February 2012 Teacher's Guide

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About the Guide

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1. What details can the study of mummies provide about the individuals who were mummified?
2. Briefly describe the steps taken in creating a mummy.
3. What chemicals are present in natron?
4. How does natron preserve tissue?
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6. How can radiocarbon dating be used to determine the age of a plant or animal sample?
7. How does an electron microscope compare to a light microscope?

Answers to Student Questions

24 Hours: Your Food on the Move!

1. **According to the article, where does digestion begin?**
   The article says that digestion begins in the brain. Sensory stimuli like the sight and smell of food triggers reflexes sent through the enteric nervous system, a sub-division of the central nervous system, to the brain, which, in turn, stimulates salivary glands and muscles in the stomach to prepare the body for digestion. The enteric nervous system is embedded in the lining of the gastrointestinal system.
2. **What are the four main parts of the digestive system?**
   The four main parts of the digestive system are ingestion, digestion, absorption, and elimination. Food is ingested in the mouth, digested mainly in the stomach and intestines, absorbed into the blood stream from the intestines and waste eliminated as urine or feces.
3. **What role do enzymes play in digestion?**
   Enzymes are biological catalysts. In the case of digestion the role enzymes play is to speed up the breakdown of food molecules into smaller molecules that can be absorbed into the body.
4. **What is a chemical catalyst?**
   A catalyst is a chemical that either speeds up or slows down a chemical reaction without being changed in the reaction. Many catalysts form an unstable intermediate compound which breaks down into the desired product leaving the original catalyst unchanged. These intermediate products have lower activation energies and so speed up the reaction. Enzymes work this way.
5. **What term is applied to food traveling down the esophagus?**
   Food traveling down the esophagus is called a bolus.
6. **What is the primary role of stomach acid in digestion?**
   Stomach acid, with a pH of between 1 and 3, provides the acidic conditions in which many enzymes work best to help digest food.
7. **In what part of the body is most food actually absorbed into the blood stream?**
   Food is absorbed through the walls of the intestines.

Attack of the Gluten

1. **What is celiac disease?**
   Celiac disease is a medical condition caused by an abnormal sensitivity to gluten in the diet.
2. **In what foods is gluten found?**
   Gluten is found in foods prepared from the grains of wheat, barley and rye
3. **Why is gluten important in the baking process?**
   Gluten provides elasticity to dough made from grains of wheat, barley and rye. It provides structure to the dough when it rises, making it light and fluffy.
4. **What is the function of carbon dioxide gas produced in the yeast fermentation of wheat flour?**
   The carbon dioxide gas produced in yeast fermentation causes the dough to rise; the risen dough is supported by the gluten.
5. **How does gluten provide the structure in raised dough?**
   Gluten is considered to be a mix of two different proteins—gliadin, a spherically-shaped molecule, and glutenin, a chain-like molecule. Together these two components bind through hydrogen bonds to form a network that is the supporting gluten.

6. **What happens when a baker "kneads" the bread dough?**
   The action of a baker when kneading the bread (which is a process in which the baker pushes and folds the dough) causes the stretching of the glutenin proteins which in turn aligns them with each other. New bonds are made between both the glutenin and the gliadin molecules which preserve the new shapes, reinforcing the entire protein network.
7. **What is behind an allergic reaction to gluten in foods?**
   The external structure of the gluten protein has some exposed amino acids that cause a person's antibodies (the immune system) to react to these amino acids, producing what is normally called an allergic reaction. It is the body's response to what it considers to be harmful foreign matter, destroying it.
8. **What are the symptoms of a celiac allergic reaction?**
   Multiple dining on gluten-containing foods produces multiple allergic reactions, slowly destroying the cells of the intestinal wall which, in turn, produces diarrhea and abdominal pain (from excess gas production). Skin rashes may also develop.
9. **What other types of food contain gluten besides baked goods, box cereals and noodles?**
   Such foods as ketchup, ice cream, and salad dressing also contain gluten to give these foods better texture.
10. **For gluten sensitive people, what are the alternatives to consuming gluten?**
    To provide structure to dough, some alternatives include sorghum (a grain) and several additives including hydroxymethylcellulose and xanthan gum (both plant extracts). Additional alternatives being investigated include corn protein and carob germ flour proteins.

Who Put Cheddar in the Cheese?

1. **What is curdled milk?**
   Curdled milk is milk that has gone sour, producing lumps that separate from the liquid part of the sour milk.
2. **What part of curdled milk is used to make cheese?**
   The lumpy part (curds) of the curdled milk is used directly to make cheese (e.g., mozzarella), or bacteria are added to the lumps to form hard cheeses such as cheddar and Parmesan.
3. **List the components or ingredients of cheese.**
   Since cheese is made from milk, it contains the same things as milk—fats, proteins, lactose (a sugar), and water (87% by volume).
4. **Why is the milk that is to be used for cheese making first warmed?**
   The milk is first warmed to 75 ^{o}F in order for the added bacteria to grow and eventually change the milk to cheese.
5. **What important changes in the warm milk are made by the added bacteria?**
   The bacteria feed off the milk, converting the sugar lactose to lactic acid which, in turn, causes the milk protein particles to unfold.
6. **Why is rennin added to the warm milk?**
   Rennin is an enzyme (biological catalyst) that helps to break down protein molecules.
7. **What is the purpose of "cheddaring"?**
   Cheddaring is the next step after the cheese has formed into small curds and the watery whey has been removed. The cheese is cut into large rectangular slabs that are stacked on top of each other, causing more whey to be released because of the pressure from the mass of stacked slabs.
8. **Why is salt added to the stacks of cheese slabs?**

When salt is added to the cheese slabs, it draws out additional water (the whey) by osmosis—water of higher concentration in the whey moves out of the whey to the salt, which has less water.

9. **What is accomplished by the process of aging cheese?**
   Aging of cheese is done to produce flavor in the cheese which is initially without much flavor. For a period of 6 months up to 3 years, the cheese contents—fats, proteins and sugars—are further broken down into simpler molecules, changing the flavor and texture of the cheese.
10. **How does a cow's diet affect the flavor of cheese?**
    The plants that a cow consumes eventually become part of the milk that is used to make cheese. The digested plants can flavor the milk from the cow. Seasonal changes to the pasture change the flavor of the milk used in cheese making.

A Super Vision for Airport Security

1. **List three materials detectable by X-ray devices.**
   Three materials detectable by X-ray devices are weapons, explosives and drugs hidden in luggage.
2. **Describe the structure of the atom, according to the article.**
   The atom is composed of a nucleus in the middle and electrons located around it, with the nucleus occupying an extremely small volume compared to the volume of the entire atom.
3. **Name the forms of radiation cited by the article that are included in the electromagnetic spectrum.**
   Radiation forms included in the electromagnetic spectrum are: radio waves, microwaves, infrared, visible, ultraviolet, X-ray and gamma ray radiations, in order of increasing frequency.
4. **Define wavelength.**
   Wavelength is the distance between one wave top and the next.
5. **How are wavelength and frequency related?**
   Wavelength and frequency are inversely related. ("Since they are all travelling at the same speed, the smaller the wavelength, the greater the frequency.")
6. **How are objects detected inside closed luggage, using X-rays?**
   In order to detect objects inside closed luggage, X-rays are aimed at the luggage; they penetrate the luggage and go through to the other side, where X-ray detectors are placed to receive the X-rays.
7. **So, if X-rays can "see" objects through the closed luggage, what's the problem—why can't the screeners easily detect <u>all</u> weapons, drugs, etc.?**
   Problems can arise when using X-ray detection devices because the sought-after items may be hidden behind other items in the luggage, or they may be tilted at an awkward angle, making them hard to identify; also, X-rays work best on metal and other very dense materials, and not all the items screeners seek are made of metal; e.g., plastic explosives. X-rays will go right through these items.
8. **What is being done to help alleviate the problems from question 7?**
   To help with the problem of viewing items at awkward angles, some screening machines can provide multiple angle views of the luggage, and to prevent plastic explosives from slipping through, manufacturers are required to add a chemical tag, a compound giving off a distinctive vapor, helping scanners to detect them more easily.
9. **Explain how Ion Mobility Spectroscopy works to detect plastic explosives.**
   IMS involves the use of a radioactive source that irradiates the sample and ionizes it, knocking off electrons and producing positively-charged ions. These ions pass through an electric field, where they are deflected into different paths, depending on their mass. Heavy

particles are not deflected much; light particles are deflected a lot. Their paths can be tracked and these tracks are compared to known explosives. The chemical tags that were added to the explosive are smaller molecules and can easily be detected.

10. **What is the main drawback to using a walk-through metal detector?**
    The main drawback to using a walk-through metal detector is that it is ineffective against nonmetallic objects.
11. **Why are radio waves being used in newer, people-screening detection devices?**
    Radio waves are being used in newer devices because "…[r]adio waves are ideal because they have a much lower energy than X-rays but are still energetic enough to provide clear images of suspicious objects."
12. **Describe the X-ray backscattering detection method.**
    X-ray backscattering involves generating a narrow, low-energy X-ray beam (a "pencil" beam) that scans a person at high speed. The beam penetrates clothing, but is reflected by the body and objects carried under the clothing. The reflected X-rays collide with a detector as they are reflected; hence, the term "backscatter". The backscattered X-rays are converted into an image by the detection device.

Unwrapping the Mystery of Mummies

1. **What details can the study of mummies provide about the individuals who were mummified?**
   The study of mummies can provide details about what the individuals looked like, who they might be, and the type of life they had.
2. **Briefly describe the steps taken in creating a mummy.**
   The body was washed. Blood was drained and internal organs removed. Corpses were then treated with natron for a month. The body was filled with sawdust or leaves and anointed with oils and perfumes. Then it was wrapped and coated with resin. The mummy was decorated and sealed in a sarcophagus.
3. **What chemicals are present in natron?**
   Natron is a naturally occurring mixture of four salts: sodium carbonate decahydrate ($Na_2CO_3 \bullet 10H_2O$), sodium bicarbonate ($NaHCO_3$), sodium chloride (NaCl), and sodium sulfate (Na_2SO_4).
4. **How does natron preserve tissue?**
   Natron preserves tissue by drawing out moisture through osmosis. When a dead body is treated with natron, the water in the cells crosses the cell membranes to dilute the concentrated salt solution until nearly all the water leaves the cells, which dries up the body.
5. **What are some of the high-tech tools used by scientists to study mummies?**
   Some of the high-tech tools used are standard X-rays, computed tomography (CT), radiocarbon dating, and electron microscopy.
6. **How can radiocarbon dating be used to determine the age of a plant or animal sample?**
   When plants and humans die, the amount of carbon-12 inside these organisms remains constant, but the carbon-14 continues to decay and is not replaced. Scientists can compare the ratio of carbon-12 to carbon-14 in the organisms to the ratio in a living organism, which allows them to determine the age of the sample.
7. **How does an electron microscope compare to a light microscope?**
   An electron microscope illuminates objects with a beam of electrons instead of light and can magnify objects several hundred thousand times, far more than ordinary light microscopes.

ChemMatters Puzzle: Chem Anagrams

Chemistry is everywhere ! And that includes some common English words. Your task in these two puzzles is to find some terms widely used in Chemistry that are present as an anagram of an English word. But to make things more interesting, the English term will have one more letter than the chemistry term. It will be your job to determine which letter that is, and solve the anagram once it's removed. For example, given the word LEMON, one could drop out the N and rearrange the remaining four letters to give MOLE.

Here's a hint. ALL the hidden words in a list have something in common. In list #1 that common theme is units for measurements, such as KELVIN (for measuring temperatures). Some are SI units and some not, but all are in common use. In list #2, it's up to you to find the category ! Once you get a few of the words, you'll know what the commonality is, and that might be helpful in solving other words.

The bottom item on each list is not really fair game, and so we've set them apart. Good luck with the two.

Have fun deciphering these terms !

LIST #1

Category : Measurement UNITS

Ex: o h m	HOME
_ _ _	mast
_ _ _	palm
_ _ _	loom
_ _ _ _	gamer
_ _ _ _	lacks
_ _ _ _ _	tiller
_ _ _ _ _ _	scorned
_ _ _ _ _ _	palaces
_ _ _	MERE

LIST #2

_ _ ? ? ?

_ _	hip
_ _ _ _	acrid
_ _ _ _	beast
_ _ _ _	least
_ _ _ _	sonic
_ _ _ _	awake
_ _ _ _ _ _	tongers
_ _ _ _ _ _ _ _	mortality
_ _ _ _ _ _ _	Born dates
_ _	YAK

Answers to the *ChemMatters* Puzzle

LIST #1	theme is UNITS	LIST #2	theme is ACID /BASE theory
	ohm		pH
	atm		acid
	amp		base
	mol		salt
	gram		ions
	kcal		weak
	liter		strong
	second		molarity
	pascal		Bronsted (as in the Bronsted-Lowry theory of proton transfer)
	rem		K_a

- K_a is an equilibrium constant that measures the strength of an acid.
- rem is a unit for measuring exposure to nuclear radiation by humans.
- mol is the official SI unit for measuring amount of substance. For example a common energy term is kJ/mol.

