, ACS web site suggests using calcium-fortified orange juice or milk as the source of the calcium ions: <http://membership.acs.org/c/chicago/chmshort/CS04.html>.

Although the lesson in this web page from Drexel University is geared to middle school, it could be adapted to high school:

[http://gk12.coe.drexel.edu/modules/doc/Matthew_Cathell/Alginate_I-](http://gk12.coe.drexel.edu/modules/doc/Matthew_Cathell/Alginate_I-Lesson_Handout_and_Quiz.pdf)

[Lesson_Handout_and_Quiz.pdf](http://gk12.coe.drexel.edu/modules/doc/Matthew_Cathell/Alginate_I-Lesson_Handout_and_Quiz.pdf). Once again, it’s important to note that this is a cross-linking of already-existing polymers. The calcium ion (2+) links to two chains of the alginate polymer. When enough calcium ions link up to two chains, this seriously reduces the flexibility of the polymer chains.

8. Be very careful of your giving students exposure to any explosive in class. (See http://seattletimes.nwsourc.com/html/nationworld/2002182345_bomb17.html, a news story of a teacher arrested for teaching students bomb-making skills in class.

9. For safety purposes, you may want to do any thermochemical explosions as demonstrations. Here are a few to choose from:

- a. **The methane can explosion:** Here is a YouTube video of this explosion, along with a nice explanation of why it happens: <http://www.youtube.com/watch?v=MhD5pZ5sZb4>.
- b. **The methanol cannon, Version A:** <http://bluestream.jcu.edu/play.php?vid=848> This video shows Dr. Mark Waner of John Carroll University giving students at a summer camp a lesson using the methanol cannon as an analogy to the internal combustion engine.
- c. **The methanol cannon, Version B:** a tennis ball cannon powered by methanol (or in this case, lighter fluid: <http://www.youtube.com/watch?v=rVTcP995Yz0&NR=1>). This isn't a great presentation, but the directions are pretty straightforward.
- d. **The methanol film canister explosion:** Here's a video to show you how to make your own, from Instructables (of course, kids can find this site, too): [http://www.instructables.com/id/Portable-Film-Can-Cannon!-Advanced-Version!/,](http://www.instructables.com/id/Portable-Film-Can-Cannon!-Advanced-Version!/) and this is an even more portable version: <http://www.instructables.com/id/SR64BUBF8Y3UDHA/>.
- e. **The "whoosh" bottle:** This YouTube video compares the burning of methyl, ethyl, propyl and butyl alcohols, singly at first, and then at the end, it shows all four in the same screen: http://www.metacafe.com/watch/2368613/whoosh_bottle_methanol_ethanol_propanol_butanol/.

A video compilation of the methanol cannon, versions A and B, and the whoosh bottle can be seen at <http://www.experiencefestival.com/forum/Video-Viewing/kdDEDr3HX7Y>. An obvious safety problem is that the instructor uses a stopper instead of a cork in the first methanol cannon. The camera shows you the hole in the ceiling tile after the explosion. DO NOT USE A STOPPER in the bottle! Use a cork! The cork is less massive and is less likely to hurt anyone as it flies out of the bottle. He also aims the version B cannon over students' heads, but a better choice would be to aim it at a wall away from students.

Be aware that all of these demonstrations involve an element of risk, and accidents involving the combustion of methanol are rather commonplace—and serious. See

<http://www.labsafetyinstitute.org/resources/mecannon.htm> for an example. Be careful!

(Perhaps you would feel more comfortable—and safer—showing videos of these.)

NOTE: There is a lot of good chemistry to teach around these demonstrations. Try to get out of a demonstration the maximum "mileage" you can; don't do the demonstrations just for the "wow" effect. Students will remember longer and understand better the chemistry if it is tied to these "wow" demonstrations!

10. A good collection of demonstrations of thermochemical reactions by Paul Groves and a colleague from South Pasadena High School that describes several of the demonstrations above can be found at <http://www.rock-hill.k12.sc.us/teachers/rhhs/mbailey/Chemistry/burning%20demos.doc>.

11. Lessons on using explosives in experiments in class that are available on the internet seem to be limited to those involving the search for and detection of explosives residue in forensics classes. Here is one such lesson, but it is a PBL (problem-based learning) unit. It takes two weeks to do, and many details seem to be left out, such as the nature of the residue the teacher "leaves behind" at the crime scene.

[\[http://www.ncsu.edu/pbl/pdf/DeborahAndersonPBLunit.pdf\]](http://www.ncsu.edu/pbl/pdf/DeborahAndersonPBLunit.pdf)

12. Taking a broader view of the term, "explosives", you could do the tried and true Alka-Seltzer in the film canister rockets as an experiment. (This probably isn't what students will have in mind when you tell them, "Today we're going to make explosions.") This write-up from Cool Stuff Newsletter is probably geared more to middle school, but it has a list of extensions at the end that could be the basis of a high school basic experiment http://www.arborsci.com/CoolStuff/New_CoolStuff_Articles/C_34_1.htm. And if the Alka-

Seltzer explosion doesn't offer enough variation for your chemistry class, you might have students use baking soda and vinegar and figure out the best combination to give maximum travel distance of the canister.

13. If you want to pursue the idea of a "blue screen" special effect, you might want to do this activity from NOVA's Teacher Domain series of special effects activities as a demonstration in class: <http://www.pbs.org/wgbh/nova/specialfx/fxguide/fxmshtr3.html>. Your physics teacher may want to pursue the blue screen idea also.

14. Educational Insights sells a kit of 30 engaging experiments that deal with the Science of Special Effects, for grades 2 & up. Some can be used/adapted to high school. (<http://www.amazon.com/Educational-Insights-3161-Science-Special/dp/B000ERAIV0>)

Student Projects

1. Students could research the history of special effects and prepare reports.
2. Students can research the history of latex and report. A good place to start is <http://www.pslc.ws/macrog/exp/rubber/menu.htm>.
3. Students can research the effect of adding various amounts of water to a specific amount of sodium polyacrylate in order to determine which mix creates the "best" snow. Student agreement would have to be reached concerning criteria for determining the properties connected to the "best" snow.
4. You could have a team of students research the individual types of materials used for artificial skin—PVA (polyvinyl acetate) glue, latex, gelatin, silicone, and alginate—and then compare the properties of each. Then they could discuss special effects preferred uses for each material, as related to its properties.
5. Students can research the development of black powder and the improvements it has undergone over the centuries.
6. Students could be assigned to do an online search for special effects in movies involving chemistry that show "bad" science. They could share their findings with the class, explaining why the chemistry in the video clip is wrong. Students may have difficulty finding specifically bad chemistry (rather than more general bad science) for two reasons: 1) the television show *Breaking Bad* that deals with "chemistry" that pops up when they try to do an online search, and the term "bad chemistry" referring to the lack of romantic realism between co-stars in a film.

Anticipating Student Questions

1. **"Where does all the fake snow go?"** *That's exactly the right question to ask! Fake snow is not just plain frozen water, and the materials it is made of don't just melt. And even if they did, they would then go into the ground and pollute it. That's why special effects specialists try to make fake snow out of ecologically friendly materials that will biodegrade into innocuous products. If that can't be made to happen, the snow must be re-collected after the movie shoot and disposed of safely.*
2. **"What about people with latex allergies? What do the special effects artists use with them?"** *This is a very good question. Obviously, people who are allergic to latex need to avoid coming in contact with the polymer. Special effects artists must use other materials for prosthetics for these people. Often the replacement of choice is silicone, because of its pliability and translucency.*

References

As was mentioned in the article, the standard reference for special effects is Rickitt, R. *Special Effects: The History and Technique*. There are two editions of this book: one by Virgin Publishing, Ltd., London, UK, 2000; and the second, which is considerably revised, by Arum Press: London, UK, 2006.

Web Sites for Additional Information

ChemMatters

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>.

Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Graham, Tim. Colors Bursting in Air. *ChemMatters*. October, 1998. 16:3, 7-9. This article focuses on fireworks and how they work.

More on explosions, More on explosives history, Sniffing Landmines. *ChemMatters Teachers Guide*. February, 2008. These two sections of the article on landmines give a bit of background information on both topics.

ChemMatters. April, 2003. 21:2, 1-2. The cover of this issue shows a futuristic scene with two space craft firing laser shots at a city, with an ensuing explosion. A sidebar on page 2 alludes to frequent science content mistakes in science fiction movies and asks students to identify at least one thing wrong in this cover scene.

More sites on special effects

"How Stuff Works" covers many of the special effects mentioned in the article—and many that are not. Topics include how the blue screen works, creature effects makeup, how special effects artists work, and how movie make-up artists work. View them in the Special Effects Library at <http://entertainment.howstuffworks.com/special-effects-technology-channel.htm>.

If you're really into special effects, you might want to take a look at the Special Effects Cookbook and its companion piece, Special Effects Recipes for Holidays and Special Occasions. Recipes include an erupting volcano cake, glow-in-the-dark gelatin and the beating heart cake. And if you buy now, you can even get a bonus, Special Effects Recipes for your Pets—free! And there's more—you also get The Cool Science in the Special Effects Cookbooks that explains how each of the special effects recipes works! See it all at <http://www.specialeffectscookbook.com/cookbooks.php>.

More sites on the history of special effects

PBS's NOVA program's web site has a brief decade-by-decade timeline of special effects achievements. You can find it at <http://www.pbs.org/wgbh/nova/specialfx2/timeline.html>.

Don't think that special effects began with movies! Check out the Elizabethan Globe Theater web site coverage of a few special effects done there during Shakespeare's time: <http://www.globe-theatre.org.uk/globe-theatre-special-effects.htm>.

More sites on artificial snow

A study by the Centers for Disease Control has shown slightly elevated endotoxin exposure in snow-making workers at ski resorts who use SnoMax®, but it reports no significant increase in health problems among this population. See <http://www.cdc.gov/niosh/hhe/reports/pdfs/1989-0348-2295.pdf>.

There are even patents on the DNA coding for ice-nucleating microorganisms similar to *Pseudomonas syringae*. One of them can be found on the Free Patents Online web site at <http://www.freepatentsonline.com/4464473.html>. You'll have to register to access the file, but registration is free. (Information about these microorganisms may be more interesting to your biology teacher colleagues, so maybe you should pass this along to them.)

And here's another patent, from Patent Storm, that uses similar microorganism that are generally regarded as safe (GRAS) to actually add to foodstuff when packaged, in order to increase the rate of ice formation when these foods are frozen. This has the effect of reducing the size of ice crystals within the food, maintaining the texture and quality of the food. (<http://www.patentstorm.us/patents/5514586/fulltext.html>)

More sites on artificial skin

The KNB EFX web site at KNB EFX Web site: <http://www.knbefxgroup.com/> shows many of their special effects from various famous movies. Be aware that there are some photos/videos that are unsuitable for students.

Freeman Supply Company has a series of videos on mold-casting on YouTube. This one is about 9 minutes and shows how a mold is made and casts are made from the mold. The shape is a car, but the concepts are the same as those for making prosthetics, etc. View it at http://www.youtube.com/watch?v=48UwkzNqREA&annotation_id=annotation_655865&feature=iv.

The MonsterMakers web site contains a page that describes making a latex monster mask in 12 easy steps (with their materials, of course). The photos show the basic steps, so students can see the entire process described in the *ChemMatters* article. View the page at <http://www.monstermakers.com/skin1/images/MAKEAMASK.pdf>.

Wesley Scoggins on "Indy Mogul" web site shows special effects "wannabes" how to do their own artificial skin effects:

Here's how to use regular PVA white glue (Elmer's glue, for example) in place of latex for special effects on skin: <http://www.indymogul.com/post/12779/wesleys-weekly-how-to-liquid-latex-alternative>

This one shows how to manufacture bulging veins on a forearm:
<http://www.indymogul.com/post/14129/wesleys-weekly-how-to-bulging-veins>

And this one shows how to use gelatin to make a prosthetic:
<http://www.indymogul.com/post/11099/wesleys-weekly-presents-molded-gelatin-prosthetic#comments>

An easy-to-make gelatin mask (the Halloween type, not the cosmetic type) can be found at <http://historichalloween.blogspot.com/2007/09/homemade-halloween-mask-from-gelatin.html>. Note that it uses a bit of glycerin (available from drug stores) to keep the gelatin pliable so it doesn't crack as easily.

This commercial site for Accu-Cast alginate shows a series of photos illustrating a facial life cast: http://www.accu-cast.us/tempsite2/Procedure_Pages/FaceCastingProcedure.html.

More sites on miniaturization

The WGBH Shop web site sells *Behind the Scenes with King Kong In Special Effects* (\$12.95 as of 9/09). Find it at <http://shop.wgbh.org/product/show/8320>. The video seems to focus on miniaturization and stop-motion effects.

Here is the trailer for the "Independence Day" video that shows the explosion of the White House: Independence Day trailer (showing the White House explosion scene):
<http://www.imdb.com/video/screenplay/vi49546009/>.

More sites on polymers

David Katz, of Pima Community College, Tucson, AZ, has a web site that includes information and class activities dealing with polymers, including latex, polyurethane foam and sodium polyacrylate. Access the polymer page of his site at <http://www.chymist.com/Polymers.pdf>. The site also has lots of other information useful to high school chemistry teachers: <http://www.chymist.com/>.

Unfortunately for high school teachers, Katz (above) uses the chemicals that are the individual ingredients for each of the solutions "A" and "B" for his activity. These are not as readily available to high school teachers as are the kits already containing solutions "A" and "B". See Andrew Stephens' "Super Foam Demo" page for a more complete lesson on the polyurethane foam reaction:
http://www.csun.edu/~aes15831/coursework/695/science_kits/index.htm. The site contains a series of photos showing the progression of the foam-producing reaction.

A rather thorough web site about the discovery and development of rubber can be found at <http://www.pslc.ws/macrog/exp/rubber/menu.htm>. It is a joint effort by Macrogalleria and the Chemical Heritage Foundation.

For a series of four microscopic modeling images of collagen molecules at various degrees of magnification, see this MIT web site:
http://web.mit.edu/mbuehler/www/research/Collagen/summary_PNAS_Aug15.pdf.

More sites on explosives

For students interested in pursuing explosives, there is (Believe it or not!) a one-week hands-on Summer Explosives Camp, run by an explosives expert and professor of mining engineering at Missouri University of Science and Technology. See this web page, http://news.mst.edu/2008/06/first_session_of_explosives_ca.html, for an article on the camp.

If you would like a more controlled approach to the Alka-Seltzer film canister rocket experiment, see <http://www.statease.com/news/news0909.pdf>. The experimenter is Mark Anderson, an engineer who designs experiments for a living. He offers some statistics on the results of his experiments. And here's a follow-up note on Mark's experimental results: <http://www.statmadeeasy.net/2007/07/>.

Here is a copy of the actual article covering the accident involving the tennis ball launch physics class: <http://www.thefreelibrary.com/EXPLOSION+BURNS+TEENS+%3B+PHYSICS+EXPERIMENT+GOES+AWRY+DURING+CLASS+AT...-a083847248>

Your physics colleagues may be interested in using the film canister explosion in a physics experiment. Have them check out http://www.sciencebuddies.org/science-fair-projects/project_ideas/Chem_p074.shtml.