NSES Correlations

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Food on the Move!**	**Gluten**	**Cheese**	**Airport Security**	**Mummies**
Science as Inquiry Standard A: about abilities necessary to do scientific inquiry.		✔			
Science as Inquiry Standard A: about scientific inquiry.		✔			✔
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 & matter				✔	✔
Physical Science Standard C: of 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: 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.

24 Hours: Your Food on the Move!

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

Me	Text	Statement
		1. Your digestive system is about 30 meters long.
		2. Scientists say you should chew most of your food 10 times before swallowing.
		3. Saliva contains digestive enzymes that begin chemical breakdown of food in your mouth.
		4. Gravity is required for swallowing your food.
		5. The primary purpose of stomach acid is to break down food.
		6. Heartburn has nothing to do with your heart.
		7. Calcium carbonate is a common antacid used to neutralize excess acid in your stomach.
		8. Your food spends about 2 hours in your small intestine.

Attack of the Gluten

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

Me	Text	Statement
		1. Gluten is required to help bread dough rise.
		2. Yeast fermentation produces oxygen gas, which makes holes in bread dough.
		3. Proteins consist of amino acid chains folded into different shapes.
		4. Hydrogen bonds help the proteins in gluten form a network to help bread dough keep its shape during baking.
		5. People who have celiac disease may damage their intestinal lining so much that their bodies cannot absorb nutrients.
		6. Gluten is found only in food containing wheat, such as breads, baked goods, and pasta.
		7. All foods can be made gluten-free.
		8. People with gluten sensitivity must live sedentary lifestyles.

Who Put Cheddar in the Cheese?

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

Me	Text	Statement
		1. Bacteria are used to make different types of cheese.
		2. Milk is about 75% water.
		3. Milk is a heterogeneous mixture called a colloid because it contains small particles that scatter light in the Tyndall effect.
		4. Bacteria create sour milk by turning sugar into acid.
		5. Acid causes milk proteins to fold into a ball.
		6. Salt is added to cheese only to improve the taste.
		7. When diffusion occurs, over time the concentration of salt becomes the same on both sides of the semipermeable membrane.
		8. The pasture and the cow's milk affect the flavor of cheese, according to the cheese maker interviewed for the article.

A Super Vision for Airport Security

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

Me	Text	Statement
		1. There is nothing between the nucleus of an atom and its electrons.
		2. All electromagnetic radiation has the same speed.
		3. The higher the atomic number of an element, the better X-rays are absorbed by atoms of that element.
		4. The longer the wavelength of electromagnetic radiation, the greater the energy it has.
		5. X-ray machines can detect plastic explosives as well as metal objects.
		6. Some threat detection devices produce strong electromagnetic fields that make protons in matter flip and emit radio frequencies that are detectable.
		7. When a swab sample is analyzed, the sample is ionized in a machine using a radioactive source.
		8. Microwaves have higher energy than X-rays.

Unwrapping the Mystery of Mummies

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

Me	Text	Statement
		1. The Egyptians left detailed records of how they created mummies.
		2. The ancient Egyptians removed internal organs and blood from the corpses.
		3. Natron was used for a month to remove water from the corpse, including water from muscle.
		4. Bodies were filled with sawdust or leaves so the original volume was maintained.
		5. X-rays and CT were used to examine the mummy of the child brought to the university described in the article.
		6. Scientists using radiocarbon dating look for carbon-12.
		7. Radiocarbon dating can be used to date anything, whether it was once living or not.
		8. Electron microscopes can determine the type of fabric used in mummification.

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

24 Hours: Your Food on the Move!

***Directions*:** As you read, describe each step in the digestive process, and how chemistry is involved in the process.

Digestive Process	What happens	Chemistry involved
Ingestion		
Digestion		
Absorption		
Elimination		

Attack of the Gluten

Directions: As you read, complete the chart below describing gluten, celiac disease, and gluten substitutes.

	What is it?	**Where's the chemistry?**
Gluten		
Celiac disease		
Gluten-free alternatives		

Who Put Cheddar in the Cheese?

Directions: As you read, describe the steps in making cheese and the chemicals involved.

Step	What happens?	How long does it take?	Chemicals involved
Milk Collection			
Heating milk			
Curd formation			
Salting			
Aging			

A Super Vision for Airport Security

Directions: As you read, compare the different threat detection devices using the chart below.

Device	What can be detected?	How does it work?
X-ray scanner		
Explosive Detection Systems (EDS)		
Explosives Trace Detection (ETD) machine		
Metal Detector Using Pulse Induction (PI) technology		
Microwaves with antennas		
X-ray backscatter detection		

Bonus: What does this article have to do with the "Open for Discussion" article on page 5 of this issue?

Unwrapping the Mystery of Mummies

Directions: As you read, complete the chart below describing the steps the Egyptians used in mummification 2000 years ago.

Step	Description, including chemistry involved	How do we know? What techniques were used to find out?
Washing the body and organ removal		
Natron treatment		
Wrapping the body		
Adorning the body		

***Bonus*:** What process was described in both this article and "Who Put Cheddar in Cheese?"

24 Hours: Your Food on the Move!

Background Information (teacher information)

More on the digestive system

The food that we eat is not in a form that the body can use. Students may not realize that most food is a mixture of chemical compounds, many of which are either too large or too complex for immediate use in the body. It is the role of the digestive process to chemically alter molecules contained in food to break them down sufficiently for them to be absorbed into the body. The human digestive system can be thought of as a "tube" running from the mouth to the anus with important organs connected to it along the way. The entire system is about 27 feet long. Its purpose is to break down ingested complex nutrient molecules into simpler molecules that can be absorbed by the body and to eliminate the unusable by-products of this set of complex chemical reactions. In a healthy human the process can take from 24 to 72 hours.

The basic components of the human digestive system include the mouth, esophagus, stomach, liver, pancreas, small intestine, large intestine, colon and rectum. In order to better understand the role of chemicals in the digestive system, it might help to understand the function of each of the organs in the system.

The article says that digestion begins in the brain. Sensory stimuli like the sight and smell of food triggers reflexes sent through the enteric nervous system, a sub-division of the central nervous system, to the brain, which, in turn, stimulates salivary glands and muscles in the stomach to prepare the body for digestion. In fact, the cells of the enteric nervous system are embedded in the digestive tract (these cells also react to danger, so in times of acute danger we often experience a jittery stomach as a result of enteric nerves.) It is interesting to note that it was the enteric nervous system at work in Pavlov's classic conditioning experiment with dogs in which he was able to cause dogs to salivate by substituting the sound of a bell in place of visual stimulation provided by food. The enteric nervous system responds reflexively to external stimuli like food and Pavlov was able to "fool" the enteric nervous system into triggering digestive processes at the sound of the bell rather than the food itself.

Ingestion of food occurs in the mouth where food is initially broken down by the mechanical action of chewing—called mastication—and by the enzymatic action of the enzyme amylase and the enzyme lingual lipase in the saliva. Amylase begins digestion of carbohydrates and lipase initiates the digestion of fats. Chewing breaks the bulk food into smaller particles, increasing its surface area, and that greater surface area will increase the rate of the ensuing chemical phases of digestion. This phase also triggers the remaining digestive system to begin to function. For example, chewing signals the lining of the stomach to begin to release stomach acid. Saliva moistens and lubricates food so that it can pass through the esophagus more easily.

The esophagus is essentially a muscular organ designed to move food from mouth to stomach without contributing significantly to digestion. It contains esophageal glands which secrete mucus that aids in the passage of food through the organ. Mucous fluid is typically produced from mucous cells found in mucous glands. Mucous cells secrete products that are rich in glycoproteins and water. If the muscle fibers at the lower end of the esophagus--the lower esophageal sphincter—do not close properly, food that has entered the stomach, as well as

stomach acid, can seep back into the esophagus causing gastroesophageal reflux disease (GERD). If the reflux occurs only occasionally the esophagus and saliva have the ability to neutralize any acid reflux. Saliva contains bicarbonate ions which act as a buffer against swings in pH. Bicarbonate ions react with hydrogen ions from the acid to neutralize the acid. If, however, the reflux recurs often, either medications or surgery may be required in order for digestion to take place painlessly.

The stomach is the site of most of the digestive process. At this point the food is in semi-solid form, and in the stomach it becomes liquefied. Aside from its biochemistry, the stomach stores the incoming food, mixes it with digestive juices and then deposits the food into the small intestine.

When food enters the stomach, hydrochloric acid is produced. The acid concentration is about 0.15 M, resulting in a pH of 1-3. This is a critical part of the process, since the HCl destroys any bacteria that makes its way into the stomach with food and provides a good working environment for gastric enzymes to work. The HCl also serves to denature the protein nutrients in food, which is the beginning of protein digestion.

Proteins are large complex polymer molecules that often exhibit a secondary coiled up or “folded” shape. The folded shape of a protein molecule is the result of four types of bonds, two primary bonds and two secondary bonds. Most of this bonding occurs in the amino acid side chains within the molecule. The two primary bonds are disulfide bonds and weak ionic bonds between amino acids that make up protein molecules. The secondary bonds are hydrogen bonding and nonpolar interactions in the hydrophobic regions of the protein molecule. Each of these bond types contributes to the folding of a protein molecule, and these bonds can be broken relatively easily in the acid environment of the stomach.

So, in the presence of an acid environment, the protein coil unfolds (denatures), but leaves the amino acids bonded together. The stomach lining also produces the enzyme pepsinogen, which is converted to pepsin which, in turn, hydrolyzes the peptide bonds between amino acids, thus breaking down the larger molecule into shorter chains. Hydrolysis is a chemical process in which a water molecule is added to a molecule resulting in the splitting of that molecule into two parts. You can view a simple hydrolysis simulation here http://nutrition.jbpub.com/resources/animations.cfm?id=7&debug=0 or here: http://www.avogadro.co.uk/organic/hydrolysis/hydrolysis.htm. Despite the complex nature of the protein bonding and related chemical reactions, it is worth noting to students that these important chemical concepts play a major role in digestion. The digestion of fats also continues in the stomach. Exposed to salivary lipase in the mouth, fats are mainly hydrolyzed in the stomach by gastric lipase.

The food, now a thick liquid called chyme, is moved from the stomach to the small intestine through the pyloric sphincter. This step signals two other processes to begin. First, the pancreas releases its pancreatic juice into the intestine. The pancreatic secretions contain a variety of enzymes that continue the breakdown of carbohydrates, fats and proteins. Among these enzymes are protein-digesting trypsin, chymotrypsin, carboxypeptidase, and elastase; fat-digesting trypsin, chymotrypsin, carboxypeptidase; and elastase and alpha-amylase which digests carbohydrates. Pancreatic fluid also contains bicarbonate that neutralizes stomach acid that is mixed in the chyme.

Second, the liver releases bile which had been stored in the gall bladder. Bile is a bitter-tasting, dark green to yellowish brown fluid with a composition of water (85%), bile salts (10%),

mucus and pigments (3%), fats (1%), inorganic salts (0.7%) and cholesterol (0.3%). Bile acids dissolve the fatty portion of food and allow it to be absorbed through the intestinal walls. About 500 mL of bile acids are produced by the liver daily. The liver also serves to detoxify the chyme by converting any poison or harmful drug molecules into compounds that can be eliminated in the feces or urine. The liver is also the organ that monitors the body's blood sugar supply. In the small intestine the final enzymatic phases of digestion takes place and the digestive process shifts from breaking down molecules to absorbing them into the blood stream. Nutrients are absorbed through the intestinal walls and transported throughout the body.

Any undigested molecules are sent to the large intestine, which includes the colon, where they are stored until expelled in a bowel movement. Most of the undigested material is fiber—complex carbohydrates—which remains in the colon for as much as three days before elimination. In the colon are hundreds of forms of bacteria that are able to break down fiber into short-chain fatty acids needed for colonic health. These healthy bacteria also resist the growth of pathogenic bacteria. Any still-undigested fiber will aid in bowel movements.

More on digestive hormones

The major hormones that control the functions of the digestive system are produced and released by cells in the mucosa of the stomach and small intestine. These hormones are released into the blood of the digestive tract, travel back to the heart and through the arteries, and return to the digestive system where they stimulate digestive juices and cause organ movement. The main hormones that control digestion are gastrin, secretin, and cholecystokinin (CCK). Each of these is a peptide hormone. Bonding in all peptides (and proteins) is a covalent chemical bond formed when the carboxyl group (–COOH) of one molecule reacts with the amino group ($–NH_2$) of another molecule, releasing a water molecule. The resulting –C(=O)NH– bond is the peptide bond.

Gastrin is a peptide hormone that stimulates secretion of hydrochloric acid in the stomach. It is also necessary for normal cell growth in the lining of the stomach, small intestine, and colon.

Secretin, also a peptide hormone, causes the pancreas to send out a digestive juice that is rich in bicarbonate. The bicarbonate helps neutralize the acidic stomach contents as they enter the small intestine.

Cholecystokinin causes the pancreas to produce the enzymes of pancreatic juice, and causes the gallbladder to empty. It also promotes normal cell growth of the pancreas. It is a linear peptide that may contain between eight and 59 amino acids.

Ghrelin is produced in the stomach and upper intestine in the absence of food in the digestive system and stimulates appetite. It contains 28 amino acids.

Pancreatic peptide YY is a hormone which is secreted from endocrine cells called L-cells in the small intestine. Peptide YY is released after eating, circulates in the blood, and works by binding to receptors in the brain. These receptors then cause a decreased appetite and make people feel full after eating. Peptide YY also acts in the stomach and intestine to slow down the movement of food through the digestive tract.

More on chemicals important in digestion

It should be apparent from the article that digestion is primarily a chemical process that includes both the food nutrients being digested and the biochemical processes involved in digesting those nutrients. Many of the digestive chemicals have been mentioned earlier in this teachers Guide, but the following is a listing and brief description of most of the basic digestive chemicals.

Many, but not all, of these are classified as enzymes. Enzymes, as noted earlier, are protein molecules that act as catalysts for biologic processes. They have six main characteristics.

1. They control the rate of a reaction, often increasing the rate in living systems.
2. Enzymes react with only one reactant, called a substrate.
3. Their action is regulated by other chemicals in the system.
4. They are not altered by the reaction. This means that an enzyme can be used repeatedly.
5. They are destroyed by heat. This is because enzymes are proteins, and all proteins are destroyed by heat.
6. They are sensitive to pH**.**

A description of enzymes can be found in the *ChemMatters* Teacher's Guide, April 2006, available online:

> Enzymes are biological catalysts. The major enzymes involved in digestion are: proteases, lipase and amylase, hydrolyzing proteins, fats, and starches, respectively. A good web site to learn more about the actions of these enzymes can be found at http://arbl.cvmbs.colostate.edu/hbooks/pathphys/digestion/pancreas/exocrine.html. A diagram at that site shows a visual representation of the breakdown of a protein to peptides by trypsin and chymotrypsin. It discusses the precursors to these proteases and, in the second paragraph under "proteases", the author says, "As you might anticipate, proteases are rather dangerous enzymes to have in cells, and packaging of an inactive precursor is a way for the cells to safely handle these enzymes." It might be an interesting statement to pose to students, asking why proteases are dangerous enzymes to have in cells.
>
> Most chemical digestion of food actually happens in the small intestine, where the above enzymes are delivered primarily by the pancreas. The liver also plays a pivotal role in digestion as it secretes material into the small intestine – mainly bile acids. These, however, act primarily to emulsify and solubilize lipids so that pancreatic enzymes can act on them chemically to hydrolyze them into fatty acids and monoglycerides, both of which can be absorbed through cell membranes. Without bile acid emulsification of lipids, the fat globules are too large for enzymes to efficiently carry out hydrolysis – the enzymes can only reach the lipids that are on the surface, the outside of the globule. The interior of the globule would never be broken down into usable fatty acids.

Enzymes catalyze reactions by first binding to another chemical (the substrate). Each enzyme molecule has an active site that allows it to bind to the substrate. This active site has a geometric shape that corresponds to a geometric shape in the substrate that allows the two molecules to fit together in what is often termed the "lock and key" model. This binding allows

the reaction to proceed more quickly (or more slowly), and when the reaction is complete the enzyme is regenerated so that it can catalyze another reaction.

Enzymes are important because most biochemical reactions take place at a very slow rate, too slow to keep up with the body's metabolism. So, nearly all chemical reactions in humans are catalyzed by enzymes. For example, to break the bonds in a typical protein molecule would require boiling in 20% HCl for 24 hours but in the body the process takes about four hours at body temperature and pH.

In the following paragraphs are listed the major chemicals involved in digestion, organized by the location of their action in the digestive tract.

Mouth

Amylase - is responsible for the digestion of carbohydrates. It is an enzyme that breaks starch down into sugar. Amylase is present in human saliva.

Salivary lipase initiates the digestion of lipids, including trigylcerides, fats and oils. Lipase is an enzyme. The same enzyme is also found in the small intestines, where most lipid digestion takes place. It acts on the glycerol part of the triglyceride molecule to break it down into monoglycerides and fatty acids.

Esophagus

Bicarbonate ions (from $NaHCO_3$) in swallowed saliva act as a buffer, maintaining a pH between 6.5 and 7.5.and neutralizes any stomach acid that may reflux into the esophagus.

Stomach

Hydrochloric acid (HCl) is an important component of gastric fluid, formed in the stomach. Although gastric juice has a pH between 1 and 3 when it is initially released, making the initial concentration about 0.03 M, the concentration is quickly reduced by dilution with water in the stomach. The acid kills unwanted bacteria and provides an acidic medium for the action of pepsin in protein digestion. Gastric fluid also contains quantities of **potassium chloride** (KCl) and **sodium chloride** (NaCl). Cells in the stomach also release **bicarbonate** ions to buffer stomach acid. Another enzyme, carbonic anhydrase, catalyzes the production of carbonic acid from water and CO_2.

$$H_2O + CO_2 \rightleftharpoons H_2CO_3$$

Carbonic acid is a weak acid and it decomposes into hydrogen ions and bicarbonate ions.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

The stomach lining produces **pepsinogen**, which is converted to **pepsin**, the enzyme that catalyzes the breakdown of protein into shorter peptide chains. These shorter chains will be further broken down in the intestines. Pepsin also stimulates the liver to produce bile.

Also produced in the stomach is **gastric lipase** which catalyzes lipid breakdown. In the stomach lipids undergo 30% of their breakdown.

The stomach produces **mucus** to protect itself from the effects of the acid environment.

Pancreas:

The digestion of carbohydrates, proteins and lipids continues as a result of enzymes produced by the pancreas. **Pancreatic amylase** digests carbohydrates. **Pancreatic lipase**: digests a variety of lipids, especially triglycerides. And three enzymes are secreted in order to break down proteins—**trypsinogen/trypsin, chymotrypsin** and **carboxypeptidase.** All three are needed because each one reacts with a few specific amino acid bonds.

Intestines

The intestines produce large amounts of **bicarbonate ions** in order to neutralize any stomach acid that seeps into the intestines.

The liver releases **bile,** which is made up primarily of **water** and **steroid-derived sodium salts**. **Bile acids** dissolve fats and allow them to be absorbed through the intestinal walls.

Meanwhile, **lipase** and three carbohydrate-digesting enzymes—**maltase, lactase and sucrase**—continue the breakdown of saccharides, while **trypsin** aids the digestion of proteins in the intestines.

Most importantly, molecules that are the end products of digestion—molecules like amino acids, glucose, glycerol and fatty acids—are absorbed into the blood stream from the small intestines. The large intestine causes **water**—ten liters per day—to be re-absorbed into the blood. The large intestine accumulates undigested material to form feces, which is 75% water and 35% solids. Of the solid portion, about a third is bacteria and the remainder is undigested matter.

Without necessarily completely understanding all of the structures, formulas, and properties of the chemical involved in digestion, students should understand the wide range of compounds that play a role in how the body processes food.

More on food chemistry (taken from the *ChemMatters* Teacher's Guide, April 2006, available online)

> The food ingested by animals (humans or dogs) consists of many different molecules, but the bulk of them are huge macromolecules that cannot be absorbed by cells in the body. Here's a look at the three main groups of macromolecules involved:
>
> **Proteins** are long chains (polymers) of amino acids linked together by peptide bonds Generally, proteins must be broken down chemically into individual amino acids in order for them to be absorbed through the cells in the lining of the stomach. Proteins can be hydrolyzed into peptides by proteases; peptides can then be further broken down into amino acids by peptidases. Both enzymes break peptide bonds.
>
> **Lipids** include fatty acids, neutral fats, waxes and steroids. (Waxes and steroids are not closely related to this article, so we will focus on the first two lipids.)

Fatty acids are the building blocks of many complex lipids, although they are not present in large quantities in animal or plant tissue. Fatty acids are chains of carbon atoms, 14-22 carbon atoms long, ending in a carboxylic acid. They usually have even numbers of carbon atoms. Their differences lie not only in the number of carbon atoms, but also in the positions of the double bonds that make them unsaturated.
Neutral fat or triglyceride is the most abundant storage form for fat in animals and plants, and is therefore the most important dietary lipid. A triglyceride molecule is made of one glycerol molecule attached at each of its three carbon atoms to different fatty acids through ester bonds. These triglycerides are very large molecules that cannot be absorbed. They must be digested by pancreatic lipase (another enzyme) into a monoglyceride and two separate fatty acids, all three of which are able to be absorbed by the body. Other lipases are able to hydrolyze triglyceride into three separate fatty acids and a glycerol molecule.

Carbohydrates are aldehydes or ketones derived from polyhydric alcohols, primarily penta- and hexahydric alcohols. Carbohydrates can be broken down into three major groups: monosaccharides, disaccharides and polysaccharides.

Monosaccharides are the simple sugars, mostly hexoses, like glucose, and fructose, or pentoses, like ribose. These are typically produced by the breakdown of more complex carbohydrates, and these are easily absorbed and transported across the wall of the digestive tract and into the bloodstream.

Disaccharides are simply two monosaccharides that are linked together by a glycosidic bond. Common disaccharides are sucrose, lactose and maltose.

Polysaccharides are large polymers made up of smaller sugars, primarily glucose. They are the most abundant carbohydrate food group in most animals. This portion of carbohydrates can be further subdivided into three main groups: starch, cellulose, and glycogen.

Starch is one of the major storage forms of glucose in plants. It consists of two main components, alpha-amylose and amylopectin. Alpha-amylose consists of glucose molecules linked together in long straight chains, while amylopectin has highly branched chains of glucose. The glucose links in most starch molecules are alpha(1-4) glycosidic bonds, which are digestible by animals.

Cellulose is the other major storage form of glucose in plants. Cellulose is made of linear (unbranched) chains of D-glucose with beta(1-4) glycosidic bonds. Animals cannot digest this form of carbohydrate. Herbivores that rely on cellulose for their diet do not digest the cellulose – their digestive tracts contain bacteria that produce cellulases that can break down the cellulose to other, digestible saccharides.

Glycogen is the major storage form for glucose in animals. It contains glucose molecules linked in chains by alpha(1-4) glycosidic bonds, just like they are in starch, hence glycogen is digestible in animals.

Carbohydrates are digested most easily. Sugars are the first of the major nutrients to be digested, beginning in the saliva and continuing in the stomach and small intestine. Starches,

the other major carbohydrate class, are digested in two steps. Enzymes in saliva and pancreatic juice break starch into maltose, and maltose molecules are broken down to glucose in the intestines.

Protein digestion begins in the stomach where they are broken down into peptide units. These are broken down to amino acids in the intestines.