If you've ever wanted to know what a specific fireworks term means (like, what's a "break"?), see <http://www.pyrouniverse.com/glossary.htm>.

Pyrotechnic Innovations at <http://www.pyroinnovations.com/videos.html> has a series of free downloadable videos on fireworks shows, as well as a few videos of the team setting up the shows.

Graham, Tim. Colors Bursting in Air. *ChemMatters*. October, 1998. 16:3, 7-9.

More sites on making special effects a vocation

SchoolsintheUSA.com lists a special effects technician as a possible career for their students: http://www.schoolsintheusa.com/careerprofiles_details.cfm?carid=1049. Maybe one of your students is interested.

The Science of Snowflakes: Crystals from the Clouds

Background Information

More on the history of the photography of snowflakes

Wilson A. Bentley, (1865-1931), aka “Snowflake” Bentley, took his first snowflake photograph in 1885. Prior to that, he had observed snowflakes through a microscope and tried to make detailed drawings of the flakes, but he became frustrated because the snowflakes always melted before he could finish. Thus he turned to photographing the intricacies of the snowflakes. He photographed more than 5000 snowflakes over his years of research and, like the article says, he never found two alike. Bentley’s work spanned more than four decades, and it is a tribute to his perseverance, given that he had to work in the outdoor (or indoor) cold while gathering the snowflakes and setting up and taking the photographs, and given that he had to do all this work with film-based images (actually, the images formed on glass plates, not film as we know it today) and very old-technology bellows cameras. He had to develop all his pictures himself, no instant pictures with digital cameras (or even a Polaroid camera, since it hadn’t been invented at that time—the Polaroid Land camera was not available to the public until 1948).

Bentley became the authority on the microphotography of snowflakes. He wrote articles for many magazines describing his work. In 1922, Bentley published a 4-page article in *Popular Mechanics* that described to readers how to photograph snowflakes. The article says that readers can take the snowflakes indoors after collecting them and can photograph them indoors—but he tells the readers that the room in which they do their work and all their equipment must be the same temperature as outside! And once the photograph is taken, the photographer then has to use a sharp tool to scrape away the emulsion that surrounds the image of the snowflake on the glass plate, in order to increase the contrast between the snowflake and its background. This was probably the most time-consuming part of the entire process. The article can be seen at <http://snowflakebentley.com/popmech.htm>.

McGraw-Hill published his book, *Snow Crystals*, in 1931. It highlighted over 2400 snow crystal images. (It is out of print, but Dover Publications, Inc. has reprinted the book in its entirety.)

If you are interested in photographing snow crystals, Ken Libbrecht’s snowcrystals.com web site has a whole page devoted to photographing snowflakes: <http://www.its.caltech.edu/~atomic/snowcrystals/photo2/photo2.htm>. He even gives a parts list and prices for the apparatus he constructed.

More on the history of man-made snow

The first man-made snow was made by a group who wasn’t even working on making snow. The research was led by Dr. Ray Ringer, in a low-temperature laboratory in Canada. The group was working on the problem of icing on the intake of jet engines. In order to study the problem, they tried to create rime icing on a jet engine in a wind tunnel by spraying water into the air just before it entered the intake of the engine. Although they were unable to create the icing that was the target of their studies, they were successful at producing snow—so much that they had to periodically shut down their jet engine and shovel out the snow from the wind tunnel. Since snow-making wasn’t their goal, they never bothered to file a patent on the process.

In 1954, the first patent for a snow-making apparatus was granted to a company that was in the ski-manufacturing business. In 1949 the company took a hit in ski sales due to a dry winter with little snow. The next spring, Wayne Pierce, one of the partners in the company announced to his partners that he knew how to make snow. They created snow via a machine that used compressed air (from a spray paint compressor) and water forced through a nozzle. These have since been dubbed, snow cannons.

Difficulties with patent infringement and lawsuits forced researchers to devise a new method for snow-making. The next step involved a fan, rather than compressed air. The other new idea involved the use of nucleating particles in the form of dirt. Alden Hanson filed for a patent on this idea in 1958. This patent is considered the pioneer patent for all snow-making machines that followed. Ensuing patents involved modifications and improvements to the Hanson patent, involving variable-speed fans, advanced shapes for the propeller blades of the fans, rearrangement of the insertion points for the nucleating agents, multiple-jet nozzles, etc., but no truly new processes have arisen. Present-day snow cannons use a combination of the compressed air of Pierce's patent and the fan and nucleation sites of the Hanson patent. In its article on snowmaking, Wikipedia has several photos of snow cannons at work at http://en.wikipedia.org/wiki/Snow_cannon.

If you're really interested in making snow, you can make your own snow at home. Several web sites offer directions for constructing your own snow-maker. Snow at Home, for instance, has free plans for four different models of snowmakers: http://www.snowathome.com/free_plans.php. Of course, they also sell them already made and assembled (or not) for a fee.

More on how snow crystals form and grow

The process by which water freezes into ice in the atmosphere is referred to as heteronucleation—using nucleating agents to freeze. Although we all know that water freezes at 0°C, distilled (pure) water that contains no nucleating agents can be supercooled under laboratory conditions (or in the upper atmosphere) to temperatures as low as -40°C before it freezes via homogeneous nucleation; e.g., without outside nucleating agents. According to V. Guthmann of the Institute of Inorganic Chemistry at the Technical University of Vienna, Wien, Austria, the coldest temperature ever recorded in a lab for liquid water was -44°C, but that was in a tiny capillary tube inside a cloud chamber.

In 1956, Dan McLachlan, of the Stanford Research Institute, wrote a paper published in the *Proceedings of the National Academy of Sciences* detailing his understanding at the time of the growth of snow crystals. The paper, entitled, "The Symmetry of Dendritic Snow Crystals", first details a bit of the history of the study of snow crystals, and then goes into some detail about the physics (and math) of snow crystal growth. He admits that his interest is not in the assumption that no two snowflakes are alike; in fact, he almost seems to assume this is correct, due to their complexity and the direct relationship between complexity and the probability of a difference. Rather, the paper was written to address the symmetry of the six branches on a given snowflake. McLachlan said, "The present discussion deals with the artistic aspects of snow crystals, but it has a scientific interest because it tries to explain the causes of the interesting shapes of snow crystals and, furthermore, because these explanations may be carried over into other fields wherein dendritic growth and branching are evident."

McLachlan's paper contains a bit of math that is probably beyond the average student's grasp, but it also offers a glimpse into the number of molecules involved in the formation of a snowflake and their actions on the molecular level. Here is a passage relevant to this discussion:

Some Statistics of Snow Formation.-Let us consider some facts which might enable us to imagine what goes on in the atmosphere during the growth of a snow crystal.

At 0° C., saturated air contains 4.835 gm. of water per cubic meter, according to the Smithsonian tables. At 20° C. the air is saturated when there is only 0.892 gm. per cubic meter. This means that if saturated air at 0° C. is chilled to -20° C., about four-fifths of the suspended water molecules will precipitate as ice as fast as these molecules can establish (or find) nuclei upon which to deposit. Expressed in partial pressures, the 4.835 gm. of H₂O per cubic meter is about 0.006 atmosphere, or 4.56 mm. of mercury. This does not appear to be a very high pressure, but it represents 1.6×10^{17} molecules of H₂O per cubic centimeter mixed with about 200 times this many molecules of air. At this congestion, the water molecules are only 0.2×10^{-3} millimeter apart. They do not have far to go to associate with one another, and they should not require very long to accomplish much, since the H₂O molecules are traveling at a mean velocity of 62,700 cm/sec. For example, if an ice crystal is suspended in the saturated atmosphere at 0° C., it is bombarded with water molecules at the rate of 2.5×10^{21} molecules per square centimeter per second, that is, about 1/250 mole/sec. This means that every 28 seconds there will be about 79 calories of heat deposited per square centimeter if every molecule sticks (this is assuming a heat of sublimation of 675 cal/mole). This accumulation of heat would raise the temperature and melt the crystal (79 cal/mole is the heat of fusion of ice).

To be more precise, let us consider an actual snow crystal of over-all dimensions of 100 μ or about 1/10 mm. Assume that it is similar to the one pictured in Figure 3 having six spines, each 20 times as long as wide and about one-tenth as thick as wide. Such a crystal has an area of 10^{-6} square centimeter. Such an area is bombarded with 2.5×10^{15} water molecules per second. Using the figure 1.4×10^{15} and the volume occupied by water molecules in ice, one concludes that the crystal should grow at a rate of about one centimeter per second in all directions. This velocity of growth is much more rapid than observed rates,⁶ since observed rates are approximately 100 μ in 30 seconds or 10^{-4} cm/sec. [In the previous sentence, the superscript "6" is a reference number from the article.] We are forced to conclude that even at fast rates of growth only about four out of every thousand molecules which strike the crystal surface stick; the other 996 bounce off.

<http://www.pnas.org/content/43/1/143.full.pdf?ck=nck>

Much of McLachlan's discussion centers on the idea of standing waves, a physics topic. The first mathematical equation he uses is a standard physics equation to find frequency of an object exhibiting wave motion. You might want to share this article with your physics colleagues.

More on artificial snow

There is some overlap between this article on snow and an accompanying article in this issue of *ChemMatters*, “Hollywood’s Special Effects: How Do They Do That?” One of the foci of that article is snow, albeit of the artificial kind. That article’s snow focus is primarily about “fake” artificial snow—the kind that isn’t made of water, but consists of various other materials, like potato flakes, or shredded paper, or sodium polyacrylate—the kind used for special effects. These might include natural snow or man-made snow, but they also include the rest of those listed above. The role of SnoMax® and *P. syringae* in making man-made snow is discussed in that article. Also check the Teachers Guide for more information.

Connections to Chemistry Concepts

1. **Polar molecules**—water molecules attract one another due to their polarity. It is this attraction between molecules that is responsible for the growth of snow crystals.
2. **Secondary bonding/Hydrogen bonding**—Hydrogen bonding between water molecules is the force that holds snow crystals together.
3. **Molecular geometry/bond angles**—The 104.5° bond angle between oxygen and hydrogen in water molecules accounts for the hexagonal structure of snow crystals.
4. **Crystal structure**—The hexagonal shape of the snow crystal is only one of many different crystal shapes evidenced by other chemical substances.
5. **Nucleation**—Dust particles serve as the nucleation sites onto which water molecules aggregate into snow crystals.
6. **Saturation point**—Snow crystals grow best when the atmosphere around them is saturated with water vapor. See the Morphology diagram at <http://www.its.caltech.edu/~atomic/snowcrystals/primer/primer.htm> for more information about the types of crystals that form at various levels of supersaturation and temperature.

Possible Student Misconceptions

1. **“Ice crystals have the same crystal structure as snow crystals do.”** *Since ice crystals form from the aggregation of liquid water molecules, they do not assume the same crystal structure as snow crystals, which form from the aggregation of water vapor molecules.*
2. **“No two snowflakes are alike; everyone knows that.”** *Although this is an age-old (since Bentley’s assertion in 1931) adage, and it probably works for large snowflakes, scientists are not sure it holds true for smaller snow crystals. [It seems logical, however, given that a snowflake holds about 10^{18} water molecules, and it would be highly improbable to have all 10^{18} molecules assuming the same positions in the crystal structure.]*
3. **“Artificial snow isn’t the same thing as ‘real’ snow.”** *Artificial snow is really snow. It’s made of frozen water vapor, just as is regular snow. The only difference is the nucleating sites: in real snow they’re believed to be dust or other particles in the air; in artificial snow, the nucleation sites are non-toxic bacteria.*
4. **“If the temperature gets too cold, it can’t snow.”** *It seems this is an old wives’ tale (“It’s too cold to snow.”), albeit not without some logic/precedent. Although the types of crystals that form differ at different temperatures, snow can occur at any temperature. But “...the catch is that you need a source of moisture and some way of lifting or cooling the air. Since very cold air does not contain much moisture, most heavy snowfalls occur when ground temperatures are above 15 °F.” (ChemMatters Teachers Guide, December 2000)*

5. “Do nuclei act as nucleation sites?” *Students may think, since the term nucleation is similar to nuclei, that atomic nuclei are actually the particles on which water molecules coalesce. In truth, atomic nuclei are many orders of magnitude too small to serve as nucleation sites (10^{-14} m for atomic nuclei vs. 10^{-6} – 10^{-4} m for dust and bacteria)*

Demonstrations and Lessons

Snow crystals and snowflakes

1. You can show students how snow crystals grow by growing your own.

SnowCrystals.com has a set of directions for **growing your own snow crystals** using Styrofoam cups, a soda bottle, a few other household items, and dry ice. This could also be done as a class laboratory activity if you can gather the materials in class quantities.

(<http://www.its.caltech.edu/~atomic/snowcrystals/project/project.htm>) See #4d, below for another improved (?) method for growing snow crystals.

2. You can show them **how (carbon dioxide) snow forms** by releasing some gas from a CO₂ fire extinguisher into the classroom. As the CO₂ leaves the tank through the valve, it immediately changes phase to a gas, and then expands adiabatically, cooling in the process to a temperature below its freezing point. The CO₂ solidifies into the white cloud students observe. Then, almost as quickly, the solid CO₂ sublimates back into a gas as the white cloud disappears. Be sure you use a CO₂ extinguisher, as the powder fire extinguishers will form the white cloud, but it won't dissipate as it clings to everything. If you don't have access to a CO₂ extinguisher, here's a quick (0:36) YouTube video of the phenomenon your students can watch: <http://www.youtube.com/watch?v=k3-zBLIYCyM>. This video is a safety video, but it illustrates the snow you want to show them. Be sure to point out to them the few “snow” flakes (dry ice) that seem to drip off the black “horn” at the end of the video.

This demonstration is a great engagement piece to get students interested in Thermochemistry topics, including potential energy changes, heat of vaporization, and heat of sublimation, as well as adiabatic expansion. Note that the CO₂ escaping from the extinguisher was not sublimating. The CO₂ in the extinguisher is actually liquid CO₂, not solid carbon dioxide. Sharper students pick up on that. The liquid CO₂ evaporates to gaseous CO₂, the gas then expands adiabatically, cools and freezes, deposits (deposition is the opposite of sublimation), and finally it sublimates back into the air. This might make a good problem for more advanced students to solve: “How much heat is involved in the complete process of discharging one mole of CO₂ into the atmosphere from a CO₂ fire extinguisher, assuming it ends up at the same temperature in the air as it began in the extinguisher?”

3. The CO₂ fire extinguisher from #2 above can also be used to show students **CO₂ snow** as it comes out of the extinguisher. Simply hold a piece of black felt cloth close to the horn as you discharge the fire extinguisher. The CO₂ snow will deposit on the cloth. If you pass it around the room, students can see the snow up close, and they can feel that it is cold as well.