Fats are most difficult to dissolve because they are not water soluble. In the intestines fats are emulsified by bile acids and broken down by enzymes into fatty acids, glycerol and cholesterol.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic compounds—**Most of the compounds discussed in this article are organic compounds. Whether or not you have studied organic compounds when you read this article, it is important for students to understand that organic compounds play an important role in many natural processes.
2. **Chemical reactions—**Digestion, like most processes in the human body, is actually a series of chemical reactions that are catabolic in nature. That is, the reactions break down larger, more complex, molecules into smaller, simpler molecules. The reactions involved in digestion are complex, but chemical reactions nonetheless. If you are able to do any of the lab activities in the "In-class Activities" section of this Teachers Guide, students can see for themselves how some digestive reactions take place.
3. **Hydrolysis—**Many of the reactions involved in digestion are hydrolysis reactions. In hydrolysis a water molecule is added to a substance resulting in the splitting of that substance into two parts.
4. **Catalysts—**Key to digestion are enzymes, which are simply biologic catalysts.
5. **Acids and Bases—**You can use the article to show some acid-base concepts, in particular, acid concentration, pH and neutralization.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"Digestion takes place in the stomach."** *From an early age, most people associate their stomach with food and digestion. While much of the digestive process takes place in the stomach, the intestines are the site of both digestion and absorption of nutrients into the body.*
2. **"Stomach acid breaks down food and helps digest it."** *As the article notes, this is a common misconception. The primary role of HCl in gastric juice is to provide the acidic environment that many enzymes need in order to function well. The acid also helps to denature protein molecules as they are broken down.*

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

1. **"The article says that Tums contains calcium carbonate and that it's the carbonate that neutralizes stomach acid. I thought a neutralization reaction involved an acid and a base. Calcium carbonate isn't a base, is it?"** *There are two ways to think about this question. First, if we think about a neutralization reaction taking place only between an acid and a base, then we need to decide if calcium carbonate can be considered a base. Thinking about the Bronsted-Lowry definition of acids as proton donors and bases as proton acceptors, then $CaCO_3$ can be considered a base. For example, if calcium carbonate is added to water the following reaction occurs:*

   $CaCO_3 + H_2O \rightarrow Ca^{+2} + HCO_3^- + OH^-$

   In this reaction the carbonate accepts a proton from the water, and the ion normally associated with bases, the hydroxide ion, is produced. A second way of thinking about the HCl-$CaCO_3$ reaction is that it is a straightforward reaction:

   $CaCO_3 + HCl \rightarrow CaCl_2 + CO_2 + H_2O$

   In this reaction the HCl is "used up" or neutralized.
2. **"Is gravity required for the digestion of food?"** *No. The article states that food is moved through the digestive system, not by gravity but by the contraction and relaxation of smooth muscles that line the system in a process called peristalsis. These muscles move food through the digestive system independent of gravity.*
3. **"What is the concentration of stomach acid "** *The pH of stomach acid is 1.5-3.5, which means the highest concentration of HCl as it is initially released is about 0.0.03 M. The acid concentration is quickly diluted in the stomach, however, by the water that is present. The article says that HCl is only 0.5% total volume of gastric juices.*
4. **"If HCl is produced in the stomach, does that mean that as food moves beyond the stomach into the intestines it continues to be acidic?"** *No. The lining of the intestines secrete sodium bicarbonate ($NaHCO_3$) which neutralizes any excess HCl.*

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

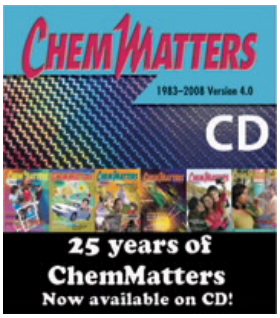
1. The article mentions the "cracker and saliva" lab activity. This version from The Exploratorium suggests that the oft-stated procedure will not work and provides background and a fail-safe procedure to observe the catalytic action of amylase on starch. http://www.exploratorium.edu/ti/conf/nsta2009/karen/bogus_biology.pdf .
   A variation of this procedure can be found on this University of Georgia site: http://apps.caes.uga.edu/sbof/main/lessonPlan/enzymeCarb.pdf.
2. The Chemical Heritage Foundation web site contains a section on "Enzyme Specificity" in their "Antibiotics in Action" module. This module contains three experiments that show the digestion of protein, lipid, and starch, respectively. Student and teacher versions of each activity can be found at: http://assets.chemheritage.org/EducationalServices/pharm/antibiot/activity/enzlab.htm.
3. This lab procedure has three parts, one for each of the enzymes involved in the major nutrients—carbohydrate, fats and proteins—and it also gives a detailed explanation of how enzymes help to digest these nutrients: http://www.indiana.edu/~nimsmsf/P215/p215notes/LabManual/Lab12.pdf.
4. This site from Great Britain is a site with experiments about a number of topics. Two of them (#14 and # 15) involve digestion experiments and their results, and three lessons (#16, #39, and #40) deal with enzyme activity. You might use these as ways to teach about digestion processes or enzyme reactions. The experiments give the setting for the experiment and then provide the results of that experiment. (http://lgfl.skoool.co.uk/keystage3.aspx?id=63)

5. This reprint of an article from NSTA's *The Science Teacher* provides a 7E inquiry approach to enzyme activity: http://science.kennesaw.edu/~mdias/SCED%204415/Biology%20Teaching%20Resources/Enzyme%20Inquiry.pdf.
6. This lab activity shows the effect of catalase on the decomposition of hydrogen peroxide: http://www.sciencegeek.net/Biology/biopdfs/Lab_Catalase.pdf.
7. This is a virtual lab on pH and enzymes: http://www.mhhe.com/biosci/genbio/virtual_labs/BL_11/BL_11.html.
8. Although this idea is not central to the topic, the article mentions iron in cereal. A procedure for measuring the iron in cereal can be found here: http://www.edu.pe.ca/agriculture/nutchems.pdf.
9. A procedure to measure the amount of antacid to neutralize stomach acid can be found on this site from Bryn Mawr College: http://serendip.brynmawr.edu/sci_edu/farber/pdf/antacid.pdf.
10. This lab procedure reacts HCl with various antacids and then titrates the excess HCl with NaOH to determine which antacid is most effective:. http://www.ulm.edu/chemistry/courses/manuals/chem1009/session_08.pdf.

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

1. Students, working singly or in teams, can research each section of the digestive system and produce a class PowerPoint, larger poster or video that connects each section correctly. Other students or teams of students might research important molecules in the digestive system and include this research into the class production.
2. Students could keep a log of their food intake for a week and then prepare a chart that categorizes the main class of nutrients in each type of food.
3. You could develop a WebQuest for digestive enzymes or any phase of the digestive systems and have students do online research. See http://webquest.sdsu.edu/LessonTemplate.html for WebQuest templates.

References (non-Web-based information sources)



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. (At the bottom of the Web site screen, click on the *ChemMatters* CD image like the one at the right.)

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 *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Some of the more recent articles (2002 forward) referenced below may also be available online at the URL listed above. Simply click on the "Past Issues and Teacher's Guides" button at the right. If the article is available online, that will be noted.

Tinnesand, M. The Dog Ate My Homework and Other Gut-Wrenching Tales. *ChemMatters* **2006**, *24* (2), p 4. This article describes the chemistry of food digestion and stresses the fact that humans do not have an enzyme able to break down cellulose, a complex carbohydrate.

Rohrig, B. Carb Crazy, *ChemMatters* **2004**, *22* (3), p 6. This article explains the chemical structure of different types of carbohydrates and their role in cellular respiration. It also explains the relationship of carbohydrates and blood sugar and examines low-carb diets and how they work and how low-carb diets lead to ketosis, the conversion of fat to ketones. The article offers pro and con research on the value of low-carb diets for teenagers.

Web sites for Additional Information (Web-based information sources)

More sites on digestion

This site from Great Britain details each organ of the digestive system and also includes a video: http://www.biology-innovation.co.uk/pages/human-biology/the-digestive-system/.

KidsHealth from Nemours also describes each organ in the digestive system in simple language.(http://kidshealth.org/kid/htbw/digestive_system.html)

The George Matelja Foundation stresses nutritional and digestive health. Along with a lot of background information, this site has a simulation, with explanations, of the digestive process. (http://www.whfoods.com/genpage.php?tname=faq&dbid=16)

This site, from the National Institutes of Health National Digestive Diseases Clearinghouse, gives a complete review of digestion: http://digestive.niddk.nih.gov/ddiseases/pubs/yrdd/.

This McGraw Hill YouTube video summarizes the digestive system: http://www.youtube.com/watch?v=08VyJOEcDos.

The Merck Manual includes a diagram of the digestive system. (http://www.merckmanuals.com/home/resources/anatomical_drawings/digestive_system.html)

This *Time m*agazine special article from 2007 relates the chemistry of appetite, the brain and digestion: http://www.time.com/time/specials/2007/article/0,28804,1626795_1627112_1626670-1,00.html.

This site from Colorado State University is mentioned earlier in the Teacher's Guide and is a comprehensive look at digestion, enzymes and other chemical components: http://arbl.cvmbs.colostate.edu/hbooks/pathphys/digestion/pregastric/index.html.

More sites on enzymes

This section of the Colorado State site describes enzyme action: http://arbl.cvmbs.colostate.edu/hbooks/pathphys/digestion/pancreas/exocrine.html.

This State University of New York site lists most of the major digestive enzymes and their organ of origin: http://faculty.clintoncc.suny.edu/faculty/michael.gregory/files/bio%20102/bio%20102%20lectures/digestive%20system/digestive%20system.htm.

Enzyme basics are provided in this site: http://www.sciencelearn.org.nz/Contexts/Digestion-Chemistry/Looking-Closer/Digestive-enzymes.

This site provides information on digestion and combines it with a listing of important digestive enzymes and how they work: http://www.foodreactions.org/articles/digestive_system.html.

This lab procedure gives a detailed explanation of how enzymes help to digest carbohydrates, fats and proteins: http://www.indiana.edu/~nimsmsf/P215/p215notes/LabManual/Lab12.pdf.

Attack of the Gluten

Background Information (teacher information)

More on celiac parameters—cause and effect

Celiac disease (also known as celiac sprue) is considered to be an autoimmune disease, rather than simply a food allergy. An autoimmune disease means that the body self-destructs; i.e., a trigger sets off the body's immune system to systematically destroy body tissue, rather than simply produce the typical symptoms of an allergic reaction with the attendant tissue destruction. Other well-known autoimmune diseases include rheumatoid arthritis and multiple sclerosis. With arthritis, the body's immune system reacts against body tissues rather than foreign bodies (bacteria, viruses), attacking the synovium, a thin membrane that lines the joints. In multiple sclerosis, the immune reaction is against the myelin sheaths that protect the nerves of the central nervous system (brain and spinal cord).

Celiac disease affects about 1 % of the global population. Nearly 2 million in the USA are afflicted. Although diarrhea is a common symptom of celiac disease, nearly half of adults with celiac do not suffer from diarrhea and therefore are not aware of their condition. Other signs that may occur in adults include anemia, arthritis, bone loss, depression, fatigue, infertility, joint pain, seizures, and numbness in the hands and feet. To determine if a patient might have celiac disease, other than relying on the above mentioned symptoms which could signal other diseases, tests or procedures that can be done include:

- Biopsy of the intestinal lining to see if there is a change in the mucosa (loss of villi),
- Endoscopic evaluation of the intestinal lining,
- Testing for specific antibodies to gliadins (found in wheat) or anti-endomysium (endomysium is connective tissue binding muscle strands together) and anti-tissue transglutaminases (related to fibrin that is associated with blood clotting), and
- A genetics test in which specific genes related to celiac disease can be detected. This test is used to determine that a person cannot develop the disease because the specific genes needed are not present. If the genes are present, it does not necessarily mean that a person will come down with celiac disease. So it is used as a negative test.

One of the experts in celiac disease research is Allesio Fasano of the Univ. of Maryland School of Medicine. He proposes that there are three components to celiac disease.

- The first is of course a trigger, the gluten protein that sets off an aberrant immune response.
- The second component is a genetic predisposition. Almost all celiac disease patients possess a gene either for the protein known as HLA-DQ2 or for HLA-DQ8. These HLA molecules display gluten fragments to immune system cells that in turn attack the intestinal lining.
- The third component of the disease is a leaky small intestine. By this is meant that normal intestinal cells are held together by links known as tight junctions. For people with celiac disease, these junctions come apart, allowing gluten fragments to get into the

underlying tissue (and blood supply), triggering immune system cells. If it would be possible to prevent this leakage, the gluten fragments would continue down the intestinal digestive tract, be further degraded into amino acid components and not create an immune reaction. This third component is a newer concept and, with further research, has identified a protein, called zonulin, which increases permeability of the intestinal wall.

More on the onset of celiac disease

It is known that people with a genetic susceptibility to celiac disease (CD) do not necessarily show symptoms of the condition soon after birth. For some, the disease develops later in life, as much as 50 years later. The question is, why the delay? Allesio Fasano proposes an important idea. He proposes that all individuals possess a collection of bacteria in their gut known as the microbiome and that these microbiomes differ from person to person. More important is the idea that these bacteria influence certain genes associated with CD. For a person whose immune system has tolerated gluten for many years, he or she might suddenly lose this tolerance if the microbiome changes in a way that causes a formerly quiet susceptibility gene to become active. If this proves to be the case, then changing the microbiome with an ingestion of selected helpful bacteria (probiotics) might prevent this activation of a quiet gene.

There are also several theories that genetically susceptible individuals will go on to develop CD because of an infection by rotavirus or human intestinal adenovirus. Ironically, there is some evidence that smoking is protective against adult-onset of CD!

More on preventing or treating celiac disease

To date, patients with CD have one therapeutic option for treating the disease—avoid all foods that contain gluten. But this option leaves patients with the difficult task of sticking to a restrictive diet. It also means they do not have good alternatives (to wheat-based products) that do as good a job as gluten-containing foods, particularly those used in baking. There are a number of options that are being worked on to try to prevent the onset of CD in susceptible people. They include the following:

THERAPY	**DRUG NAME**
Degrade otherwise indigestible gluten fragments so they cannot evoke an immune response.	ALV003 (Alvine and separately, AN-PEP), in human trials in the Netherlands.
Block zonulin from making the gut permeable (leaky)	Larazotide, in human trials
Keep tissue transglutaminase (an enzyme) from modifying gluten fragments in ways that stimulate the immune system.	A no-name drug (Numerate) under study in Stanford Univ. labs
Stop HLA-DQ2 from attaching to gluten peptides and displaying them to helper T cells (part of the immune system)	Mimics of gluten are being studied at Leiden Univ. and Stanford Univ. labs.
Vaccinate patients with selected gluten fragments to induce helper T cells to tolerate, rather than react to, gluten displayed by HLA-DQ2 molecules.	Nevax 2 in human trials in Australia.
Block migration of killer T cells from the blood into the intestinal lining where an immune response takes place.	CCX282-B in human trials.
Start a hookworm infection which in turn dampens a host's	Hookworm parasites being used

immune responses in the gut.	in human trials in Australia.