4. As the title of the article implies, snow crystals form from clouds of water vapor in the air. You can demonstrate for students **how clouds form** by doing the old **cloud-in-the-bottle** demonstration.

a. A description of a simple (close to the original) version of this activity can be found on pages 16 and 17 in the October, 2003 issue of *ChemMatters*. This issue can be found on the *ChemMatters* 25-year CD, described below in the Web References section of the Teachers Guide. The article is actually written as a student do-at-home activity.

- b. This one does it perhaps with a new twist. Use a 2-liter beverage bottle, a tire stem and a tire pump, a match and a little water. To prepare the apparatus for pumping air into the bottle, poke the tire valve stem into and through a one-hole rubber stopper that fits the bottle and attach a tire pump valve to the valve stem. Add a little water to the bottle (~10 mL) and swish it around the sides to coat them to maximize surface area and evaporation. Light a match, blow it out and hold the match head in the mouth of the bottle to allow smoke particles (nucleation sites) to enter the bottle. Pump the tire pump a few times (15-30). Observe that the bottle gets warm. This warms the air and the water vapor inside the bottle. The water inside evaporates more quickly into the warmed air, creating a saturated system. Then pop the stopper out of the bottle; voila, instant cloud! Popping the stopper instantly reduces the pressure inside, adiabatically cooling the system. It takes less water vapor to saturate the air at a lower temperature, so the excess water vapor instantly condenses into a cloud. You can view the demonstration (and show it to students if you can't do the demonstration yourself) on Steve Spangler's web site at <http://www.stevespanglerscience.com/experiment/00000030>. There are three videos, each a little different, showing Steve performing this demonstration on a local television show. One of the three has a fairly detailed explanation of what is happening, while the other two are more entertaining than educational. One of them uses rubbing alcohol instead of water, which seems to give an ever-so-slightly more visible cloud, but it is done at the expense of now having a more "synthetic" system, as he has a cloud of condensed alcohol vapor molecules, instead of a "real" cloud of condensed water vapor. This one seems more "fake". A tab on this site also provides an explanation for the phenomenon. As you and your students reach a conclusion in class about why this happens, be careful not to use the explanation that the cooler air can't "hold" the water vapor, as the air isn't holding anything! For an explanation of this misconception, see "How much moisture can the air "hold"?" at <http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/relhum.html#c5>.
- c. You can view a simpler way to do the cloud-in-a-bottle demonstration on YouTube at <http://www.youtube.com/watch?v=E8AvfXar9zs>. This one avoids the need for the tire pump and apparatus. The bottle is merely squeezed and released several times to get a similar (although slightly less obvious) cloud formation. It has no discussion, so students can think about why it is happening as they view the video.
- d. The AIM (Aeronomy of Ice in the Mesosphere) web site has a classroom activity that is yet another version of the same demonstration using two 2-liter bottles attached to each other: http://aim.hamptonu.edu/hea/docs/AIM_Make_a_Cloud.pdf.
5. You can simulate the supercooling of water in clouds by preparing your own supercooled water and observe that it (most likely) remains liquid, unless you provide nucleation sites. Directions for a student experiment are found on the Science Buddies web site at http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p033.shtml. The end of the experiment also provides ideas for further experimentation based on the results of the first experiment. This site from the University of Wyoming (<http://faculty.gg.uwyo.edu/kempema/supercool.html>) shows a small tank of water supercooling when a seed crystal of ice is added. The temperature is shown as the freezing of the ice progresses. The temperature jumps as the ice front touches the temperature sensor. This adds another dimension to the demonstration, that of latent heat. A YouTube video of the process using a bottle of bottled water can be seen at http://www.youtube.com/watch?v=fSPzMva9_CE.

Other types of crystals

6. Mineral and salt crystals grow by a similar process to the way snow crystals grow. Wayne Schmidt, an engineer with degrees in mechanical engineering and plasma physics, has an extensive web site (“This and That”) dealing with many esoteric topics in great detail, one of which is **growing crystals**. This is an extensive web page (it scrolls down for about 40 screens) in which he describes more than 30 different crystal-growing experiments. His site reflects his background as an engineer—and a scientist—as he narrates the many experiments to indicate improvements and questions/hypotheses about how to improve them even more, and he approaches each experiment with a scientific eye. And he shows his successes as well as his failures. (It would be good to have students merely look at a few of his experiments to see what he says in terms of questions that arise and hypotheses made in response to the questions.) The first set of about ten experiments is listed as “fast, simple crystal growing projects”. Next he has “Advanced crystal growing projects”, followed by experiments to grow specific crystals and crystal-growing projects. For all of them, he indicates whether they would be good for classroom demonstrations, and for a few he tells us they are “duds”. View the site at <http://www.waynesthisandthat.com/crystals.htm>. You could choose many of these for in-class experimenting. Here are a few of those choices:

- a. Growing a **crystal garden** using Mrs. Stewart’s laundry bluing; these grow quickly, within hours to a few days. This experiment especially contains many anecdotal comments by engineer/scientist Schmidt.
- b. **Rock candy**—again, with many variations (This is always a favorite with students, for some reason.)
- c. His **best choices of crystals to grow**: alum, alum with chrome alum, and copper sulfate
- d. **Growing snow crystals**—About nine-tenths of the way down his web page you’ll find directions for an improved method for growing snow crystals. It reflects his engineering background.

Note that crystal growing can take a long time—weeks or longer. This may make these activities more useful as student projects than in-class lessons.

7. About.com: Chemistry offers a series of **recipes for crystal-growing** based on several categories, including crystal color and the way the crystal looks when it’s grown (photo selection). View these at

http://chemistry.about.com/od/growingcrystals/Growing_Crystals.htm.

8. You can **grow instant crystals** with a **supersaturated solution of sodium acetate**.

You can obtain sodium acetate from science supply companies, from reusable hand warmers (the kind with the clear, colorless liquid in a clear pouch) from outdoor sporting goods stores or ski shops, or you can make it yourself from baking soda and vinegar.

a. Dave Brooks’ web site of chemistry teacher resources contains a demonstration from the series, “Doing Chemistry”, showing the rapid crystallization of supersaturated sodium acetate. The page offers a complete lesson for teachers, including hazards, procedure, materials, time, student handout, etc. Each demonstration/lab usually includes a short video clip that is also a mini-lesson by itself. While you’re at this page, you might want to go surfing through his “Main Page” or “Chemistry Teacher Resources” pages. His site contains a wealth of information useful to high school chemistry teachers. View the demonstration at <http://dwb4.unl.edu/Chemistry/DoChem/DoChem058.html>. All other pages on his site can be reached from this page.

b. Students can actually make their own sodium acetate from vinegar and baking soda. The “Instructables” web page contains all the directions, step by step (a 15-step process on this page), at <http://www.instructables.com/id/Crystallization-of-homemade-sodium-acetate/>. This page also includes a video clip of the crystallizing of a flask of supersaturated sodium acetate. You must decide whether you want to tell students it can

be done at home, as there is heating (and frothing) of the vinegar-baking soda mixture involved.

c. About.com: Chemistry also has the baking soda and vinegar method for preparing sodium acetate to make the supersaturated solution at <http://chemistry.about.com/od/homeexperiments/a/make-hot-ice-sodium-acetate.htm>.

This site (and almost the whole internet world) calls this demonstration, "Hot Ice". Seeing the activity on About.com: Chemistry might make one feel a little safer telling students about the experiment. (I'd prefer the Instructables version as it is a little more scientific in its approach.) Actually, About.com: Chemistry also has a video of the process, done by Dr. Helmenstine, the Chemistry Guide, at <http://video.about.com/chemistry/How-to-Make-Hot-Ice.htm>.

d. Here's another teacher lesson that uses the supersaturated sodium acetate solution (in a reusable hand warmer) to teach the concept of latent heat and phase changes: <http://www.geosociety.org/educate/LessonPlans/LatentHeat.pdf>.

e. A great short video that shows up close the crystal growth of sodium acetate crystals can be seen on YouTube at http://www.youtube.com/watch?v=HnSg2cl09PI&feature=player_embedded#.

9. Students can **make their own crystal garden** by using Mrs. Stewart's Bluing. This is a laundry additive, but you can also use it to grow salt crystals. The growth begins within a few hours and can continue for days or weeks, if the ingredients are added over time. You can find the directions directly on Mrs. Stewart's Bluing web site, at <http://www.mrsstewart.com/pages/scginstructions.htm>, along with an explanation of why it works at <http://www.mrsstewart.com/pages/explanation.htm>. The site also offers a 4-page downloadable teacher brochure at <http://www.mrsstewart.com/pdf/MSBTeacherBrochure084pg.pdf>.

10. An interesting lab that would probably be more suitable to a biology class (and maybe AP, to boot) that tests the effectiveness of *P. syringae* relative to other bacteria in ice nucleation. It can be found at <http://www.plantpath.wisc.edu/fac/joh/Exp2TeachGuide.htm>. Students must design their own experiment to test two hypotheses re: ice nucleation.

Student Projects

1. Students could research the similarities and differences between naturally-occurring snow and man-made snow, and then debate/discuss whether man-made snow is "real" snow. This discussion could be based both on processes and properties.
2. Students could grow their own snow crystals and photograph them. They could control variables to see if they are able to grow specific snow crystal types. And then they could report their findings to the rest of the class. Two methods of growing snow crystals are referenced and web sites listed in Demonstrations and Lessons, #1 and #4d, above.
3. Students could investigate the "ice spike" phenomenon first by researching the phenomenon online, and then by attempting to make them in their own home freezer. They should approach the project and their experiments in a scientific manner. This site could be a good starting point: <http://www.physics.utoronto.ca/~smorris/edl/icespikes/icespikes.html>.
4. Students could research and report on the pros and cons of snow-making as a commercial enterprise. Factors to consider include natural resources consumption (water and electricity), costs, ecological effects, benefits to mankind.
5. Students could grow their own crystals, trying for most perfect or largest. Growing crystals takes a long time, so they shouldn't expect instant results. See Demonstrations and Lessons #6 and #7, above for sources.

Anticipating Student Questions

1. **“How large can snowflakes be?”** *One snowflake was recorded to have a 35 cm diameter, although it has never been verified. There is no established theoretical limit, but the larger snowflakes get while in the air, the more likely they are to bump into other snowflakes and break apart.*
2. **“Why can’t two snowflakes ever be alike?”** *The complexity of the snowflake due to the sheer number of water molecules involved in its formation probably precludes the possibility of that many molecules ever depositing identically on two flakes. Also, each snowflake as it is forming is exposed to different conditions of temperature, humidity, altitude, etc., so if the conditions are different, it is almost certain that the flakes will be different also.*
3. **“Are all snowflakes perfectly symmetric and ‘beautiful’?”** *No, all snowflakes aren’t ‘beautiful’. Charles Knight, a researcher from Boulder, Colorado who studies and photographs individual snowflakes, notes that more than 99% of all snowflakes are asymmetric and “downright ugly”. Apparently, “Snowflake” Bentley only photographed (or published) the beautiful; i.e., symmetric ones.*
4. **“Is snow always made of solid water?”** *Well, that depends on your definition of snow. Here on Earth, we all seem to agree that snow is solidified water. On Mars, however, astronomers have evidence of snowfields at the poles, and these deposits are solidified carbon dioxide, dry ice. Instruments indicate no water in these deposits, so it’s not our kind of snow, but it’s snow to those scientists.*
5. **“If branching occurs when the growing snow crystal depletes water vapor from the surrounding air, why does branching only occur under conditions of high humidity? Wouldn’t water vapor depletion be more likely to occur in low humidity conditions?”** *This does seem counterintuitive at first, but in order for the branches to grow, there have to be water vapor molecules available for that growth, and in low humidity conditions, there would be few molecules available to coalesce on the newly formed branches. But in high humidity, it is still relatively easy for the atmosphere close to a growing crystal to be depleted of water vapor molecules, if the growth rate is rapid. But under those conditions, it won’t be long before more water vapor molecules enter the area around the crystal, only to be added to the growing branches of the crystal.*
6. For more Anticipated Student Questions, see that section of the “Artificial Snow” article on the *ChemMatters* Teachers Guide, December, 2000, available on the *ChemMatters* 25 year CD.

References

Libbrecht, K. G. The Physics of Snow Crystals. *Reports on Progress in Physics*. 2005, 68, pp 855-895.

Web Sites for Additional Information

ChemMatters

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Rohrig, Brian. Artificial Snow: Powder for the Slopes. *ChemMatters*. December, 2000. 18:4, 10-11. This is a good introduction to how and why artificial snow is made.

Background Information, Artificial Snow. *ChemMatters Teachers Guide*. December, 2000. This section of the Teachers Guide gives extensive information about both natural and artificial snow.

Rosenthal, Anne. Clouds. *ChemMatters*. October, 2003. 21:3, 12-15. This article was part of a special NASA issue of *ChemMatters* dealing with the Earth's atmosphere. The focus of the article is on how clouds form, cloud seeding, and the NASA instruments that monitor the Earth's atmosphere.

More sites on the history of the photography of snowflakes

WBZTV did a short video on a few highlights of the life of "Snowflake" Bentley on one of their weather broadcasts. You can view the clip at <http://snowflakebentley.com/vid.htm>.

The "Snowflake" Bentley web site has a biography of Wilson Bentley at <http://snowflakebentley.com/vid.htm>. And their newsletter web pages give some further insights into his life and his accomplishments: <http://snowflakebentley.com/news.htm>.

The Buffalo Museum of Science web site contains a large collection of the original Bentley (b&w) snow microphotographs, organized according to the Magono and Lee classification scheme. You can find them at <http://www.bentley.sciencebuff.org/collection.asp?page=1>.

More sites on how snow crystals form and grow

The "Snowflake" Bentley web site newsletters also contain some scientific discussions of Bentley's work and his findings: <http://snowflakebentley.com/news.htm> .

In their "Wonders of Weather" series, Discovery Channel has a 3:37 video that shows Bentley at work in his backyard with his microscope, discusses the temperatures at which various types of crystals grow, and claims that 99% of all snow crystals are "downright ugly". (Bentley only photographed the pretty ones.) View it at <http://dsc.discovery.com/videos/wonders-of-weather-snow.html>.

A brief coverage of *P. syringae* and its role in ice formation can be found at http://bioweb.uwlax.edu/bio203/s2008/campbell_rach/index.htm. This is a report made by a university biology student.

More sites on shapes of snow crystals

The Beltsville Agricultural Research Center (BARC) has a web site with extensive coverage of snowflake shapes. Images on the site have been taken with normal light microscopy as well as Low Temperature Scanning Electron Microscopy (LT-SEM). The images are astounding. [<http://emu.arsusda.gov/snowsite/default.html>] Some of the images are stereographic images, although they may be difficult to see in 3-D. Be sure to visit their "Magono and Lee Classification", pages 1 and 2. These two pages show drawings of approximately 80 different identified snowflake crystal structures, and more than 60 of those have enlargeable LT-SEM photographs representing those types of crystals. These are really worth seeing! Note that all these images are in black and white.