(Source: Fasano, A. Surprises from Celiac Disease. *Scientific American 301* (2), 2009, pp 54–61)

A non-drug approach that is being tested begins with infants in their first year of life who test positive for susceptibility genes. During the first year, while the immune system is maturing, infants eat nothing containing gluten. This may delay the onset of CD or even prevent the condition since it is possible that the avoidance of gluten in the first year might "train" the immune system to tolerate gluten as occurs in healthy, non-CD prone people.

More on predicting celiac disease

One of the more recent ideas about preventing the occurrence of celiac disease has to do with detecting the presence of auto-antibodies that appear in the blood years before people show symptoms of the disorder. There are tests that can detect these molecules and could warn a potential patient of CD to take preventive action. The auto-antibody reacts with the tissue enzyme transglutamine which normally modifies many newly made proteins. This auto-antibody can be detected in a person's blood seven years before the onset of CD symptoms, allowing an individual to take preventive action through a gluten-restricted diet.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Hydrogen Bonding**—The intricate, large and specific structures of polypeptides (proteins) is due in part to hydrogen bonding between different parts of the polypeptide chain, which in turn produces folding components to their structure (secondary and tertiary).
2. **Amino Acids**—Because of the amine group and the carboxyl group attached to a central carbon atom in the amino acid molecule, amino acids can link up to each other to form a long chain or polymer through covalent bonding. A carboxyl group in one amino acid and an amine group in a second amino acid react to form the covalent bond, splitting out a molecule of water. With twenty one essential amino acids, the combinations of these amino acids can produce many different large molecules (known as polypeptides or proteins) that serve many different biological functions including structure and catalysis, among others.
3. **Protein (polypeptide)**—These large biological structures, synthesized from linking amino acids through peptide bonds, produce a very large collection of molecules that provide a number of important biological functions including transport and storage, catalysis, motion, information transmission, genetic information, and formation of structural tissues.
4. **Fermentation**—A biological process that depends on specific enzymes (can be isolated to produce the fermentation outside a living cell or system) is important not only in the production of bread but also in the formation of desired pharmaceutical products that are excreted from genetically altered cells such as those of yeast and bacteria as well as animal tissue cells. Glucose is a common molecule of cells that is the source of energy for a variety of biological functions and is one of the substrates that yeast cells use in the fermentation reaction. The energy in the bonds of glucose is made available within the cell through a series of efficient bond-breaking and bond-making reactions. Ethanol is produced in the fermentation reaction by yeast in the bread-making process or beer fermentation. This process represents an energy conversion reaction that is not as efficient as that of respiration in human cells. Ethanol contains more chemical potential energy than water, one of the products in respiration. (Both fermentation and respiration produce carbon dioxide).

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"If celiac disease involves the immune system, then you should be able to treat the condition with allergy medicine."** *Celiac disease does involve the immune system but it is a different type of reaction in which tissue is destroyed, which is not true in a regular allergic reaction. Further, with allergies, the release of histamines produces the complications of itchy eyes, skin, and asthmatic conditions. Allergy medicine is essentially an antihistamine. With celiac disease, the immune system is not releasing histamines. Rather, antibodies released are involved in the destruction of body and organ tissue. The body self-destructs, so to speak. Hence the term autoimmune for an immune reaction such as celiac disease in which the lining of the small intestine is slowly destroyed after multiple immune reactions.*

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

1. **"Is celiac disease inherited?"** *Celiac disease seems to have some genetic component to it. It is considered a recessive trait which means you would have to inherit both recessive genes for celiac, one from each parent. It is thought to be more prevalent in Scotch-Irish people, red heads and those with fair complexions. If a relative such as a parent, child, or sibling has the disease, you have a 1 in 22 chance of developing the condition. If an aunt, uncle, or grandparent has the disease, the risk for you is 1 in 39 for developing celiac.*
2. **"At what age does celiac disease begin?"** *The disease can occur at any age. In some cases, symptoms of the disease do not emerge until after some form of trigger. Triggers can include an infection, pregnancy, severe stress, surgery, or physical injury.*
3. **"Can celiac disease cause psychological problems?"** *From the responses of celiac patients, it appears as though the condition can spark various mood swings and irritability.*
4. **"Are there any risk factors that might contribute to the development of celiac?"** *Known risk factors include Type 1 diabetes, autoimmune thyroid disease, Down syndrome, and microscopic colitis.*
5. **"What complications can develop if celiac is left untreated?"** *If left untreated, celiac disease can lead to malnutrition due to poor absorption of vitamin D, folate and minerals such as iron and calcium. Loss of vitamin D and calcium can lead to loss of bone density (osteoporosis in adults, osteomalacia in children). Due to damage to the small intestine, people can develop lactose intolerance which, in turn, produces diarrhea and excessive gas from fermentation of the lactose in the gut. This in turn produces abdominal pain. There is some evidence to suggest that people with celiac disease who don't maintain a gluten-free diet also have a greater chance of contracting several forms of cancer including intestinal lymphoma and bowel cancer. Finally, celiac disease has been associated with disorders of the nervous system including seizures and nerve damage (peripheral neuropathy).*
6. **"What are some diagnostic methods used to determine if you have celiac disease?"** *Some of the standard tests for celiac disease include blood tests, biopsy of the small intestine, and using a camera pill to examine the entire small intestine (endoscopy). Blood tests look for specific antibodies associated with celiac, including anti-endomysium (endomysium refers to the intestinal lining) and anti-tissue transglutaminase. In addition to these tests, a genetic test can be done to rule out celiac disease. People can test positive for the gene but do not necessarily develop the disease. In other words, the test does not diagnose celiac disease. It simply places an individual into an "at-risk" group and would be*

closely monitored for the antibodies mentioned above. In the U.S. population, about a third test positive for the gene but only 1–4% are thought to actually develop the disease at some point in their lifetimes. Part of this statistic may relate to certain triggers that are thought to set off the celiac condition to which many of the positive group are never exposed.

7. **"What food products besides the obvious may contain gluten?"** *The list includes the not-so-obvious, such as toothpaste, pet food (wash your hands after handling such), soy sauce, gravies, marinades, communion wafers and matzo.*

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

1. Students can measure the rate of a fermentation reaction. (effect of temperature, type of substrate [different sugars], inactivated yeast [heated]). If you have lab probe equipment, students can measure rate of carbon dioxide production with gas pressure sensors. See information about the gas pressure sensors and their use at http://www.vernier.com/files/manuals/gps-bta.pdf . Another approach to measuring the rate of the fermentation reaction using yeast is to collect the carbon dioxide gas in balloons. But you need to do this experiment yourself to make sure that it progresses in enough time for class. Otherwise, do it ahead of time and show the results to the class. A reference for the setup of this approach is found at http://www.exploratorium.edu/cooking/bread/activity-yeast.html. You could introduce the variable of temperature in this setup. But the first set up using Vernier-type gas pressure sensors works better for the effect of temperature.
2. If you want to simply do a side activity involving carbon dioxide gas (reminding students that the carbon dioxide generated by yeast cells produces the rise in bread making), the demonstration found at the following website impresses students. See http://portal.acs.org/portal/PublicWebSite/education/whatischemistry/scienceforkids/chemicalphysicalchange/chemicalreactions/CSTA_014880. Going farther afield, so to speak, a carbon dioxide-powered rocket (micro scale) can be produced according to following website reference: http://portal.acs.org/portal/PublicWebSite/education/whatischemistry/scienceforkids/chemicalphysicalchange/chemicalreactions/CSTA_014888
3. What is unleavened bread? Any advantage? The history of matzo in the Jewish tradition relates to the hasty exodus of the Hebrews from Egypt, taking unleavened bread with them which later became a symbol for the celebration of Passover. See http://www.christcenteredmall.com/teachings/feasts/unleavened-bread.htm for more details about the history of this event.
4. Students can test the effect of different amounts of kneading on the elasticity of the dough. Why the difference? Besides having students observe the preparation of bread dough (and later baking?), there is a clear difference in the texture of the bread depending on the amount of kneading. The more kneading, the more gluten that is produced and the "tougher" the bread after baking. An animated reference about what happens to gluten in dough making can be found at http://www.exploratorium.edu/cooking/bread/glutengood1test.html
5. What is the effect of temperature on the height of rising bread? Why the differences? (Yeast activity is temperature dependent.) Students can make bread dough with a standard recipe, then subject the "mound" of dough (or dough placed in bread pans) to varying environmental temperatures (use small toaster ovens with calibrated temperature control knobs and oven thermometer). Measure the height of the center of the dough mound after a specified time (30 minutes should give measureable results).
6. The use of antigen-antibody reactions is used to identify specific antigens present in various biological sources. One of the more common tests is blood typing. For the classroom in this

day of HIV and AIDS, students are no longer allowed to provide their blood for testing. But there are kits available that use blood facsimiles and are available from different science supply companies, including this website from Science Kit: http://sciencekit.com/search.asp?t=ss&c=0&ss=blood+typing&x=22&y=9 . Here's an additional company website for a large collection of immunology kits, including one for testing for the presence of Salmonella so often implicated in food contamination, particularly in eggs: http://www.bioeraindia.com/products_teaching_kit_immu.asp.

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

1. Students can research actual recommended diets for celiac patients and sources of gluten free food. A starting point could be http://www.mayoclinic.com/health/gluten-free-diet/my01140 .
2. For students interested in history/literature, they could research the origin of the celebration of Passover and the use of matzo which is unleavened bread. See the website, http://www.christcenteredmall.com/teachings/feasts/unleavened-bread.htm
3. One of the official sites for a celiac disease organization can be found at www.csaceliacs.info where there is a lot of information for student research.

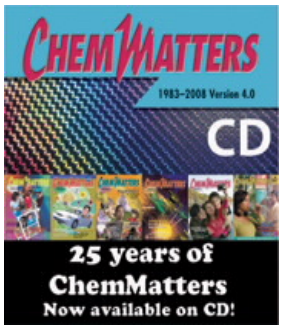
References (non-Web-based information sources)

Notkins, A.L. New Predictors of Disease. *Scientific American* March, **2007**, pp 72–79. The author of this article describes the manner by which scientists expect to predict diseases in the future that a person might encounter because of genetic makeup. For some of these diseases, including celiac disease, both predictions and preventions are listed.

Fasano,A. Surprises From Celiac Disease. *Scientific American* August, **2009,** pp 54–61. In this very comprehensive article on celiac disease, the author provides in depth background on the current status of cause and effect of the condition, including some current approaches to limiting or preventing the disease. The author is one of the leading experts in the field.

The ACS chemistry program entitled ***"Chemistry in the Community"*** (ChemCom) has an entire chapter on food ("Food: Matter and Energy for Life") which includes some activities and lab exercises for the main food categories (carbohydrates, fats, proteins), background chemistry with molecular diagrams, chemical equations, energy diagrams (from sun to table food), energy requirements for teenagers engaged in a variety of activities, and caloric value of different foods among other topics. The book can be purchased at the ACS Web site—or access the Web site of the W. H. Freeman, the publisher (which also includes access to the ACS Web site) at http://www.whfreeman.com/catalog/static/whf/chemcom/.

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. (Part way down the Web site screen, click on the *ChemMatters* CD icon like the one shown here at the right.)



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 *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.) (http://www.acs.org/chemmatters)

Dillard, B. How the Cookie Doesn't Crumble. *ChemMatters* **2007**, *25* (4), pp 11–13. This article describes the role of various ingredients in the making of cookie dough, including the presence and function of gluten to give structure to the cookie, preventing collapse as in wheat bread. Included in the article is a lab exercise in which students have to identify four white compounds that are used in baking, using information found in the article about these substances.

Rudolph, M. Leavening: How Great Cooks Loaf. *ChemMatters* **1996**, *13* (2), pp 4–5. This article, written by a student, describes the role of various chemicals used in the baking process. Reaction equations are included.

Web sites for Additional Information (Web-based information sources)

More sites on immune system components and their functions

The human immune system has many components that complement each other. It is more than antibodies and antigens. Refer to the following websites for information on these components and their function. http://science.howstuffworks.com/environmental/life/human-biology/immune-system.htm and http://science.howstuffworks.com/environmental/life/human-biology/immune-system4.htm.

Another website on the immune system with good diagrams and photos of the system components is found at http://uhaweb.hartford.edu/BUGL/immune.htm#intro.

More sites on HIV (the virus) and AIDS (the condition)

"AIDS (Acquired Immune Deficiency Syndrome) is a disease caused by HIV (the Human Immunodeficiency Virus). This is a particularly problematic disease for the immune system because the virus actually attacks immune system cells. In particular, it reproduces inside Helper T cells and kills them in the process. Without Helper T cells to orchestrate things, the immune system eventually collapses and the victim dies of some other infection that the immune system would normally be able to handle." Refer to this website for additional references: http://science.howstuffworks.com/environmental/life/human-biology/immune-system14.htm.

A plethora of questions related to AIDS is found at http://www.sfaf.org/hiv-info/basics/.

More sites on grains in relation to celiac disease

For a definitive description of specific grains that are known to cause celiac disease and related issues, refer to http://wheat.pw.usda.gov/ggpages/topics/celiac.html.

More sites on the chemistry of baking

For a complete description of the role, chemically speaking, of the various ingredients used in baking, particularly that of bread making, refer to: http://www.nzic.org.nz/ChemProcesses/food/6D.pdf. This document is written by a high school teacher for the New Zealand Institute for Crop and Food Research.

For a more complete description of the role of the main bread ingredients (enzymes, starch, yeast), refer to http://www.bakeinfo.co.nz/Facts/Bread-making/Bread-ingredients.

For a description of the various steps in bread making and what takes place within the bread mixture (including the effect of temperature, rising, kneading, and actual baking), see the website http://www.bakeinfo.co.nz/Facts/Bread-making/Science-of-bread-making.

More sites on the behavior of gluten molecules

A diagrammatic visual that shows the changes in gluten molecules during the kneading of bread is shown at http://www.exploratorium.edu/cooking/bread/glutengood1test.html.

Who Put Cheddar in the Cheese?

Background Information (teacher information)

More on the history of cheese making

The making of cheese has a long history that can be documented for certain cheeses, such as Parmesan. As an example, Parmesan from the Parma and Reggio regions of Italy has been produced for over 700 years and was described by Boccacio in his *Decameron* in 1348. Moliere in France would eat nothing but Parmesan cheese in his final days. And the diarist Samuel Pepys actually buried his Parmesan cheese to save it from the Great Fire of London in 1666. The word Parmesan was a French word adopted by the British in the 16th Century. Technically speaking, unless the cheese comes from the Parma region, it cannot be labeled as official Parmesan cheese. (This is similar to the situation with French champagne. Any champagne-like alcoholic drink cannot be labeled champagne if produced in any other country besides France.)

In the early days, there was intense competition between cheese producers in the Po valley as to which cheese was the best. Eventually the Parma and Reggio won the distinction. All other cheeses in the area were grouped under the generic name of Grana. The registration procedure for Parmesan cheese sets up specific criteria for the production of this hard cheese. The regulating body ensures adherence to these strict rules of production among some 800 dairies today. The standardized daily procedures include letting the milk from the evening milking stand overnight; the next day the cream is skimmed off to make *mascarpone*. This milk is then mixed with the product of the morning's milking in huge copper caldrons to which rennet is added to start the cheese-making process. Another important regulatory control is that the cows can graze only on grass and hay—no feed supplements. Additional processing techniques include floating the cheese in brine baths for 21 days to protect the rind over the long aging process. This takes place at a temperature of 22 ^{o}C for 6-7 months. The cheese is turned every 4-5 days during this time. For the next 6-7 months, the cheese is turned every 10-12 days. After this, the individual producer determines how much more time is allowed for the maturation process. (American Parmesan is aged for less time, uses pasteurized milk, is mechanically pressed, and contains less salt from the brining process.)

Because of the specific controls and location of the cheese-making process, the European Union has designated the Parmesan label (below) as a protected designation of origin. Any other Parmesan cheese produced outside the region cannot carry the official label.

More on origins of Roquefort cheese

Like Parmesan cheese, Roquefort cheese has a storied past (with a touch of the fable) that includes the exclusive nature of its name—again a registered and protected one. The history of this cheese begins somewhere back in 1666 when the Parlement of Toulouse, the highest court of southwestern France, decreed that anyone trying to sell cheese described as Roquefort but not actually made in the town of Roquefort-sur-Soulzon, according to the traditional methods of the trade, would be subject to a fine of a thousand livres. These strict laws remain in effect to this day. The cheese must come from one of thirteen producers whose caves are buried in the cliffside near the streets of the town. The cheese is unique.

So what is the unique manner by which Roquefort is made? First, Roquefort is made from sheep's (ewe) milk, not milk from cows, as with Parmesan cheese. The cheese is developed from that milk which is placed in these special caves that provide the moisture and correct temperature for aging. Because of the natural structure of the caves that includes narrow gaps in the limestone, an airflow is created either out of the caves in winter or into the caves in summer which in turn keeps the temperature nearly constant within the 44-48 ^{o}F range. The relative humidity is also steady at about 95%.

On the cave walls has occurred the growth of the special mold *Penicillium roqueforti,* named for the town in which it was first identified. It is this mold that is peculiar to Roquefort cheese production. There are stories that go back to antiquity as to how someone discovered the role of this mold in turning ordinary cheese into the cheese laced with blue-green mold. But most if not all of these stories are romantic fiction. The more accepted theory is that in the days when the Romans occupied France (Neolithic times), peasants, who kept bread for storage in these caves in the summer months of harvesting, found that the bread naturally turned moldy.

And since throwing away bread was sacrilege, the farmers added cheese to make it more palatable. The combination suggested that maybe cheese by itself would taste better if it had the mold in it! So, the historical theory goes that a process evolved in which moldy bread was mixed in with the milk as it was coagulating. The result was that the "moldy" cheese tasted better and lasted longer than ordinary cheese. This cheese was a softer one as well. The taste and texture proved to be popular, particularly among the Roman occupiers whose cheese tended to be dry and hard.

In 1842, the cheese producers established a society of Roquefort cheese cultivators with the shortened name of The Society. (The complete name, translated to English, is *"The Anonymous Society of Caves and United Producers of Roquefort*".) This society has become a singular and private company controlling 80 percent of the cheese production in the town of Roquefort.

The cheese-making process begins with the milk from a particular breed of sheep that has been around since people first started using the caves for cheese production. Having evolved in the particular climate of the region, which is harsh, an individual sheep produces about 35 gallons of milk per season, which is not very much at all. There is need for an amount of milk that would require 800,000 ewes, primarily raised on the local countryside, though imports of milk also come from other places like Corsica. Because of the thin layer of soil, the grass that the sheep graze on is very delicate, which in turn adds a special richness to the milk taste. Recall the grazing conditions for the cows producing milk for Parmesan cheese—you are what you eat if you are a cow or a sheep!

The *Penicillium* mold is cultivated on large loaves of rye or rye/wheat bread that are placed in the caves. The bread has a thick, burned crust to keep the loaves moist inside. Because the blue-green mold is endemic to the caves, its spores settled on the bread over time and multiply inside the bread. After ten weeks, the bread contains a powdery green mass of mold. The spores are collected, dried, and strained for use. A quarter to a half pound of spores will be used with two tons of milk (a gallon of milk is about eight pounds; two tons equals 500 gallons).

Milk is heated to 86 ^{o}F; rennet is added and the milk curdles in about two hours. From there, the cheese is drained of excess liquid and poured into molds. As it is poured, minute quantities of *Penicillium* is mixed in. The cheese is salted over a week's time, then pierced from end to end with long needles to provide holes for air circulation into the cheese and to allow the release of carbon dioxide as fermentation proceeds. The cheese units are placed in the caves and the mold spores begin to develop in the cheese under the ideal environmental conditions of moisture and steady temperature. After about four weeks, the individual cheese units are wrapped in tin foil to reduce the air contact and placed in refrigeration at 35 ^{o}F to slow the growth rate of the mold. After about 90 days, the cheese is ready for consumption. After the tin foil is removed (and reused), the texture and the color and spread of the mold are evaluated.

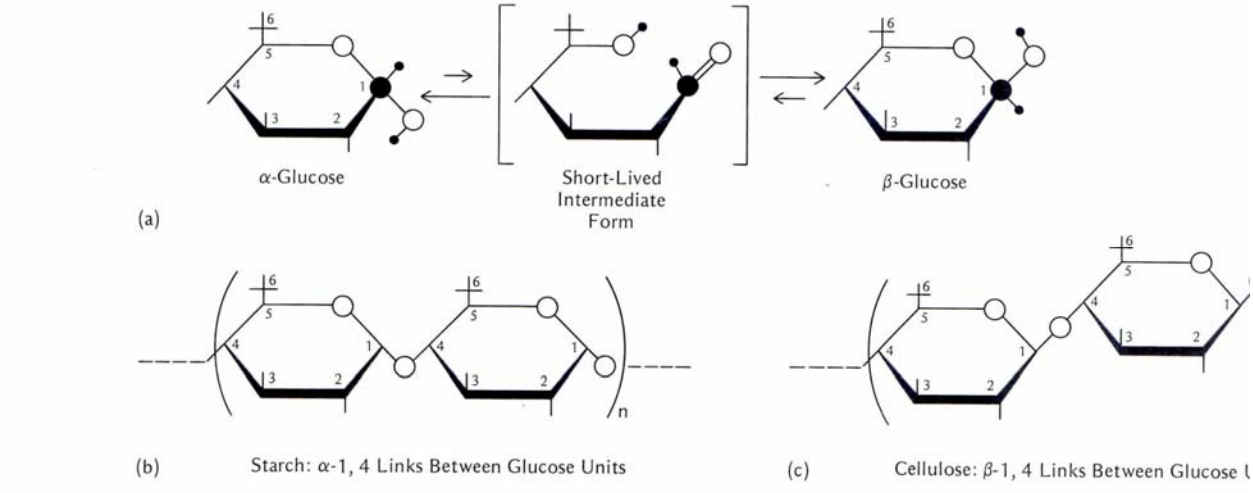
Compared with Parmesan, Roquefort cheese is more expensive because of the expense of milking 30 ewes versus one cow. But Roquefort is richer in flavor because sheep milk has twice the butterfat compared with cow's milk.

More on rumination

Since we are dealing with milk for cheese making, it is helpful to look at the sources of milk. There are many animals that produce milk that is used in different societies to make cheese. Included on this list would be all the ruminants (those animals with multiple stomachs for digestion, which includes fermentation)—cows, goats, sheep, buffalo, bison, yak, camels, antelope, deer, and giraffes. If you have ever watched a cow chewing its "cud" you can appreciate the origin of the word (verb) ruminate—the pause that refreshes!

The milk that is produced by these different animal types comes from the digestion of plant cellulose. The digestion is actually performed by special bacteria and protozoans in the rumen that produce digestive (hydrolytic) enzymes that split off glucose units. Humans cannot

digest cellulose because we lack these special bacteria and protozoans. Cellulose is a polysaccharide (300 to 15,000 D-glucose units) which differs from starch only in the physical arrangement of the glucose units—beta-linkages in cellulose rather than alpha-linkages as in starch. (See molecular representation below) We possess enzymes to digest starch into individual glucose units.



Source: Kirk, D. *Biology Today,* 3rd Ed.; Random House, New York, 1980, p 61.

Found in milk is lactose, or milk sugar, which is important for the formation of the curds by lactobacilli (bacteria). Lactose makes up about 5% of cow's milk and 7% of human milk. Lactose is formed from a molecule each of D-glucose and D-galactose. The bond between the two sugars is cleaved by the enzyme *lactase.* Again, the lactobacilli are responsible for producing this enzyme in making cheese. In humans, the enzyme is produced without the use of bacteria. However, a certain percent of the world's population lacks the enzyme lactase and is unable to digest the lactose sugar found in milk products. Those who are deficient in lactase tend to be descendants from those originating in the Middle East, the Orient, and Africa. Those who are lactase deficient have some digestive problems associated with undigested lactose that can ferment in the digestive system, creating gas which in turn creates cramps along with diarrhea. But compared with gluten intolerance, people can still consume milk-based products by first taking a pill that contains the lactase enzyme. Sometimes it appears as if lactose intolerance develops after childhood when people stop drinking milk. It is not known just why the body stops producing lactase. But with gradual introduction of milk again, some people are able to stimulate lactase production again. For others, it is truly a genetic deficiency, and there is no way to get the digestive system to produce lactase. There are milk products on the market that are lactose-free. And, as mentioned before, there are also lactase-containing pills that can be taken before ingesting milk products, reducing the symptoms of undigested lactose.