For a gallery of color images of a vast array of snowflake microphotographs, visit SnowCrystals.com at <http://www.its.caltech.edu/~atomic/snowcrystals/photos/photos.htm>.

The American Chemical Society has a one-page PDF file that illustrates a 14-step process by which a snowflake forms and grows can be found here: http://acswebcontent.acs.org/journalist_resources/snowposter.pdf.

More sites on shapes of crystals (not snow)

The All About Gemstones web site has several pages dealing with crystalline structure, crystal forms and crystal habit. (http://www.khulsey.com/jewelry/crystalline_structures.html) Coverage includes discussion of the unit cell, refractive indices, the Mohs scale of hardness, and mineral classification.

Your Gemologist is another web site that covers the seven crystal systems, with great photographs of minerals exhibiting each of the systems: <http://www.yourgemologist.com/crystalsystems.html>. This site also has a separate page, with photos, for each of the minerals/gemstones.

The Crystallography web page is an extensive site that contains a detailed study of all the crystal forms and all the minerals that assume that form. It includes a Java-animated model, and PDF paper models of each of the crystal shapes that range from the really simple to the extraordinarily complex. (<http://webmineral.com/crystal.shtml>) This is a treasure trove of information about crystals.

The Naval Research Laboratory hosts an extensive site that offers an index of almost 300 common crystal lattice structures. Each page shows a graphical representation and other useful information. This would be useful for students to see how atoms are attached to each other in the crystal structure. Coverage includes face-centered, body-centered, and hexagonal close-packing structures with examples of minerals that have those structures. (<http://cst-www.nrl.navy.mil/lattice/>)

More sites on artificial snow

About.com's web site contains a short article about the history of making snow: <http://inventors.about.com/library/inventors/blsnow.htm>.

General Web References

The best web reference for information on snow is probably SnowCrystals.com, at <http://www.its.caltech.edu/~atomic/snowcrystals/>. It has been referenced a number of times in this Teachers Guide and in the article itself.

Space Food

Background Information

More on nutrition in microgravity

As the article says, the nutritional requirements of humans in space is very important, especially since the amount of time an astronaut remains in space on any given flight has increased greatly since the early days of space travel.

The nutritional requirements in microgravity are actually based on the United States Dietary Reference Intakes currently in use. These references used to be called Recommended Daily Allowances. Studies have shown that many, but not all, nutrients are absorbed in space much like they are absorbed on Earth. Energy requirements are also important.

Of primary concern is the number of calories utilized during space flight. These are determined according to standards set by the National Research Council. Basal energy expenditure (BEE) is calculated according to the Harris-Benedict equation:

For women, $BEE = 655 + (9.563 \times W) + (1.850 \times H) - (4.676 \times A)$

For men, $BEE = 66.5 + (13.75 \times W) + (5.003 \times H) - (6.775 \times A)$

where W = weight in kilograms, H = height in centimeters, and A = age in years.

Astronauts in space, however, tend to consume 500-1000 less calories per day than these calculations would seem to require. This leads to weight loss and consequent loss of muscle mass and bone mass. NASA nutritionists study the energy utilization of astronauts by analyzing diet history during flights, and doing metabolic studies. The two methods of metabolic studies are bomb calorimetry and calculating carbohydrates, proteins and fats from the food records kept on all flights. Food intake is recorded on a food log kept by astronauts or by scanning barcodes on all foods consumed. The nutrient calculations are done as a result of chemical analysis after the flight.

The tendency has been for astronauts' in-flight diets to be higher in carbohydrates and lower in fats than their pre-flight diets. This may be the result of many food items in space being higher in carbs.

Protein intake is more important in space because of the loss of muscle mass as a result of reduced caloric intake. Astronauts should consume protein in excess of what they would eat on Earth in order to reduce loss of muscle mass. Studies indicate that added protein intake is necessary but not sufficient to minimize muscle mass loss. Added intake should be coupled with an exercise regimen and in some cases medication to prevent bone loss, as well as sodium, phosphorus and magnesium supplements, and Vitamin D. The need for vitamin D arises because the astronauts are shielded from solar radiation in space. On Earth sunlight causes the body to produce its own vitamin D.

Calcium is another nutrient that behaves differently in microgravity than at 1 G, as the article describes. An increase in calcium intake will not reduce bone loss, which may be as much as 1-1.6% for longer stays in space, apparently because the body's calcium-metabolizing process slows down in microgravity. An added problem is that excess calcium in space

increases the chances of the astronauts developing kidney stones. Fluid intake is an important factor in preventing kidney stones. Optimum fluid intake is about 2,000 mL per day.

In contrast to nutrients that must be supplemented in space food, iron intake must be decreased, as the article states. Since total volume of blood is reduced in space, hemoglobin levels are reduced and, hence, the need for iron is also reduced. In space the iron intake of both male and female astronauts should be no more than 10 mg per day.

Another nutrition-related problem with food in space, especially for longer trips like a Mars mission, is spoilage. Many essential vitamins, amino acids and fatty acids in foods will degrade over the course of such a long mission. In 2006, NASA food scientists tested several foods taken into space by a space shuttle mission. Broccoli au gratin, salmon, tortillas, almonds and dried apricots were analyzed after 13 days, 353 days, 596 days and 880 days. The tortillas lost 54% of their thiamine content and 47% of the folic acid over the 880 days. Broccoli lost 72% of beta carotene and 21% of its vitamin C. Such degradation could jeopardize the nutritional balance of foods in long space flights. The nutrient components of some of the foods, in fact, increased during the study. Beta carotene increased in the apricots, for example.

In a later section of this Teachers Guide, you will find information on ways NASA food scientists are trying to eliminate food spoilage by preparing and packaging foods for space.

NASA continues to use chemistry to study nutritional requirements in microgravity. According to a May, 2009, NASA announcement (at http://www.nasa.gov/mission_pages/station/science/experiments/Clinical_Nutrition_Assessment.html):

In order to provide nutritional recommendations to crew members for long-duration space travel, we need to better understand how nutritional status and general physiology are affected by the microgravity environment. Dietary intake during space flight has often been inadequate, and this can greatly compromise nutritional status. Data from both short- and long-duration space flights provide evidence that energy intake is typically 30-40% below World Health Organization recommendations, but energy expenditure is typically unchanged or even increased. This imbalance may explain some of the observed negative changes in overall nutritional status during flight. However, blood concentrations of some nutrients, such as vitamin D, continue to be low even when astronauts receive supplements during flight. The space environment itself results in physiologic changes that can alter nutritional status. For example, changes in iron metabolism are closely associated with blood chemistry alterations during space flight. Similarly, increased levels of radiation and oxidative stress during flight likely contribute to decreased antioxidant status and genetic damage during or after space flight.

There are six components to the research program

- The food system provides a six to ten-day menu cycle; before each mission, crew members participate in food-tasting sessions, and dietitians plan menus that will use crew choices and best fulfill the defined nutritional requirements for space flight.
- During flight, crew members are asked to record their dietary intake once per week using a Food Frequency Questionnaire (FFQ) designed for use with the space flight food system. The FFQ is

designed to obtain a near real-time estimate of intakes of energy, protein, water, sodium, calcium, and iron, as well as to collect information about vitamin supplement use and any crew comments. The questionnaire inputs from the astronauts are transmitted to the ground and results are calculated and reported to the flight surgeon within 24 to 48 hours.

- Body mass is determined pre, post, and in-flight, while body composition is determined pre and post flight using laboratory measurements. Body mass is determined in-flight using a body-mass measuring device.
- Blood and urine samples are collected pre and post flight for analysis of whole blood, plasma, serum, and various analytes; blood pH and ionized calcium levels are measured in-flight using finger sticks.
- Biochemical analysis of the blood and urine samples are performed at Johnson Space Center using standard laboratory methods.
- Statistical analysis of the analytical results is performed to detect differences in nutritional status from preflight to post flight.

In addition to the lab mentioned in the article, NASA also operates the Nutritional Biochemistry Lab. From NASA: “The primary goal of the Nutritional Biochemistry Laboratory is to determine the nutritional requirements for extended-duration spaceflight. Integral to that are the goals to maintain astronaut health and to develop, evaluate, and validate nutritional countermeasures to prevent or minimize the negative effects of long-duration spaceflight on the human. The Nutritional Biochemistry Laboratory activities are split between operations and research. The primary operational activity is the support of the Clinical Nutritional Assessment profile, which is completed before and after International Space Station flights. Dietary intake and body mass are monitored during these long-duration (4- to 6-month) missions. In addition to general dietary intake issues, several specific nutrients are also of concern. Vitamin D levels decline during flight, most likely related to the lack of ultraviolet light exposure. This is very important for bone and calcium metabolism, as well as other body systems. Folate, another vitamin, also appears to decline during flight, which may be related to the content of the food, the stability of the food on orbit (related to both time and radiation exposure), or changes in the body's need for folate.” (http://hacd.jsc.nasa.gov/labs/nutritional_biochem.cfm)

More on space food

In order to provide astronauts with a nutritional food supply, NASA must take into account more than just nutrition. Among the other issues related to space food, NASA must take into account the actual task of eating in microgravity, how the food is prepared and preserved, the weight of food and its packaging, the need for water and the need to dispose of a minimum of package waste.

Space food preparation

The article discusses six types of space food preparation--rehydratable foods, intermediate moisture foods, thermostabilized foods, irradiated foods, natural form foods, and fresh foods.

According to NASA, “Rehydratable items include both foods and beverages. One way weight can be conserved during launch is to remove water from certain food items. During the flight, water generated by the shuttle fuel cells is added back to the food just before it is eaten.”

Foods which are prepared to be rehydrated include scrambled eggs, chicken à la king, salmon, barbecue, frankfurters, shrimp cocktail, chicken consommé, cream of mushroom, casseroles like chili macaroni and chicken rice. All vegetables are freeze-dried and fall into the rehydratable category. All of these foods are packaged in flexible containers to aid in trash compacting on board the space craft.

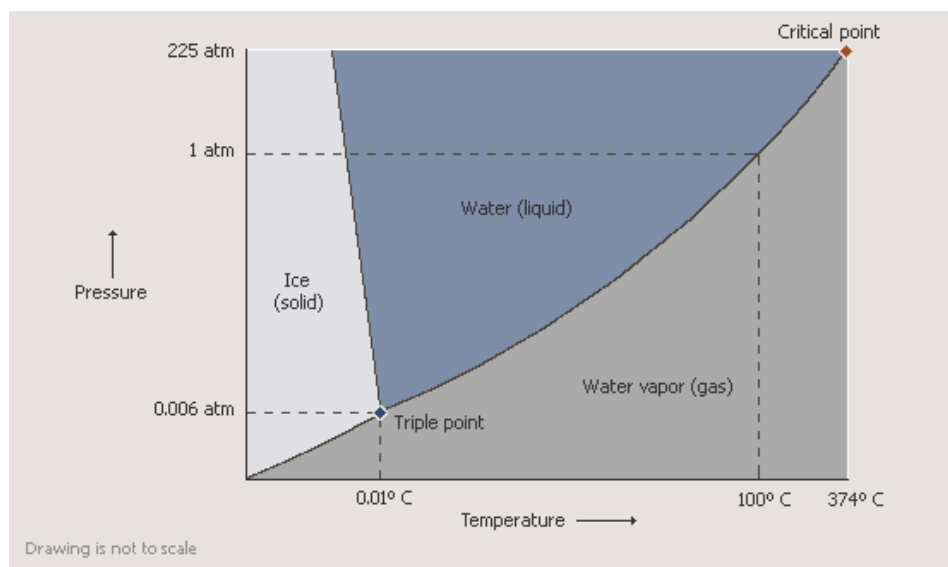
Food is rehydrated via an electronic water-dispensing system that inserts water into food packages via a needle. The system is calibrated to deliver 2, 3, 4 and 8 ounces of water. When the food package is inserted into the station, the needle penetrates the package and the required amount of water is delivered. The food and water are mixed and heated if necessary. Rehydratable beverages are processed in a similar way.

In June, 2009, NASA announced that it had developed a new hydratable beverage. According to the NASA press release, “We developed the hydration formula to perform optimally under the most extreme conditions. The health of our highly trained astronauts was paramount,” explained John Greenleaf, now a former Ames research scientist and inventor of the formula. “With all that Americans and the government have invested in the space program and our astronauts, this is one clear way to protect and maximize that investment. And now the general public will benefit from this research as well.”

“The novel electrolyte formula contains a specific ratio of key ingredients, sodium chloride and sodium citrate, for rapid restoration of hydration. These electrolytes, dissolved in water, optimize the levels of sodium ions in the body. The beverage is an isotonic formulation that restores both intra- and extracellular body fluid volumes in dehydrated astronauts, athletes and others.” Wellness Brands launched this new formula, “The Right Stuff”, in June, 2009. (<http://www.therightstuff-usa.com/>)

Freeze-drying is a method of preparing food by removing the water by sublimation. NASA invented freeze-drying. As most chemistry students will know, it is fairly easy to remove water from a substance—just add heat. You might have done this with chemical hydrates in class. However, dehydrating food is not so simple. There are two problems. The first is that heating food removes only 90-95% of the water. The second problem is that heating changes the shape, texture or makeup of the food, like what happens when we cook food.

Your students may be familiar with sublimation, the basic process by which foods are freeze dried. They will know that temperature and pressure are the two factors that determine the phase of a substance. Temperature and pressure are the variables on phase diagrams. The article provides the phase diagram for water (see below). Water is a solid (ice) at temperatures 0°C or lower under normal pressure and temperature conditions. We are used to the solid-liquid transition (melting) for water at ambient conditions. However, if the pressure is lowered to 0.006 atm (0.61 kPa) and the temperature increased, then ice will change to a vapor—it will sublime. This is the principle of freeze drying.



(Image from ChemMatters article)

Freeze drying takes place in a chamber that is attached to a compressor, vacuum pump and freezing unit. The food to be freeze-dried is placed in the chamber and the temperature is lowered so that the water in the food freezes. The pressure is then lowered in the chamber below 0.006 atm (0.61 kPa) and the temperature is raised slowly. As the temperature rises, the ice sublimates. The water vapor is evacuated from the chamber, freeze-drying the food in the chamber. The food is then sealed in an air-tight bag.

A second category of space food is thermostabilized food. NASA says, "Thermostabilized foods are heat processed to destroy harmful microorganisms and enzymes. Individual servings of thermostabilized foods are commercially available in aluminum or bimetallic cans, plastic cups, or flexible retort pouches. Most of the fruits and fish such as tuna and salmon are thermostabilized in cans. The cans open with easy-open, full-panel, pullout lids. Puddings are packaged in plastic cups. Most of the entrees are packaged in flexible retort pouches. This includes products such as beef tips with mushrooms, tomatoes and eggplant, chicken à la king, and ham. After the pouches are heated, they are cut open with scissors. The food is eaten directly from the containers with conventional eating utensils.

Some space food is irradiated to protect it from spoiling and give it a longer shelf life for extended space missions. The nuclear radiation, known as ionizing radiation, kills microbes that would otherwise cause the food to spoil. The nutritional value of the food is not altered when it is radiated nor is the food radioactive. Irradiated food may taste slightly different than the original, but other than that changes in irradiated food are very difficult to detect. The food is cooked and prepared the same as non-irradiated food. Irradiated food has been tested for years and has been deemed safe by the United States Food and Drug Administration, the Centers for Disease Control and the World Health Organization.

Food is irradiated by radiation given off by a radioactive substance. This can be either a radioactive form of the element cobalt (Cobalt 60) or of the element cesium (Cesium 137). These substances give off high energy photons, called gamma rays, which can penetrate foods to a depth of several feet. The food is placed in a chamber made of thick concrete walls, which

prevent the radiation from escaping. The radiation source is stored in a pool of water, and is removed from the water to begin the radiating process. Other methods of radiation use electrons or X-rays as radiation. Radiation dose is measured in an SI unit called the Gray (Gy), which is defined as one joule of energy absorbed per kg of food. The lethal effect of irradiation on microbes is measured in D-values. One D-value is the amount of irradiation needed to kill 90% of that organism. For example, it takes 0.3 kiloGrays to kill 90% of *E. coli* O157, so the D-value of *E. coli* is 0.3 kGy.

Foods such as nuts, granola bars and cookies are classified as natural form foods. They are ready to eat, are packaged in clear, flexible pouches that are cut open with scissors, and require no further preparation for consumption in flight. Condiments include commercially packaged individual pouches of catsup, mustard, mayonnaise, taco sauce and hot pepper sauce. Polyethylene dropper bottles contain bulk supplies of liquid pepper and liquid salt. The pepper is suspended in oil and salt is dissolved in water.

The article also refers to intermediate-moisture foods. These are preserved by restricting the amount of water available for microbial growth, while retaining sufficient water to give the food a soft texture and let it be eaten without further preparation. Water is removed or its activity restricted with a water-binding substance such as sugar or salt. Intermediate moisture foods usually range from 15 to 30 percent moisture, but the water present is chemically bound with the sugar or salt and is not available to support microbial growth. Dried peaches, pears, and apricots, and dried beef are examples of this type of space food.

NASA continues to look for better ways to prepare foods, especially for longer space missions like a Mars mission. NASA is developing a sterilization process that depends on pressure more than temperature. In this method the food is sealed in a pouch and the pouch is heated to about 250°F for several minutes. It is then placed in a drum filled with water under a pressure of 100,000 psi (689,500kPa). At that pressure microbial cells are destroyed.

Space Food Packaging

The chemical culprit that requires great care in preparation and packaging is primarily the Maillard reaction. This multi-step reaction is very complex. You can read more here: <http://www.chm.bris.ac.uk/webprojects2002/rakotomalala/maillard.htm>. The Maillard reaction is a reaction between amino acids and sugars which causes food to turn brown and degrade. Food exposed to even small amounts of oxygen or water will turn rancid and degrade also. Microbial activity will likely also increase. So the packaging of space food is important. But the need for impermeable packages must be balanced by the need for packaging to be light weight.

Packaging of food for space flight is, therefore, very important. Packaging must be lightweight and be able to provide increasingly longer shelf life for foods needed on extended flights. Typically there is a limit on food weight and packaging. On Shuttle flights the limit was 3.8 pounds per person including a one pound limit on package weight. Packaging must sustain a shelf life of nine months to five years under ambient conditions. On International Space Station missions, food is stored using a five layer co-extrusion of nylon/ethylene vinyl alcohol/tie layer of polyethylene/linear low density polyethylene. Food packages are often flushed with nitrogen before being sealed.

As NASA plans for extended space flights, like a mission to Mars, characteristics of space food packaging, in addition to light weight and impermeability to water and air, include the ability to hold together under high pressure (which is used in new sterilization processes),

microwave safe (also used in sterilization), and leaves no ash on incineration (one way of disposing of mission waste on Mars). For these longer missions NASA is developing a polyethylene package that is coated in Al₂O₃ nanoparticles. This package can protect food for as long as 18 months.

Currently food packages are compacted after use on space flights, but NASA would like to improve on this system, which requires that bags of trash be brought back to Earth from space after each mission. The trash presents a storage problem on longer missions. One new technology is a system to dry the waste and recycle the resulting water vapor for drinking water. Recycling a commodity as important as water represents a step forward, provided the weight of the drying system can be reduced for use in space. This kind of system is currently used for drying lumber on Earth.

More on space food history

Early space flights were of such short duration that there was no need for astronauts to eat in space. The Mercury flights were long enough that food had to be supplied. It was not very appetizing by today's standards. Food in the early space program was originally designed for pilots of U-2 spy planes (The U-2 spy plane incident of 1960, in the midst of the Cold War, involved a craft, piloted by Gary Francis Powers, which was shot down over the Soviet Union.). Most foods were either semi-liquid packaged in plastic tubes or compressed cubes of food coated with gelatin to prevent crumbs—"cubed or tubed" or "meals in a pill" were the terms applied to early space food. John Glenn was the first American to eat in space.

The astronauts either squeezed food from the tubes like toothpaste or sucked it out through straws. Other varieties were compressed or dehydrated and re-hydrated using the astronauts own saliva.



Mercury astronauts had primitive space food. Pictured are packets of mushroom soup, orange-grapefruit juice, cocoa beverage, pineapple juice, chicken with gravy, pears, strawberries, beef and vegetables. (NASA photo)

In the mid-1960s, on the Gemini missions, astronauts had more variety in their food. The advance in preparation here was freeze-drying. Turkey, shrimp, soup and pudding were on the menu. An on-board water source allowed the crew to rehydrate the food. In the Apollo missions, astronauts had hot water and utensils, meaning that they did not have to squeeze the food into their mouths. Also new during the Apollo flights were wetpacks—flexible pouches that kept food moist, avoiding the need to rehydrate.

The Skylab flights in the early 1970's had a large dining area for the astronauts and refrigeration and a food warmer. There were more than 70 types of food on the menu for Skylab. By the time the Space Shuttle flights began, space food looked a lot more like food eaten on Earth, as the article describes. Astronauts were able to design their own menu from a slate of food and beverages.



The Skylab program of the 1970s used trays like this to keep food in place. (NASA photo)

For future space missions of much longer duration NASA is looking for ways to grow food during the mission. On an extended moon or Mars mission, for example, fruits and vegetables could be grown and prepared much the same as they are on Earth. NASA has plans to develop space farms, which will be greenhouses using artificial light and hydroponics to grow crops like soy, peanuts, spinach, cabbage, lettuce and rice. Another possibility is to carry food ingredients like soy beans on the flight and prepare foods on Mars. Since there is gravity on both the moon ($1/6^{\text{th}}$ the Earth) and Mars ($3/8^{\text{th}}$) eating would be similar to Earth.

More on the Space Food Systems Laboratory

The Space Foods Systems Laboratory is developing food for longer missions into space. In addition to researching improved food storage systems, the lab is investigating how to prepare food "from scratch" in space.

According to NASA the goals of the lab are to:

- "Develop a stored food system that is nutritious, palatable and provides a sufficient variety of foods to support significant crew activities on a mission of at least 3 years duration. Foods should maintain safety, acceptability, and nutrition for the entire shelf life of 3 - 5 years. Shelf life extension may be attained through new food preservation methods and/or packaging.
- Develop new packaging technologies to minimize waste from packaged food.
- Develop handling procedures for minimally processed vegetable crops.
- Develop equipment to process crops in reduced gravity that are highly automated, highly reliable, safe, and minimize crew time, power, water, mass, and volume.

- Develop recipes, galley operations, and galley equipment for extended surface missions.”

The Lab employs food scientists, registered dietitians, packaging engineers, food systems engineers and technicians to blend their knowledge of chemistry, engineering, biology, microbiology and nutrition to conduct experiments, plan projects and investigations, write specifications for space food products and coordinate with other teams. All these scientists work on products for the space shuttle, the International Space Station and future exploration missions.

Scientists perform chemical analyses by testing the food's moisture, pH, water activity, nutrients, color and texture, as well as considering time and temperature changes.

More on food and taste in space

Studies show that food does not taste the same in space. Many astronauts report changes in their sense of taste during flights. Sometimes astronauts report that foods just taste bland in space. In other cases astronauts find that food they would not normally eat actually tastes better in space. Research studies show, however, that not all astronauts agree on this changing sense of taste. Many find no difference.

In space, microgravity causes fluids to build up in the upper body, including sinuses. Because the sense of smell is such a big part of the sense of taste, this congestion limits taste in space. Other odors from substances in the space capsule may mask the more pleasant food odors. Another reason for the change is that food that is stored for long periods of time—as in space flights—degrades over time and changes in taste. Food exposed to radiation in space may also taste different. Still another reason is lack of variety. Space meals are planned on an 8-day cycle, and so there is limited variety.

Some astronauts claim that they want spicy foods to be a bigger part of their space diet. That may be why the foods prepared by Emeril Lagasse were so well received. Here is one of his space recipes. Note the spices in the recipe.

Spicy Green Beans with Garlic

1/4 cup clarified butter or vegetable oil
 3 cloves garlic, thinly sliced
 2 small green peppers such as jalapeno or serrano, stems and seeds removed, minced
 2 teaspoons turmeric powder
 2 teaspoons ground cumin
 1/8 teaspoon cayenne
 1 pound green beans, tough ends removed
 1/4 cup water
 1 1/2 teaspoons salt
 3 tablespoons sesame seeds

Directions: In a large saute pan, heat the butter or oil over medium-high heat. Add the garlic, peppers, turmeric, cumin, and cayenne, and cook, stirring, until the garlic begins to turn golden, about 2 minutes. Add the green beans, water, salt, and stir well. Cover and cook over medium-low heat, stirring occasionally, until the beans are tender, 4 to 5

minutes. Add the sesame seeds and cook uncovered, stirring, until toasted, 2 to 3 minutes.

More on fuel cells

The article describes the alkaline fuels cells used in space missions and the chemistry involved. The chemistry is also explained on this site from Princeton University: http://www.princeton.edu/~chm333/2002/spring/FuelCells/fuel_cells-chemistry.shtml .

Fuel cells are nearly ideal for use in space because they are efficient, quiet and can operate anywhere the ambient temperature is lower than the operating temperature of the cell. However, fuels cells require both oxygen and hydrogen, and these must be carried into space in order to fuel the cells. On the plus side, the chemical product of fuels cells is water, a scarce commodity in space.

In addition to the electrolytic (alkaline) fuel cells currently in use, researchers are working on other types. Alkaline technology is now considered an older technology, and newer types of cells are being developed. One new type of fuel cell is proton-exchange-membrane (PEMFC) type. This type is more powerful, lighter and more reliable. It uses hydrogen as the fuel, but replaces the alkaline electrolyte with a polymer membrane that is permeable to protons (hydrogen ions) when saturated with water. At the anode, hydrogen molecules are split into protons and electrons. The protons pass across the membrane. The electrons flow into an external circuit generating electricity. At the cathode the protons combine with oxygen to produce water.

Another new type of fuel cell is the regenerative fuel cell (RFC) systems, These cells use hydrogen and oxygen to produce electricity, heat and water. The added feature is a solar-powered electrolyzer that breaks up the water into hydrogen and oxygen for re-use in the cell.

Solid-oxide fuel cells are a third new possibility. The electrolyte is a thin ceramic solid oxide material which allows oxide ions to pass through. In this case the oxygen molecules are split into oxide ions by adding electrons. The oxide ions pass through the solid electrolyte and combine with hydrogen at the anode, releasing electrons.

A fourth new technology is the membrane-microbial fuel cell. Various types of bacteria have the ability to produce electrons from solid waste. These electrons are used to produce electricity.

Connections to Chemistry Concepts

1. **Biochemistry**—The article connects to several topics that might be considered either chemistry of biology—diet, nutrition, energy requirements, organic compounds, etc. Depending on where in your course you use this article you can emphasize any of these topics.
2. **Phase changes**—The section of the article on freeze drying is based on change of phase concepts, primarily sublimation. If you have reached change of phase in your courses, the phase diagram and this section of the article provides a good application.
3. **Electrochemistry**—Although the fuel cell section of the article is not its primary focus, it does show how different concepts in chemistry are often interrelated in the real world. You

can use this section as a review or jumping-off point for covering oxidation-reduction reactions.

4. **Properties of Matter**—The article discusses, for example, the need to find food packaging substances that can both protect food in space and not add excessive weight to the flight. This is one example of chemists having to find materials with a specific combination of properties that fit a given set of requirements. You can point out to students that this is part of what chemists do—develop substances that have specific properties for an application.

Possible Student Misconceptions

1. **“There is no gravity in space.”** *We commonly refer to microgravity as a condition in space meaning no (or very little) gravity. In fact, there is gravity in space. Earth's gravitational field at about 250 miles above the surface is 88.8 percent of its strength at the surface so astronauts in Earth orbit space flights are affected by gravity. The space shuttle, for example, is kept in its orbit by gravity. The craft is actually in free fall, but it is traveling at a rate of speed that prevents it from actually falling to Earth. People and objects in the shuttle craft are also falling, and this creates the sensation of “weightlessness.”*

Demonstrations and Lessons

1. * An activity on ripening of fruit in space, from NASA, http://www.nasa.gov/pdf/166970main_Ripening_Fruits_Vegetables.pdf
2. * Students can classify and compare their diet with those of Shuttle astronauts at http://www.nasa.gov/pdf/190537main_Classifying_Space_Food.pdf.
3. * Students can simulate preparing a rehydratable food for space at http://www.nasa.gov/pdf/190539main_Food_Preparation_Space.pdf.
4. * Students can measure mold growth in this exercise from NASA: http://www.nasa.gov/pdf/190542main_Mold_Growth.pdf.
5. * This activity on food packaging in space measures the weight of packaging: http://www.nasa.gov/pdf/190541main_How_Much_Waste.pdf.
6. * This activity on food dehydration enables students to determine the weight saved on space flights by dehydrating space food: http://www.nasa.gov/pdf/190538main_Dehydrating_Food.pdf.
7. The teachers' handbook including the activities listed above and more can be found at <http://virtualastronaut.tietronix.com/teacherportal/pdfs/Space.Food.and.Nutrition.pdf>.

*Designed for middle grades students but is adaptable for older students.

Student Projects

1. Students can collect and prepare space food recipes. If you can obtain a copy of *The Astronauts Cookbook* (see references, below) students can use these recipes. Otherwise, an internet search will produce a few recipes. A space food menu can be found here http://www.cdsc.nasa.gov/PDFs/space_food.pdf

2. Students can compare food available on missions in space from Mercury to the International Space station.
3. Students can research foods developed for space that became “Earth food” as well. Tang and Space Sticks are two examples.
4. Students can access a Skylab food list here: <http://www.ag.iastate.edu/centers/ftcsc/media/Skylab.Food.List.pdf>. They can categorize the foods according to the table given in the article (rehydratable, irradiated, etc.)