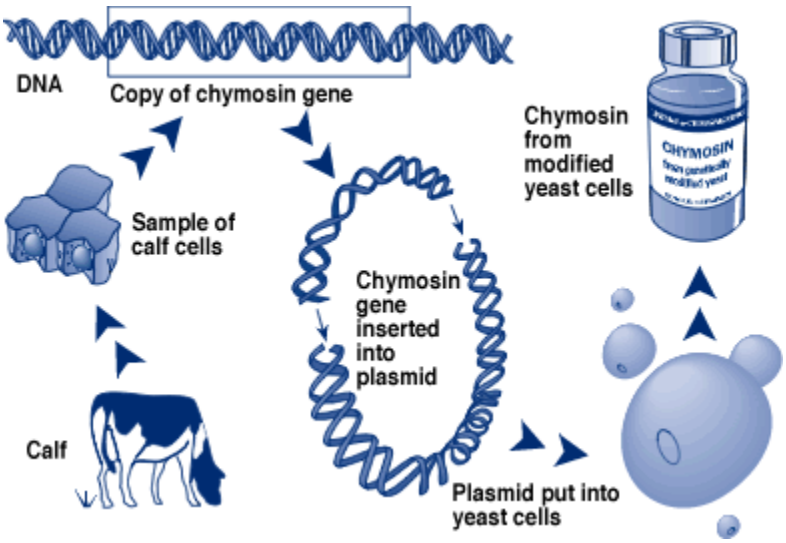
More on rennin (chymosin)

One important ingredient for the making of cheese is the enzyme called rennin or chymosin. It is what is known as a proteolytic enzyme, meaning that it is involved in the digestion of protein (cleavage of amino acid linkages). Chymosin is an enzyme normally secreted by the stomach of very young animals (including humans) for the purpose of causing the milk in the stomach to coagulate, thereby keeping the milk semi-solids longer in the stomach for initial protein digestion. Otherwise, as a liquid, the milk would pass out of the stomach too

quickly for stomach enzymes to work. Because the stomach produces the chymosin, it used to be that commercial rennin (chymosin) was obtained from the lining of the stomach of young cows. In recent years, other sources for rennin have been developed (see below). As an animal matures, the role of chymosin is replaced by the enzyme pepsin. Both enzymes operate in an acidic environment. (As food proceeds through the digestive tract, pH changes—and with it so do the enzymes that operate in that particular pH environment.)

The operation of chymosin to coagulate milk (in the stomach and for the production of cheese) depends on the interaction of the enzyme with a particular milk protein called casein. (There are four types of casein.) In essence, the enzyme cuts and inactivates one of the casein types (kappa) that normally keeps the other casein types from precipitating. With the proteolytic cutting of the kappa casein, it is no longer able to keep the other caseins from coagulating and therefore precipitating as the curd of cheese making. What happens is that the "balls" of protein (called micelles) unravel, allowing the unraveled strings of protein to join together to form clusters of insoluble protein. The term "Rennet" is given to any enzymatic preparation that clots milk, regardless of its source.

By the 1960s, it was predicted that there would be a shortage of calf-derived rennin. As a result several substitutes were developed. Three came from fungi. In 1990, a different source of rennin was approved by the FDA- genetically modified bacteria that can secrete the rennin or chymosin of exactly the same molecular structure as that from animal stomachs. The most popular bacterium used is the workhorse of the microbial word—*Escherichia coli.* This bacteria is modified through the insertion of the gene (a process called recombinant DNA) found in cows that controls the synthesis of the chymosin enzyme. Given the proper substrate in the bacteria's environment, the bacteria can synthesize chymosin the same way as happens in a cow's stomach tissue. (See the illustration below showing recombinant DNA used to change yeast cells into chymosin-secreting cells.)



(source: http://www.ncbe.reading.ac.uk/ncbe/gmfood/chymosin.html)

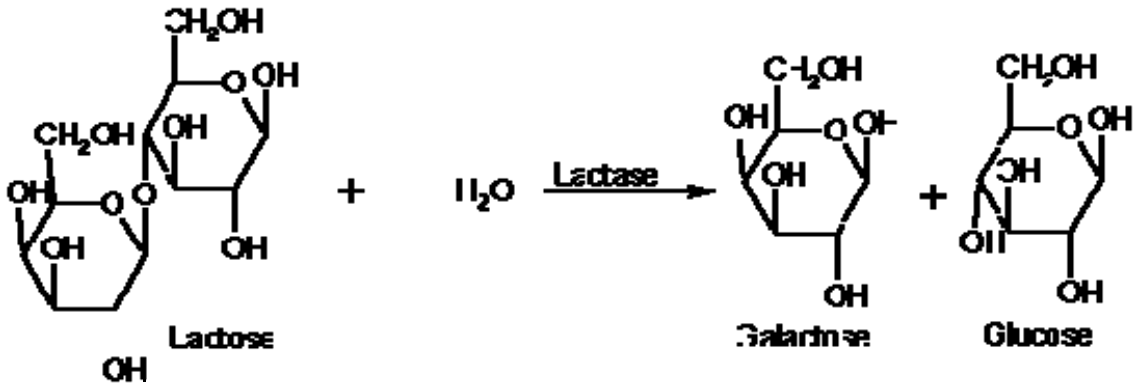
In comparison with cow-derived chymosin, the recombinant chymosin has fewer impurities. As a result, it is also cheaper to produce than the traditional method of extraction from a calf's stomach. An ounce of this enzyme can coagulate 50 gallons of milk into curdles and whey.

More on lactobacilli

Bacteria involved in changing milk into cheese curds are living organisms which are feeding on the milk contents in order to generate biological energy. To do this, they use the enzyme lactase to facilitate the conversion of the sugar lactose into lactic acid.

First the lactose sugar is cut into glucose and galactose. The galactose is converted back to another glucose molecule. Both glucose molecules are put through a series of enzyme-controlled steps to produce cellular energy in the formation of adenosine triphosphate (ATP), along with the 3-carbon pyruvic acid. Additional hydrogen atoms (and electrons) that come off the glucose molecules and added to the pyruvic acid form the lactic acid ($CH_3CHOHCOOH$), a reduction process, chemically speaking. If the process was aerobic rather than anaerobic, the products would be carbon dioxide and water from the pyruvic acid.

Our muscles produce lactic acid under stress (exercise) and low oxygen conditions, going through the same steps that the bacteria utilize in converting glucose to lactic acid. The process is for the production of the energy-rich ATP but is less efficient than under aerobic conditions (38 ATP molecules from one glucose molecule aerobically vs. 2 ATP molecules under anaerobic conditions). When blood oxygen levels increase (as when resting) the lactic acid is converted to carbon dioxide and water for additional ATP molecule production. (Check the Kreb's cycle for more detailed information.) The muscles are using the same fermentation process as that of the lactobacilli (an anaerobic process), changing lactose to lactic acid. The lowered pH from the lactic acid actually preserves the milk by preventing the growth of putrefactive and/or pathogenic bacteria that cannot tolerate an acid environment.



Lactic acid is a three carbon, carboxylic acid with the formula CH_3 CH(OH)COOH.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Enzyme—**Using an enzyme such as rennin in cheese making accelerates the breakdown process of milk into smaller component parts.
2. **Gel—**With a mix of liquid and solids in the formation of cheese, a gel state is established, giving the mix a semi-solid state, ready for removal of the water component.

3. **Organic molecules—**The important compounds in milk that become incorporated in cheese are organic**—**sugars (lactose, glucose), protein, and fat molecules.
4. **Homogeneous vs. heterogeneous mixture—**Raw milk, as it comes from the cow (or sheep or ...) is a heterogeneous mixture, with the cream rising to the top. Homogenized milk is processed to make the particles of the mixture small enough so that they don't separate from the mixture, making it homogeneous in appearance. Yet, if you look at homogenized milk under a microscope, you can see individual micelles within the liquid.
5. **Colloid—**Milk is a good example of a colloid with its suspended particles of protein and fat that produce a heterogeneous mixture, testing positive for the Tyndall effect.
6. **pH—**Converting the sugar lactose to lactic acid changes the pH of the milk in cheese making, causing the unfolding of the milk protein globules into long chains that are more easily broken down into smaller molecules. The acidic pH preserves the milk products by preventing pathogenic bacteria from developing, since they prefer a less acidic environment. Also, the pH affects the activity of various enzymes involved in the breakdown of food molecules (sugars, proteins, fats).
7. **Covalent bond—**In the cheese-making process, many different types of larger molecules are broken down into smaller molecular fragments through the breaking of covalent bonds.
8. **Osmosis—**Preservation of foods is dependent on killing bacteria through osmosis. Adding sugar or salt to food material dehydrates both the food and the bacteria in the food.
9. **Micelle—**This molecular structure (arrangement) that can be as simple as a one-layer droplet produces a form that can remain suspended in water indefinitely (stable suspension or emulsion) because there are both hydrophobic and hydrophilic ends to the component molecules. Micelles made from protein strands (casein) in milk are spherically shaped, kept together with calcium and phosphate ions, producing soluble microscopic particles that remain in solution. (illustrative explanation can be found at http://www.foodsci.uoguelph.ca/deicon/casein.html)

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"If Roquefort cheese (blue cheese) is made from mold (a fungus), it is unhealthy and dangerous to eat it."** Not all fungi are dangerous or harmful, medically speaking, to the body. In fact, we ingest mold when we are treated with the antibiotic penicillin which is related to the blue mold of Roquefort cheese. Some molds should not be ingested but this particular blue mold is not one of them, obviously.
2. **"If cows and sheep, as ruminants, produce methane gas in their digestive system, they will explode."** *There is explode and there is explode! For the methane to explode (chemically) there would have to be a spark to ignite the gas inside the animal. Exiting gas (flatus) would likely dissipate too quickly to be ignited. But it is also true that sheep and cows can come close to exploding from the buildup of gases, including methane, in the stomachs. This happens sometimes in spring if the animals are left to graze too long on new pasture growth that is too lush. As a result of taking in too much of this very green forage (compared with the old hay fed during the winter) the fermentation process in the animals' rumen creates gas at a rate faster than can be expelled. When animals get into this stressful (and fatal) condition, their abdominal wall has to be punctured, literally, to release the gas—just like popping a balloon!*

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

1. **"What is blue cheese and how is it formed?"** In the cheese-making process, *instead of adding bacteria to convert lactose, a mold is used instead. The mold of choice for blue cheese formation is* Penicillium Roqueforti *or* Penicillium Glaucum*. The mold in the cheese is blue. Historically, farmers in the Roquefort area of France placed cheese for ripening in caves that had cultivations of Penicillium on the cave surfaces. To increase the amount of mold available, they placed loaves of rye bread in the cave upon which the blue-green mold developed. The dried mold taken from the bread was then scattered onto the aging cheese.*
2. **"Is it true that Parmesan cheese comes only from Italy?"** *Although the origin of Parmesan cheese (some 700 years ago) is in fact from the Parma region of Italy, the cheese is made today in many different countries. However, to be labeled an authentic Parmesan cheese (with a trademark label), it has to be from the Parma region and approved by a special agency.*
3. **"Is it true that cheese can be made from milk that comes from other animals such as goats, sheep and camels rather than from cows?"** *Depending on the particular society, cheese and other milk-derived products have come from the milk of other animals including goats, sheep, and even camels. True feta cheese is made from sheep's milk. Goat's cheese is another popular cheese that carries the true taste (smell?) of the goat and is easily distinguished from that of sheep and cow. Camels have been a source of milk in desert communities for centuries, but the milk is more difficult to use for making cheese. Other animals that produce milk for cheese include the yak, buffalo, and horse (mare).*
4. **"Why don't cows and sheep explode if they are producing methane gas in their digestive system?"** *Actually sheep and cows can "explode" when they are put onto new pasture (spring time) and allowed to eat too much at one time. As a result, the fermentation process in their stomachs generates too much gas that cannot be eliminated quickly enough. As a result, their abdomen expands considerably and they can die from the condition if not relieved of the gas by puncturing their abdominal wall, literally deflating their body like a balloon! For an explosion of the "fire" type, a spark or flame would be needed. The gas buildup is in fact methane along with carbon dioxide. All ruminants such as cows, sheep, and goats produce methane which they either belch or pass out the back end, contributing to global warming, believe it or not!*
5. **"Can cheese be made from human milk?"** *Since human milk contains lactose (more than in cow's milk), cheese can be made from it. But it is a question of how much milk would be available. Recently somebody in England began making ice cream from human milk as a specialty item for sale!*

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

Insulin, sugar and the pancreas

1. Making soft cheese such as ricotta can be done with the following recipe: http://biology.clc.uc.edu/fankhauser/Cheese/Ricotta/RICOTTA_00.HTM.
2. Students can make yogurt following the recipe found at http://biology.clc.uc.edu/fankhauser/Cheese/yogurt_making/YOGURT2000.htm.
3. Since the term colloid was mentioned in the article, it is easy to demonstrate the Tyndall effect with some (just a little) milk added to water. A laser beam is the best kind of light source. Other solution mixtures that are not colloidal can be compared with the dilute milk mixture.