Anticipating Student Questions

1. **“Wouldn’t it take a long time to freeze dry a sample of food? How does the water get from inside the food?”** *Freeze drying often takes days to complete. Think of liquid water evaporating. It might take days for several inches of water to evaporate. Sublimation is a similar change of phase. At the molecular level water molecules are able to overcome their attractive forces and move far enough apart to be considered gas molecules. Even at greatly reduced pressures, this process takes place slowly. As molecules of ice leave the food surface, molecules deeper in the food can also escape.*
2. **“Is it really possible to grow food in space?”** *There have been numerous experiments conducted during space missions to find out how plants grow in microgravity. NASA is doing continuing research on how to grow food crops in microgravity at the Kennedy Space Center’s Space Life Sciences Lab. The four growing factors being studied at the lab are light, temperature, carbon dioxide and variety of plants. Inside closed plant growth chambers at KSC, radishes, lettuce and green onions grow “hydroponically” in nutrient-enriched fluid. Light, temperature and carbon dioxide levels are carefully controlled. How the plants absorb nutrients is one area of research. Another concern is available light.*

References

Charles T. Bourland, Gregory L. Vogt, *The Astronaut’s Cookbook: Tales, Recipes, and More*, Springer-Verlag New York, LLC, 2009.

Michalovic, Mark, “The New Chemistry of Fuel Cells”, *ChemMatters*, December, 2007, page 17.

Web Sites for Additional Information

More sites on space food

NASA has a web site, including videos, on space food. Be sure to check out the link to the Space Food Fact Sheet, lower right. (<http://spaceflight.nasa.gov/living/spacefood/index.html>)

For a complete overview of space food see http://www.nasa.gov/centers/johnson/pdf/167750main_FS_SpaceFood508c.pdf.

NASA has this site on space food: http://www.nasa.gov/audience/forstudents/postsecondary/features/F_Food_for_Space_Flight.html.

From HowStuffWorks, more on space food: <http://science.howstuffworks.com/space-food4.htm>

Space Food Sticks were all the rage in the late 60s and early 70s. Here's a link to print and TV ads: <http://www.spacefoodsticks.com/pres.html>.

What would eating in space be like on a mission to Mars? NASA predicts: http://www.nasa.gov/pdf/137398main_FS-2005-10-055%20Cuisine_1.pdf.

To see an historical slide show on space food, click <http://www.gourmet.com/foodpolitics/2009/05/space-food-slideshow#slide=1>.

To see two videos on space food see <http://videos.howstuffworks.com/nasa/2205-how-space-food-processing-works-video.htm> and <http://videos.howstuffworks.com/nasa/2205-how-space-food-processing-works-video.htm>.

More sites on Dietary Reference Intake

For a comprehensive look at current dietary requirements on Earth, see http://fnic.nal.usda.gov/nal_display/index.php?info_center=4&tax_level=2&tax_subject=256&topic_id=1342.

More sites on space food packaging

Iowa State University produced this brochure on space food packaging: <http://www.ag.iastate.edu/centers/ftcsc/media/packagingbrochure.pdf>.

More sites on the NASA Nutrition Lab

For a NASA video on its nutrition research, visit <http://www.science.tv/watch/a3f7cba1e6c53e8fa684/Nutrition-in-Space>. Note that the first part of this video seems aimed at younger students, but later sections are appropriate for chemistry students.

More sites on the NASA Space Food Systems Laboratory

A description of the lab facilities can be found here <http://hefd.jsc.nasa.gov/spacefood.htm>.

More sites on fuel cells

For a complete history of batteries and fuel cells in space see <http://www.electrochem.org/dl/Interface/fal/fal99/IF8-99-Pages25-30.pdf>.

To learn more about fuels cells see http://www.princeton.edu/~chm333/2002/spring/FuelCells/what_is_fuel_cell.shtml.

The Vinland Map: The Vikings' Best Kept Secret

Background Information

More on the discovery of isotopes

The idea of the existence of atoms first proposed by the Greeks around 500 BC begins the tale that eventually led to the proof of the existence of isotopes. Democritus, in describing the primary matter from which everything is created, proposed the existence of small particles which could not be further divided. These "atoms" differed from each other in mass, size, and shape. As insightful as we now know this idea to be, Aristotle's influence outstripped that of Democritus. His earth, air, fire, and water explanation for all matter influenced science, philosophy, and theology for the next 2000 years.

In the late 1700s advances in the ability to measure mass allowed scientists to verify that when two substances reacted with each other, the mass of the product was exactly the same as that of the original reactants. These results led John Dalton in 1803 to resurrect the idea that all matter was composed of atoms. Atoms of the same element weighed the same and atoms of different elements had different weights.

From the measurement of the masses of substances that took place in chemical reactions, it was possible to measure the relative atomic mass of the elements. The masses of the elements were compared to the mass of hydrogen.

William Proust in 1815 realized that the relative atomic weights in use were whole number multiples of the hydrogen atom. Proust explained this by proposing that atoms of elements were composed of different number of hydrogen atoms. Elements like carbon weighed 12 times that of hydrogen, and oxygen atoms weighed 16 times as much. Increases in the accuracy of balances and the ability to measure relative atomic weights showed that the atomic weight of chlorine was not a whole number but a fraction 35.5 times the mass of hydrogen. This result disproved Proust's proposal.

J. J. Thomson discovered the existence of the electron in 1897. Fourteen years later in 1811 Ernest Rutherford and his team performed the series of experiments that led to the discovery of the nucleus and the nuclear atom. Atoms must have the same positive charge as the negative charge of the electrons. In 1913 H. G. Moseley found the atomic number, as the sum of the positive charge was called, of several elements. Moseley bombarded atoms of different elements with high energy electrons. The bombarded atoms emitted x-rays of different wavelengths. Moseley concluded that the frequency of the x-rays was determined by the total positive charge of the nucleus.

In the same year, J. J. Thomson, while studying the make-up of "canal rays", sent a stream of ionized neon through an electric and a magnetic field while measuring the deflection of the rays on a photographic plate. Rather than the expected single patch of light on the plate, Thomson observed two patches of light. The neon particles had travelled in different parabolic paths. Thomson came to the conclusion that some of the neon atoms were heavier than others.

In 1918, Francis W. Aston, using a mass spectrograph, was able to separate atoms of the same element which differed in mass. The term “isotope” was coined in 1913 by a Scottish doctor, Margaret Todd, during a conversation with Frederick Soddy. Soddy’s experiments at Glasgow University appeared to show that several elements occupied the same position in the periodic table. Todd suggested the term “iso” for same and “topos” for place and coined the term isotope to describe the different elements that appeared to occupy the same position on the periodic table.

The final key to solving the riddle of atoms of the same element having different atomic weights came with the discovery of the neutron by James Chadwick in 1932.

More on carbon-14 dating

The 1960 Nobel Prize in chemistry was awarded to Willard F. Libby “...for his method to use Carbon-14 for age determinations in archaeology, geology, geophysics, and other branches of science.” One of Libby’s nominators wrote, “Seldom has a single discovery in chemistry had such an impact on the thinking of so many fields of human endeavour. Seldom has a single discovery generated such wide public interest.” Libby and his team’s work, following his research on radioactive elements as part of the Manhattan Project during World War II, is considered one of the most significant discoveries of the twentieth century. The ability to precisely date artifacts revolutionized a large number of scientific fields, even though archeological dating receives the greatest amount of press.

Two discoveries were the basis of Libby’s work: Ernest Rutherford’s and Frederick Soddy’s 1903 discovery of half-life decay and Martin Kamen’s and Sam Ruben’s 1940 discovery of the carbon-14 isotope. Libby came to the conclusion that living plants and animals constantly replenished their supply of carbon-14. Using Geiger counters available at the time, Libby confirmed that the amount of carbon-14 in solid samples decreased with time. To further confirm his initial results, Libby analyzed archeological samples whose ages were known by other methods and tree rings whose ages could be determined from the number of rings.

The developments that refined the ability to date artifacts included converting the solid carbon samples to carbon dioxide for analysis in gas proportional counters, and the use of liquid scintillation counters to measure radioactive decay in the early 1950’s. The most significant advance occurred in 1977 when an accelerator mass spectrometer was used to separate the carbon isotopes. The use of the mass spectrometer greatly reduced the size of the sample needed for analysis. As a general technique, the atoms to be separated are ionized—given a positive charge by stripping one or more electrons. The beam of ions is passed through the field of a strong magnet. Ions with a greater mass are deflected by a smaller amount than lighter ions with the same charge. As detectors improved, the high-low range of the date of the sample in question narrowed significantly. Collection of the sample to be analyzed is a key component to accurate dating. The Laboratory of Archaeometry at The National Center for Scientific Research Demokritos in Greece provides the following information in collecting a sample for analysis:

The collection of the samples for radiocarbon dating should be done together with the archaeologists and the researchers of the laboratory in order to obtain the best results. If this is not feasible, the person who will perform the sampling should have in mind the following rules:

- 1) The sample should never be collected with bare hands; on the contrary clean stainless steel tools (scalpel, tweezers, scoop, etc) should be used.
- 2) As large an amount of sample as is possible should be collected.
- 3) The sample should be collected in a region where the stratigraphy is undisturbed.
- 4) Attention should be drawn to the avoidance of pieces of samples mixing from upper layers during sampling, e.g. falling down of charcoal pieces due to vibrations, from stepping or bore hole drilling, on a close bank in the sampled region.
- 5) All visible extraneous materials should be removed from the sample, e.g. stones, plant roots, leaves, soil and sand.
- 6) Detailed notes should be kept during sampling according to the form attached.
- 7) Samples with high moisture content should be left to dry in the shade for 2-3 days in order to avoid microbiological contamination during the storage time. Additional attention should be paid during this time period for the samples not to be contaminated or mixed with other ones.
- 8) Different types of samples should be packed separately, e.g. charcoal, bones, wood, sea shells, land shells, etc.
- 9) The samples should be properly wrapped in an aluminum foil sheet and then placed inside polyethylenium bags or inside glass bottles. Textiles, cotton, wool, or paper sheets should never be used, as they are carbon rich materials. Plastic bags from PVC and PVA should be avoided as they may contain plasticizers, which may be absorbed by the material of the sample.
- 10) All samples should be properly labeled and the labels should not be in direct contact with the sample itself.
- 11) Any known contamination should be pointed out to the laboratory staff in order to prepare the proper chemical pre-treatment for each sample, e.g. the presence of animal excreta and bat droppings in the excavated area. The ash from the cigarettes, fat, oil, human hair or hair from brushes, as well as food remains are common contaminating factors.
<http://www.ims.demokritos.gr/archae/C14WebdocENGL.html>

Once the sample has been collected, it must be pretreated to remove any contamination that might have occurred. Thomas Higham in the Radiocarbon Web-Info website (<http://www.c14dating.com/pret.html#effect>) presents a complete set of pretreatment methods depending on the type of sample. In general, there are three general steps to getting a carbon-14 date: sample preparation, getting the ratio, and using a calibration chart to get the age from the ratio. Before dating, samples are first soaked in an 8% HCl, and then an NaOH basic solution to clean them of contaminants, such as dirt, microbes, tree sap, and humic acids. While this soaking removes some good material too, it does not change the C-14 / C-12 ratio of the good material.

After removing contaminants, a small piece taken from the interior of the sample is burned. Besides the unknown sample, calibration samples are also burned producing gaseous carbon dioxide. Burning slightly alters the C-14/C-12 ratio, but the effect is the same in both the unknown and calibration samples. The carbon dioxide gas is then set into the mass spectrometer where the ratios of C-12, C-13 and C-14 are measured. The age is then calculated from a calibration chart that represents age vs. ratio. Major advances have occurred

over the years in fine-tuning the calibration charts. Fine tuning the charts is a major research area in the field of carbon-14 dating.

More on proton induced X-ray emission

Proton or particle induced X-ray emission (PIXE) is an analysis technique that allows for very precise elemental analysis and very small samples. Sven Johansson of Lund University, Sweden, first proposed the technique in 1970. The technique is nondestructive. The analysis is performed without inflicting any damage to the original artifact. The nondestructive nature of the technique makes it especially popular with art conservators, archeologists, and geologists. Although the technique only provides elemental analysis, the presence or absence of a particular element can prove that an artifact is a fake if an element is shown to be present that was not present/available during the time period associated with the artifact. This premise moved McCrone to declare the Vinland Map a fake. His discovery of a form of titanium dioxide that appeared to be anatase, not available prior to 1917, influenced McCrone to declare the map a forgery. His analysis was based on the use of a transmission electron microscope which uses a beam of electrons instead of light to view the crystals.

PIXE does not use a beam of electrons. It bombards the targets with ions of sufficient energy (usually MeV protons) produced by an ion accelerator, which cause inner shell ionization of atoms in a specimen. Outer shell electrons drop down to replace inner shell vacancies; however, only certain transitions are allowed. X-rays of a characteristic energy of the element are emitted. An energy dispersive detector is used to record and measure these x-rays and the intensities are then converted to elemental concentrations.

(<http://www.mrsec.harvard.edu/cams/PIXE.html>)

The Harvard site referenced above describes the technique and system they have developed to fulfill the needs of the archeology and art conservation community. Included are the schematics of the Harvard instrument.

The advantages of PIXE over other analytic methods are: (1) high sensitivity, (2) measurements can be made at atmospheric pressure, (3) multi-element capability—from sodium to uranium in a single spectrum, and (4) a non-destructive proton beam.

Samples to be analyzed should be flat and of uniform composition. These are not conditions commonly found in archeological samples. Since the ion beam strikes the surface of the sample, the surface needs to be uniform not only along the surface but uniform to depth of a few microns. Analysis of different areas of a particular artifact is used to determine elemental composition.

In the Vinland Map article, the results using PIXE showed that one-third of the ink lines they tested showed no titanium above a minimum detectable limit. Their results cast doubt on the earlier conclusion reached by McCrone and his associates.

More on iron-gall ink

Lois Fruen, a frequent contributor to *ChemMatters*, introduces the topic of iron-gall ink in the textbook *The Real World of Chemistry* by stating that “Iron-gall ink was the most important ink in Western history. Leonardo da Vinci wrote his notes using iron-gall ink. Bach composed with it. Rembrandt and Van Gogh drew with it. The Constitution of the United States was drafted with it (Ink Corrosion). And, when the black ink on the Dead Sea Scrolls was analyzed using a

cyclotron at the Davis campus of the University of California, it was found to be iron-gall ink. Pliny the Elder (23-79 AD) wrote in his histories that galls were used to produce dyes. He described an experiment that he did using a piece of papyrus that he dipped in gallic acid. He noted that when he dripped a solution of iron salt onto the papyrus, it turned black.” Fruen’s article includes a comprehensive set of references.

Fruen obtains much of her information from The Ink Corrosion Website, (<http://www.knaw.nl/ecpa/ink/index.html>). “This website presents information on iron gall ink—its importance in (art) history, and its slow, self-destructing properties known as iron gall ink corrosion. The latter is a major threat to our cultural heritage and of concern to people throughout the world. This site was developed to inform collection keepers, conservators, scientists and any other interested parties of ongoing research on all aspects of iron gall ink corrosion.”

The earliest inks were carbon based inks—the mixing of soot with water and gum. The carbon soot was suspended in the ink and coated the surface of the material on which it was placed. Smudging of the ink posed a serious problem. With the passage of time, the carbon based inks and iron-gall inks have a similar appearance and are difficult to distinguish without sophisticated analytic techniques. Both inks can turn brown with age. A quantitative test for the presence of iron is needed to distinguish between the two. A positive test does not necessarily prove the ink to be iron-gall ink. Some poor quality carbon inks include iron impurities.

The transition from carbon to iron-gall inks is difficult to pin down. The reference to Pliny indicates that the iron-gall ink was known to exist in the first century A.D. Further references and a recipe for making the ink appear in the fifth century A.D. Some medieval manuscripts contain both inks. Advances in education and writing materials and advantages in the properties of iron gall ink helped fuel the transition from carbon ink to iron gall ink. Iron gall ink was easier to produce, generally did not clog the writing tool, and was permanent. It did not smudge and was hard to remove from the surface to which it was applied. The permanent nature of the ink was of special importance to “official” documents or records.

Iron gall ink is produced from four primary ingredients: Tannin, vitriol (iron sulfate), gum Arabic and water. “Tannin” refers to chemicals used in tanning animal hides to make leather. Certain tree galls were found to have a high concentration of tannins. Galls are growth produced by trees defending themselves against irritants secreted by aphids, flies, or wasps which lay eggs in tree branches. Hatching larvae feeding on the tree produce the irritant that causes the tree to surround the irritant with a growth that becomes the gall. The tannins, especially gallotannic acid, are extracted from the galls. Allowing the tannin solution to ferment or by cooking the tannins in wine (a slightly acid solution) produces the gallotannic acid.

The vitriol, iron(III) sulfate or ferric sulfate, was known to the ancients under a variety of names: copperas, sal martis, sulfate of iron, copper red, English vitriol, Roman vitriol, vitriolum cyprinum, and vitriolum hungaricum. The Greeks referred to it as *chacantum* (“blood of copper”) and the Romans as *atramentum* (“black” or “making black”). The mixing of the gallotannic acid with the vitriol produced the black iron(III) or ferric tannate complex.

The gum Arabic obtained from the Acacia tree is a vegetable gum which forms as globules on the surface of the tree. It acts as an agent suspending the insoluble pigment particles. It also modifies the consistency of the ink allowing it to flow from the pen onto the paper binding the ink to the surface of the paper.

The Vinland Map article contains formulas of the ingredients listed above. The Ink Corrosion Website includes a variety of historical recipes for making one's own ink. The recipes include: Recipe 1: "instant ink," preparation time: 1-2 hours; Recipe 2: ink prepared by boiling galls, preparation time: 4-5 hours; Recipe 3: ink prepared by fermenting galls, preparation time: 2 months; and Recipe 4: ink prepared by fermenting galls and adding logwood, preparation time: two weeks.

Documents prepared with iron-gall ink are in danger of being destroyed by the acidic nature of the ink. In some instances the ink has eaten completely through the paper. The Iron Corrosion Website contains extensive information on the techniques used in the preservation of documents written with the iron-gall inks.

Connections to Chemistry Concepts

1. **Chemical nomenclature**—The article states the archaic and pre-Stock nomenclature for iron(II) sulfate heptahydrate. Originally the compound was known as "green vitriol". It then became ferrous sulfate. The article does not include the seven water molecules bonded within the crystal. The preferred name today is iron(II) sulfate heptahydrate. The Roman numeral (II) indicates the charge on the ion. Metals capable of forming more than one positive ion have the charge on the ion indicated by a Roman numeral.
2. **Interpretation of organic structural formulas**—The gallic acid and amido black organic structures allow for a review of how organic structures should be interpreted.
3. **Isotopic notation and structure of isotopes**—Isotopes are atoms of the same element that differ in mass; i.e., that differ in the number of neutrons in the nucleus. The article follows the symbol of the element with the mass number of the particular isotope. C-12 indicates a carbon atom with a mass number of 12. C-12 must have a nucleus containing 6 protons and 6 neutrons. C-14, on the other hand, is a carbon atom whose nucleus contains 6 protons and 8 neutrons.
4. **Half-life of a radioactive isotope**—The half life of a radioactive isotopes is the amount of time needed for half of the original isotope to decay. Decay of carbon-14 was crucial in determining the age of the parchment used in the Vinland map.
5. **Carbon dating**—The half life of carbon-14 is measured at 5730 years. Living organisms constantly replenish their supply of carbon-14. Once an organism dies and no longer replenishes C-14, the C-14 present at death begins to decay. After 5730 years one half of the original C-14 left. Comparing the ratio of C-12 to C-14 left in a sample allows for the determination of the age of the sample. That's how Olin was able to date the parchment's age between 1411 and 1468.

Possible Student Misconceptions

1. **"The fact that the worm holes in the map exactly matched the wormholes in the Tartar Relation means the map must be authentic."** *The fact that the worm holes match indicates that the page on which the map was drawn belongs to the book, but the map itself may have been drawn at a later time.*

2. **“Just as the worm holes matching added to the case for the possible authenticity of the map, the C-14 dating proves the map’s authenticity.”** *Again, the results prove that the parchment on which the map was drawn matches the age required for the map to be authentic, but a forger might have removed all text from the parchment and then used the clean parchment to draw the fake map. In this instance, questions concerning the ink become very important.*
3. **“Carbon-14 can be used to date any archeological sample.”** *Because of the 5730 year half life of carbon-14, samples older than 10 half-lives do not have enough remaining carbon-14 for an accurate analysis. Use of other isotope ratios is required for older samples. The sample to be tested must also have come from a living plant or animal. The carbon-12 to carbon-14 ratio begins to change as soon as the sample dies and carbon-14 is no longer replenished.*

Demonstrations and Lessons

1. Isotopic Pennies

Rising prices for copper in the late 70’s and early 80’s forced the US mint in 1982 to change the composition of the penny from almost pure copper to a penny with a zinc core and a very thin copper cover. The change was forced because pennies were being melted and the resulting copper sold on the open market for more than the original cost of the pennies. The original copper pennies had a mass of 3.1 g while the new zinc/copper clad pennies had a mass of 2.5 grams. In 1982, pennies minted in the beginning of the year were the copper variety, but pennies minted toward the end of the year were the new zinc pennies. As a result, all 1982 pennies appear to be the same, but, in fact, they differ only in mass. This property allows pennies to be used in a simulation to determine the isotopic composition of a sample of pennies. Any mix of pre- and post- 1982 can be used, but if 1982 pennies are selected, the sample to be analyzed will appear to be completely uniform. 1982 pennies can be collected by having students sort through pocket change and deposit the pennies in a marked beaker in the classroom. Or a number of rolls of pennies can be purchased from a bank and searched for any 1982 pennies.

To perform the exercise, the students need to know (1) the mass of a pre-1982 copper penny, (2) the mass of a post-1982 penny, (3) the total number of pennies in the sample, and (4) the total mass of the sample to be analyzed.

Two relationships are needed to determine the number of each “isotopic” penny.

Total mass of the pennies = mass of Cu pennies + mass of Zn pennies

$$(1) \quad M_{\text{tot}} = m_{\text{Cu}} + m_{\text{Zn}}$$

Total number of pennies = number of Cu pennies + number of Zn pennies

$$(2) \quad N_{\text{tot}} = n_{\text{Cu}} + n_{\text{Zn}}$$

Given that the mass of one pre-1982 Cu penny = 3.1 grams
and the mass of one post-1982 Zn penny = 2.5 grams,

Therefore, mass of Cu pennies = number of Cu pennies x mass of one Cu penny

$$m_{\text{Cu}} = 3.1 \times n_{\text{Cu}}$$

And mass of Zn pennies = number of Zn pennies x mass of one Zn penny

$$m_{\text{Zn}} = 2.5 \times n_{\text{Zn}}$$

Substituting the two mass values into equation (1)

$$(3) \quad M_{\text{tot}} = 3.1x n_{\text{Cu}} + 2.5 x n_{\text{Zn}}$$

This leaves one equation with two unknowns— n_{Cu} and n_{Zn}
Rearranging equation (2), one derives

$$(4) \quad n_{\text{Zn}} = N_{\text{tot}} - n_{\text{Cu}}$$

Substituting this value for n_{Zn} into equation (3) one derives the equation which will allow for the calculation of the number of each “isotopic” penny.

$$(5) \quad M_{\text{tot}} = 3.1x n_{\text{Cu}} + 2.5 x (N_{\text{tot}} - n_{\text{Cu}})$$

Solving the equation for n_{Cu}

$$M_{\text{tot}} = 3.1x n_{\text{Cu}} + 2.5 x N_{\text{tot}} - 2.5x n_{\text{Cu}}$$

$$(3.1x n_{\text{Cu}} - 2.5x n_{\text{Cu}}) = M_{\text{tot}} - 2.5x N_{\text{tot}}$$

$$0.6 x n_{\text{Cu}} = M_{\text{tot}} - 2.5x N_{\text{tot}}$$

$$(6a) \quad n_{\text{Cu}} = (M_{\text{tot}} - 2.5x N_{\text{tot}})/0.6$$

And, from equation (4)

$$(6b) \quad n_{\text{Zn}} = N_{\text{tot}} - n_{\text{Cu}}$$

In practice, samples of mixed pennies can be provided in snack-size zipper lock plastic bags. In this case, the students need to count the total number of pennies in the bag and then determine the total mass of the pennies.

Or, the pennies can be supplied in small capped condiment containers. The mass of container and the number of pennies in the container are marked on the container. Students mass the container and calculate the total mass of the pennies by subtracting the mass of the container from the total mass of container and pennies written on the container.

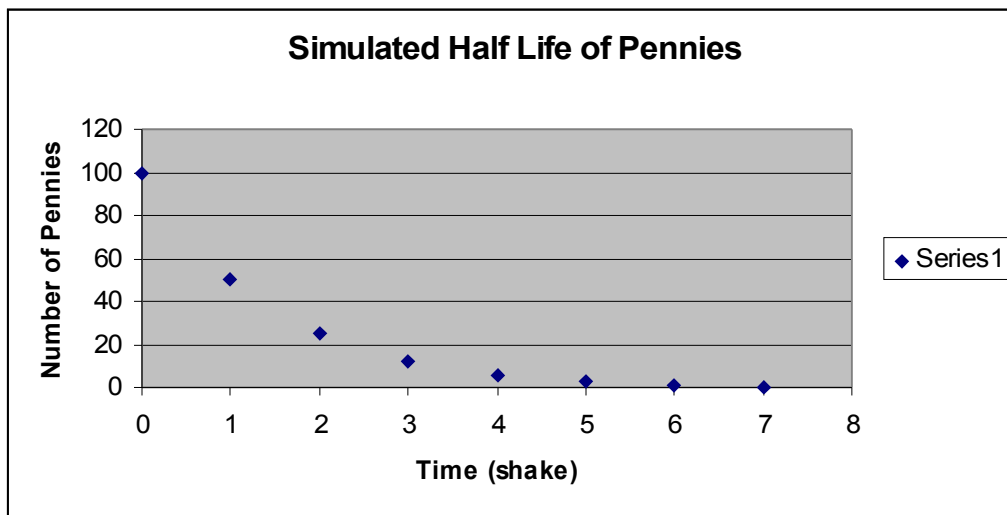
To check the individual results of the calculations, if a mixture of pre- and post-1982 pennies is used, the students simply separate the pennies into two piles, one pre-1982 and the other post-1982, and count the number in each pile. NOTE: this is done after the calculations have been completed.

If the student sample consisted of a mix of only 1982 pennies, the students will have to mass each penny to determine the number of Cu 1982 and Zn 1982 pennies. Again, this is done after the calculations are finished.

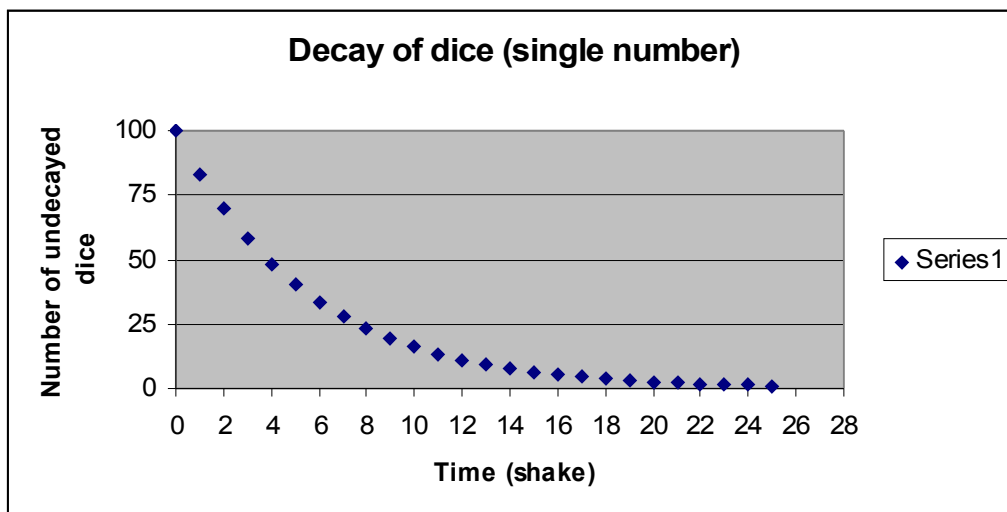
2. View the PBS program *The Viking Deception*, first aired on Feb. 5, 2005. The DVD is available at most public libraries. The article closely follows the sequence of events presented in the video. The video “fleshes” out the article. Individuals, places, and instrumentation described in the article are all viewed in the video. The program does reach the conclusion that the Vinland Map is a fake. Students can be asked to reach their own conclusions whether the map is really a fake or if there is a possibility that is genuine.

3. After viewing the video, use the Teacher’s Guide at <http://www.pbs.org/nova/vinland> to perform an experiment to learn about the chemical pigments of some plant-based dyes. The experiment describes the extraction of dyes from blueberries, blackberries, red onion skins, and yellow onion skins. The five-page Teacher’s Guide contains a one page overview of the video program and a student handout, teacher description of the activity, and an “answer” sheet of expected lab activity results.

4. Demonstrate half-life using pennies or dice—use 100 pennies in a shoe box. Begin with all pennies in the heads position. Shake the box vigorously (students appear to enjoy the noise created by the shaking). Open the box and remove any pennies in the tails position. These represent atoms that have decayed. Repeat the process, removing the pennies in the tails position. Each shake represents a unit of time. Plot the number of remaining pennies on the y-axis and the shake on the x-axis. Time = 0 represents the initial sample. Analysis of the graph should show that the time needed to reach 50 pennies represents the half-life of the sample. The time required to reach 25 pennies from there should match the original observed half life. The larger the initial number of pennies the better the resulting data. The same experiment may be performed using a large number of dice. After shaking the sample dice, those with a particular number may be selected as the decayed dice. The length of time represented by the half-life can be changed by selecting two or more of the numbers on the six-faced dice. An ideal graph is shown below.



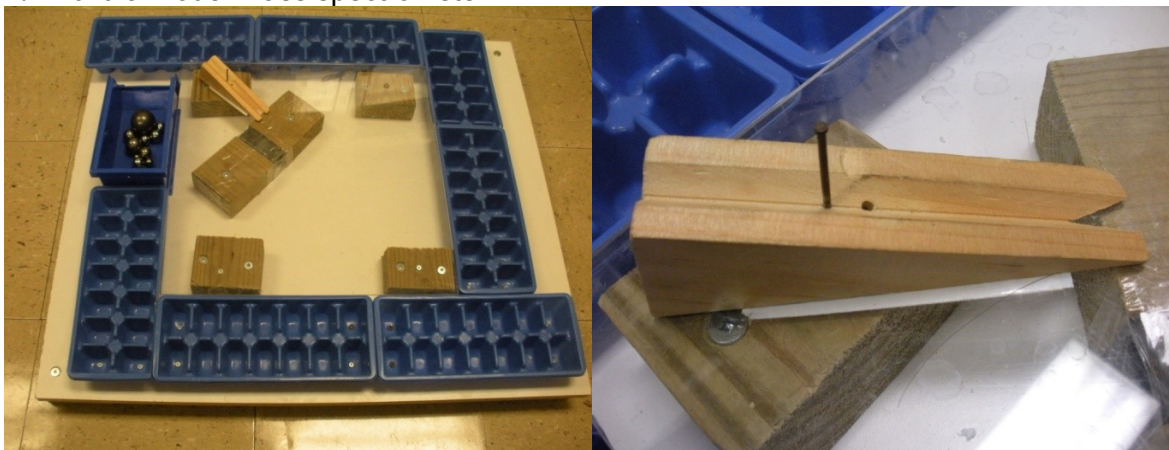
Because each penny has only two sides, each shake represents a half-life.



In the case of the box of dice, the half-life appears to be four shakes or time units because it took that many shakes to reach 50 dice, one half of the original sample.

Student Projects

1. Build a model mass spectrometer



Pictured above is a permanent model of the spectrometer described below. All of the pieces have been screwed into a large piece of particle board.

The instructions below allow you to build a model similar to the one above, but the individual parts are placed on a flat surface—lab table—and can be taken apart and stored after the experiments.

- Obtain a 30" (75 cm) square sheet of 3/16 in. (4mm) transparent plastic or Plexiglas. The thickness of the sheet of plastic should be sufficient so that it will not sag when steel spheres (ball bearings) are rolled along the sheet of the material.
- Obtain 10 pieces of wood 2" x 4", each side 3 in. (7-8 cm) in length.
- Obtain 6 empty egg cartons (or ice cube trays as in the photograph)
- Mount the transparent sheet on the 2" x 4" pieces so that the sheet is parallel to the table surface and 2 in. above the surface.
- Place a 4 in. (20 cm) length of 2-sided tape on the upper surface of the transparent sheet at an angle close to the diagonal (cf. photograph).
- Mount the "launching ramp" on the 2-sided tape. The tape will have to be replaced periodically.
- Place the magnet (taped between 2 lengths of the 2" x 4" blocks) beneath the transparent sheet so that the long edge of the magnet is parallel to and just in front of the long edge of the launching ramp.
- Arrange the egg cartons (ice cube trays) around the perimeter of the transparent sheet. It may be necessary to secure the egg cartons (ice cube trays) with small squares of 2-sided tape between the egg cartons and the table surface.
- Roll steel spheres (ball bearings) down the ramp and, if necessary, adjust the position of the magnet so that spheres of different sizes are deflected into different egg carton (ice cube tray) slots.

The model spectrometer will separate spheres of different mass (isotopes), delivering spheres of the same mass into the same position in the egg cartons or ice cube trays. Lighter spheres will be deflected more than heavier spheres. A glass (non-magnetic sphere

will not be affected by the magnet and will roll in a straight line down the ramp. The position and direction of the ramp with regard to the magnet may have to be adjusted so that lighter spheres will land in one of the openings in the egg cartons or ice cube trays. The second photo shows a close-up of the launching ramp. The ramp needs a groove so that the ball bearing moves down the center of the ramp with each delivery.

2. The article describes the medieval use of iron-gall ink. Students can explore the history of ink and how the process of making ink as changed over time, and the role of chemistry in those changes.

3. Beside the exploration of the history of ink, the students can make and test samples of iron gall ink following a series of ancient recipes. The ingredients are inexpensive and readily available. The following two websites provide recipes taken from ancient sources. http://www.knaw.nl/ecpa/ink/make_ink.html describes how to make ink. The link is a part of the Corrosion Website. “This website presents information on iron gall ink; its importance in (art) history; and its slow, self-destructing properties known as iron gall ink corrosion. The latter is a major threat to our cultural heritage and of concern to people throughout the world. This site was developed to inform collection keepers, conservators, scientists and any other interested parties of ongoing research on all aspects of iron gall ink corrosion.” The site provides a list of ingredients, equipment and supplies, and recipes and instructions on making a variety of iron-gall inks. Interest in the production and properties of the ancient inks is being fostered by the efforts to preserve historically precious documents in danger of being destroyed by the acid characteristics of the ancient inks.

<http://www.clt.astate.edu/elind/oldinkrecipes.htm> contains recipes for old writing and drawing inks. Evan Lindquist, an Emeritus Professor of Art, Arkansas State University, Jonesboro, pulled from his files some old directions for making ink. On these pages he shares the formulas with students who would like to experiment and synthesize a variety of these inks.

4. The following website, <http://www.furryelephant.com/content/radioactivity/half-life-simulation/>, allows the student to “see” what 'half-life' means and why radioactivity changes with time by following the process of radioactive decay through a series of animations. Students are also able to carry out experiments in which they can use carbon dating to date ancient remains.

Anticipating Student Questions

1. **“Who is Enzo Ferrajoli, the Italian book dealer, who first brought the Vinland Map to the public? Where did he find the map?”** *The questions are very good ones and represent some of the questions surrounding the provenance of the map. Ferrajoli, who may have had a shady background, died before he ever explained how he obtained the map.*

2. **“Does the discovery of the Viking artifacts in Newfoundland, which prove that the Vikings arrived in North America before Columbus, prove the authenticity of the Vinland Map?”** *There is no direct relationship between the arrival of the Vikings and the authenticity of the map. In fact, one of the challenges to the authenticity of the map is that there are no other Viking maps known to exist. Some historians claim that the Vikings did not use maps in their journeys.*

3. **“How does one reconcile conflicting data—the McCrone data, which he interprets as proof that the map is a fake, and the re-testing of the ink utilizing Proton Induced X-ray Emission, which contradicts the McCrone data and conclusion?”** *This represents one of the challenges when analyzing contradicting data. In many instances, such as the issues concerning the Vinland Map, it is very difficult—in fact, almost impossible—to come to an undisputed conclusion without added uncontested evidence.*

4. **“Can carbon-14 dating be used to date any archeological artifact?”** *Carbon-14 dating can only be used on samples that were alive at some time in the past. The half-life of carbon-14 is accepted as 5730 years. Samples more than 60,000 years old have decayed for more than ten half-lives. At the end of the ten half-lives, so little carbon-14 remains that the analysis will not allow for accurate dating. Different isotopes ratios are used to measure ceramics and samples older than the 60,000-year limit for C-14. The isotope ratios include the following methods: samarium-neodymium, potassium-argon, rubidium-strontium, and uranium-thorium. An internet search on the pair of isotopes provides added information.*

References

Fruen, Lois. Real or Fake? The James Ossuary Case. ChemMatters. Vol. 24, No. 1. Feb. 2006. pp. 8-10. The article discusses carbon dating, especially its limitations in proving provenance.

Bleacher, Lora. “Follow the Carbon” Follow the What?, ChemMatters. Vol. 26. No.1. Feb. 2008. pp. 16-19. Provides a description of how carbon radioisotopes are used in the analysis of the Martian soil as scientist look for signs of life.

Washburn, Wilcomb E., Editor. Proceedings of the Vinland Map Conference. The Smithsonian Institution, 1966. Chicago: University of Chicago Press. 1971.

Seaver, Kirsten A. Maps, Myth, and Men The Story of the Vinland Map. Stanford, CA: Stanford University Press. 2004. Seaver’s book is the first book to address all aspects of the debate raging around the Vinland Map—composition of the ink, the map’s lack of provenance, identity of the mapmaker, source of the parchment used, and other historical and cartographical questions.

Skelton, R. A.; Marston, Thomas; and Painter, George. The Vinland Map and the Tartar Relation: New Edition. Yale University Press. 1995.

Summary: The Vinland Map, dated to about A.D. 1440 - at least fifty years before Columbus landed in the Americas - is a unique map of the world that shows an outline of the northeast American coast and a legend describing its discovery in about 1000 by Leif Eriksson, the Norseman from Greenland. The map was published by Yale University Press in 1965 and generated an enormous amount of debate. Chemical analysis of the ink later suggested that the map might be a forgery, but recent appraisals of both scientific and humanist evidence argue that it is indeed authentic. Now, on the thirtieth anniversary of its original publication, here is this classic of historical cartography in a new edition. It reprints unaltered the original text on the Vinland Map and an account of Friar John of Plano Carpini's mission to the Mongols from 1245 to 1247 (the Tartar Relation), with which the map had at some stage been bound. To this have been added a new introduction by George D. Painter, sole survivor of the original team of editors, who discusses the verification of the map's authenticity; a new essay by Wilcomb E. Washburn, director of the Smithsonian's American Studies Program, on the map's provenance and scientific testing; and a new discussion of the map's compositional and structural aspects by Thomas A. Cahill and Bruce H. Kusko, of the Crocker Historical and Archaeological Projects at the University of California, Davis. There is also an account by the rare-book dealer Laurence C. Witten II, who died while this new edition was in

preparation, of his acquisition of the map in 1957. (Summary by Cincinnati Public Library)

Web Sites for Additional Information

More sites on the Vinland Map

<http://www.pbs.org/nova/vinland> is the companion web site to the PBS program provides articles, interviews, interactive activities, and resources for the program.

<http://www.webexhibits.org/vinland/> is a website under development in which students are asked to vote on whether they believe the map is an authentic artifact, a fake, or not enough evidence to make a decision after being presented with the evidence available today.

http://en.wikipedia.org/wiki/Vinland_map provides a detailed presentation on all issues and tests surrounding the Vinland Map. The site includes a photo reproduction of the original map and a complete set of references.

More sites on the Vikings: The North Atlantic Saga

<http://www.mnh.si.edu/vikings/start.html> describes the history of the Vikings and sheds light on their culture.

More sites on the authenticity of the Vinland Map

This article reports that the latest evidence proves that the Vinland Map is authentic: <http://www.reuters.com/article/scienceNews/idUSTRE56G58320090717>. Students may read the article and reach their own conclusion.

More sites on radiocarbon dating of the Vinland Map

<http://www.bnl.gov/bnlweb/pubaf/pr/2002/bnlpr072902a.htm> presents the July 29, 2002 press release by Brookhaven Lab reporting the C-14 dating of the Vinland Map parchment. From the article: "...date of 1434 A.D. plus or minus 11 years...Recent testing, however, only revealed trace quantities of titanium, whose presence may be a result of contamination, the chemical deterioration of the ink over the centuries, or may even have been present naturally in the ink used in medieval times. Another recent study detected carbon, which has also been presented as evidence of a forgery. However, carbon can also be found in medieval ink. Current carbon-dating technology does not permit the dating of samples as small as the actual ink lines on the map..."

More sites on high resolution reproduction of the Vinland Map

<http://www.bnl.gov/bnlweb/pubaf/pr/photos/2002/vinland.jpg> provides a high resolution image of the Vinland Map.

More sites on radiocarbon dating

http://id-archserve.ucsb.edu/anth3/courseware/Chronology/08_Radiocarbon_Dating.html gives a complete description of how samples are prepared for analysis. A series of videos describes the process. A separate video calculates the age of a sample based on the C-14 analysis. Limitations of C-14 analysis are presented

More sites on Particle Induced X-ray Emission

<http://www.mrsec.harvard.edu/cams/PIXE.html> is the Harvard site responsible for PIXE measurements. The site provides a complete description of the advantages and the details of making actual measurements.

General Web References

<http://www.isidore-of-seville.com/vinland/index.html> **Welcome To Vinlanda: The Vinland Map On The Web.** The following is the author's description of the web site: "This page explores the controversy surrounding the so called 'Vinland Map', assembling some 100 pages on the topic from every corner of the web. Here you will find serious scholars pro and con as well as a bevy of quacks—all categorized and described. I've added a certain amount of material on the other, less dubious, sources for Viking activity in North America—the sagas and archaeological excavations at L'Anse aux Meadows, Newfoundland—and some general links on Scandinavian history. "A lot has happened in the last few months, including new analyses of the parchment and ink. The debate resembles a tennis match more every day. Check out the [Recent Developments](#) section. Your help finding new material, and your comments, are most welcome."

More Web Sites on Teacher Information and Lesson Plans

<http://www.pbs.org/nova/vinland> , as stated above, is the companion web site to the PBS program on the Vinland map. It provides a lesson plan and articles, interviews, interactive activities, and resources for the program.

<http://www.pbs.org/nova/vinland> As stated above, this the companion web site to the PBS program provides a lesson plan and articles, interviews, interactive activities, and resources for the program

<http://school.discoveryeducation.com/lessonplans/programs/elementsandcompounds/> The lesson plans describes an experiment similar to the one described examines the concept of radioactive decay/half-life using M&M's or coins.

<http://apps.caes.uga.edu/sbof/main/lessonPlan/Calculating%20Halflife%20Twizzlers%20MMs.pdf> Calculating the Half-Life of Twizzlers and M&Mium. This lesson plan includes two labs designed to teach the concept of half-life. The Twizzler lab is designed to introduce the topic and is best if used before the M&Mium lab.

<http://www.sciencenetlinks.com/lessons.php?DocID=176> Isotopes of Pennies. This exercise demonstrates that isotopes of an element have different masses; that isotopes are atoms of the same element that have different numbers of neutrons; and that atomic mass is the weighted average of the naturally occurring isotopes of an element. This is the first in a three-lesson series about isotopes, radioactive decay, and the nucleus. The second lesson, [Radioactive Decay: a Sweet Simulation of Half-life](#), introduces the idea of half-life. The final

lesson, [Frosty the Snowman Meets His Demise: An Analogy to Carbon Dating](#), is based on gathering evidence in the present and extrapolating it to the past.

http://www.greenwickschools.org/uploaded/central_ms/DocsJL/9-12_Science_RadiationAndHalfLife%282%29.pdf Radiation and Half Life Lesson Plan. Similar to the procedure described in the Demonstrations and Lessons presented earlier in the Teacher's Guide, this exercise allows students to learn about the discovery of radium and radioactivity, to understand the process of radioactive decay, and to perform an experiment to better understand half-life.