4. There are a number of experiments with rennin that can be performed by students. See the references http://www.pgjr.alpine.k12.ut.us/science/whitaker/Cell_Chemistry/enzyme.html, and http://faculty.clintoncc.suny.edu/faculty/michael.gregory/files/bio%20101/bio%20101%20laboratory/enzymes/enzymes.htm.
5. Students can study the effect of different factors on the rate of reactions catalyzed with enzymes, in this case, the catalysis of hydrogen peroxide into water and oxygen. See http://www.vernier.com/experiments/bwv/6b/enzyme_action_testing_catalase_activity/, which makes use of lab probes (pressure sensors) to measure gas production over time. Real time graphing is possible; data can be graphed for a hard copy as well. You can also do the fermentation reaction showing the effects of temperature and different substrates (glucose, lactose, sucrose) acted upon by yeast.
6. For showing the action of lactase enzyme on lactose in milk, refer to http://www.accessexcellence.org/AE/AEC/AEF/1996/crumlish_enzyme.php.
7. Have students test osmotic effects using potato cores—punch out equal length potato cores using a cork borer. Students mass the cores, then place individual cores in various saline solutions—distilled water, 0.1, 0.5, 1.0, 2.0, 3.0,and 5.0 % salt. Remove cores, pat dry with paper towel and re-mass. Have students explain the change in mass of the cores in the different salt solutions based on osmotic principles. See the following for more specific details: http://www.utsouthwestern.edu/media/other-activities/251270osmodemo.pdf.
8. An excellent short video with good diagrammatic illustrations on osmosis is found at http://www.youtube.com/watch?v=MUcP_sZ1eCk.
9. An activity for removing casein from milk by precipitation can be done by students. In this experimental procedure, casein is removed from milk using first an acid (coagulated material can be used to make cottage cheese), then using rennin for cheese making. Finally, soy protein in soy milk is precipitated using magnesium sulfate; the precipitate is used for making tofu. See the following procedure: http://www.accessexcellence.org/AE/AEPC/IFT/pdfs/unit3activity.pdf. Part of the procedure is to test the precipitates for protein content, using the Biuret test.
10. Another set of activities similar to #9, with good reading background on protein is found at http://www.accessexcellence.org/AE/AEPC/IFT/unit_three.php.
11. A demo that can be done to show the precipitation of milk protein using rennin is described at http://www.accessexcellence.org/AE/AEPC/WWC/1991/cheese.php.
12. A simple activity in which students quickly make cheese from buttermilk and whole milk is very doable. As part of the process that involves using cheesecloth, they will come to understand why cheesecloth is called just that! See the illustrated procedure at http://biology.clc.uc.edu/Fankhauser/Cheese/Cheese_5_gallons/CHEESE_5gal_00.htm.
13. Analysis of milk can be done in the lab by students. Refer to the following reference for the lab procedure: http://course1.winona.edu/jfranz/Lab/milklab.htm.
14. Making white glue from milk is another revealing exercise for students. (Ever wonder why Borden's, a milk products company, makes white glue?) Refer to the following procedure at http://voices.yahoo.com/how-white-glue-home-5371415.html?cat=24
15. Making your own cheddar curds can be done following the instructions found at http://cooking-from-scratch.blogspot.com/2009/07/cheddar-cheese-curds.html.

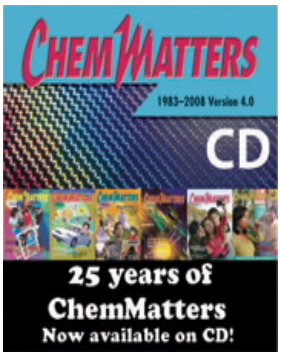
Out-of-class Activities and Projects (student research, class projects)

1. Students could further investigate the science behind recombinant DNA as a way to change an organism such as yeast or *Escherichia coli* to secrete a marketable chemical. This is

particularly useful in the pharmaceutical industry. A variant on this general idea is changing the genetic machinery in goats to secrete silk in their milk!

2. Any of the activities listed in the "In Class" section above could be assigned as projects for interested students. You need to ensure proper safety procedures can be and would be followed.
3. Students might find it interesting to research the issue of lactic acid buildup in muscle during exercise, why it occurs (biochemistry), and what biological ("survival") function it serves. The biochemical process can be compared with fermentation by the lactobacillus in cheese making. It can also be compared with fermentation by yeast with ethyl alcohol as a product rather than lactic acid.

References (non-Web-based information sources)



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. (At the bottom of the Web site screen, click on the *ChemMatters* CD image like the one at the right.)

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 *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Baxter, R. Say Cheese. *ChemMatters* **1995**, *13* (1), pp.4–7. This is a very complete overall view of different kinds of cheeses with descriptions of the cheese-making process and some related chemistry. It also includes a recipe for making lemon cheese.

Evans, G. Yogurt. *ChemMatters* **1989**, *7* (3), pp.9–12. This article provides the chemical and biological details for what happens in the making of yogurt. There is also a recipe for making Greek yogurt from regular yogurt. There is also an interesting introduction about the history of making yogurt, including the very special recipe from the Mongols who mix horse blood with the milk concoction that becomes their yogurt!

Web sites for Additional Information (Web-based information sources)

More sites on the how and why of cheese making

From the website, http://www.purifymind.com/CheeseRennet.htm, one can find a very complete description of cheese making and both the biology and chemistry behind the process. The differences among various cheese types are also explained. Information on the genetic engineering of chymosin rounds out the cheese-making reference.

An article on new foods through biotechnology elaborates on the many different food products that have been developed and their advantage in the food industry. Included in this article is the use of the whey from cheese making for use in other food products, the development of specialized yeasts for use in the fermentation process and the development of

an enzyme that reduces cheese-ripening times. The article can be found at http://www.accessexcellence.org/RC/AB/BA/New_Foods_and_Producers.php.

A very good history of microbial fermentation and how it changed the course of human history can be found at http://www.accessexcellence.org/LC/SS/ferm_background.php.

A video showing how to make cottage cheese is found at http://www.youtube.com/watch?v=50Mn6ivJEzE.

A recipe for making cottage cheese can be found at http://extension.missouri.edu/p/G9550.

Complete and illustrated instructions for making cheese can be found at a chemistry professor's website, http://biology.clc.uc.edu/Fankhauser/Cheese/Cheese_5_gallons/CHEESE_5gal_00.htm.

This same professor shows the old technique for obtaining rennin from the stomach of calves if you would like to see the gory details (instructional photos). (http://biology.clc.uc.edu/fankhauser/Cheese/Rennet/rennet_preparation.html)

More sites on lactose and lactose intolerance

The subject of lactose intolerance in humans who consume milk products can be found at a number of sites including:
http://www.mayoclinic.com/health/lactose-intolerance/DS00530,
http://www.lactaid.com/understandsymptoms/lactose-intolerance,
http://www.lactaid.com/understandsymptoms/lactose-intolerance, and
http://www.lactaid.com/products-home#Fast_Act_Caplets.
The last website listed is a commercial one that describes their product and how it works.
A government website that covers the topic, including a long list of foods that contain lactose, is found at http://digestive.niddk.nih.gov/ddiseases/pubs/lactoseintolerance/.

More sites on nutritional value of milk products

A very useful reference for determining the nutritional content of various foods of your choosing is found at http://www.nutritionanalyser.com/food_composition/?fid=01077.

More sites on the history of Parmesan and Roquefort cheese making

The history and lore of cheese making can be found at the following sites:

For Parmesan cheese: http://www.theparmesancheese.co.uk/history.html and http://www.kwintessential.co.uk/articles/italy/Italian-Parmesan-Cheese/356.

For Roquefort cheese, refer to these websites:
http://www.robertwernick.com/articles/Roquefort.shtml, and
http://franceinsandiego.wordpress.com/2010/04/16/roquefortfiles-or-the-history-of-french-cheese-roquefort/.

More sites on lactic acid and exercise

There is some debate as to the effects and value of lactic acid buildup during strenuous exercise. The standard, common explanations can be found at http://www.scientificamerican.com/article.cfm?id=why-does-lactic-acid-buil.

An important alternative explanation for the value of lactic acid buildup and suggested changes to conditioning exercise programs is found at http://www.nytimes.com/2006/05/16/health/nutrition/16run.html.

A Super Vision for Airport Security

Background Information (teacher information)

More on the history of airport security

In 1970, in response to a Palestinian threat to destroy four hijacked airplanes, then President Nixon put sky marshals on selected flights to deter terrorists. Unfortunately, he couldn't order sky marshals on every flight, so in December 1972 the Federal Aviation Administration (FAA) gave airlines one month to begin a general all-inclusive search of passengers and their bags. Apparently, some airports had already installed passenger screening devices, as "The world's first passenger screening system is introduced at New Orleans. [Louis Armstrong International, Moisant Field, MSY] Only 'suspicious-looking' passengers are asked to pass through it." (*Airports International*, June/July 2003)

The only technology available at that time that could accomplish this task was a metal detector then in use by logging companies. Loggers needed to know if any metal was imbedded in their logs, since cutting with their huge saws into logs containing pieces of metal could result in severe damage to the saw blade and lost time to loggers. Airlines simply took the metal detector concept and rigged it into a magnetometer to detect metal in passengers and baggage.

At the inception of the magnetometers, people worried about the dangers of being exposed to radiation, but scientists determined the amount of radiation was extremely low and posed no threat, even to frequent fliers; and the FAA worried that our court system would find that this type of search would violate the Fourth Amendment of the Constitution, the protection against illegal search and seizure. Luckily, the courts found that it was a violation, but an acceptable one, so long as the search was done universally, with no hint of discrimination, and limited to search for weapons and explosives.

In the 1980s, the War on Drugs and drug trafficking resulted in airlines using drug-sniffing dogs and new pat-down procedures for passengers. These actions helped to reduce the transportation of drugs and other contraband.

The next security thrust was the result of the Christmas 1988 Pan Am flight 103 explosion over Lockerbie Scotland that killed 270 people. The FAA began screening more thoroughly portable computers and radios on flights from the Middle East and Europe. Another rule that was initiated at that time required that the only bags that could board a plane were those accompanied by a passenger. Most security measures, including screening of passengers throughout the above history, was done by private personnel hired as security staff.

September 11, 2001 changed everything. On November19, 2001, the US Congress passed the Aviation and Transportation Security Act, which established the Transportation Security Administration (TSA), a government agency that now is responsible for all airport screenings of passengers and their baggage. No longer are private agencies allowed to serve as screeners in airports. The TSA was originally under the control of the Department of Transportation, but later (March 2003) it was made part of the Department of Homeland Security. New rules from the TSA: Knives, scissors and box-cutters were not allowed on planes and were subject to being confiscated; secondary screenings of suspicious passengers became

policy; and a No-Fly List of individuals who would not be allowed to fly on any airplane was instituted.

Terrorist attempts that followed 9-11 also resulted in changes to security measures. In December 2011, the "shoe bomber" caused TSA officials to make the removal of passengers' shoes for examination a requirement. A plot in 2006 to manufacture in-flight bombs from a combination of liquids prompted TSA officials to limit the volume of liquids allowed on flights. The "underwear bomber's" attempt to blow up a plane with explosives hidden in his underpants caused many airports to install full-body scanners.

As terrorists and criminals evolve in their methods, it is almost certain that airport security screening will adapt to the new challenges, and passengers are likely to be subjected to even more invasive techniques to ensure their own safety and that of others.

More on chemistry tied to Superman (article's reference) and other comic book characters

Many comic books utilize chemistry in their content. Plots and characters based on elements have been in comic books for decades. In fact, students (and you) can find a complete periodic table of elements collection that links you to an online comic book reference to an element whenever it is mentioned in any comic book. Frequently, elements are used in plots in science fiction comics, like *Superman*, *The Doom Patrol*, *Metamorpho*, and the *Fantastic Four*, but surprisingly, elements are sometimes mentioned in very unscientific comic books, like *Donald Duck* and *Woody Woodpecker*. The *Periodic Table of Comic Books* Web page was developed by two chemistry professors at the University of Kentucky. (http://www.uky.edu/Projects/Chemcomics/, last updated in 2005)

One comic book series, *The Metal Men*, focused on stories about individual android robots who each have the (admittedly anthropomorphic) properties of one of the individual elements iron, gold, silver, copper, cobalt, lead, tin, mercury and platinum (and maybe others). These robots are seen frequently in the URLs referenced in the comic book periodic table. See http://en.wikipedia.org/wiki/Metal_Men for more information about this comic book series.

A sample page from the *Periodic Table of Comic Books* Web page follows:

Source: http://www.uky.edu/Projects/Chemcomics/html/sc_37_7_fe.html

(You'll have to forgive Metal Man Lead for his symbol; although there have been many different alchemical symbols for lead in recorded history [see, for instance, http://www.rsc.org/chemsoc/visualelements/pages/alchemist/alc_lead.html], "L" doesn't seem to be one of them. I guess the artist took poetic license.)

More on X-Ray scanning of airline baggage

An object subjected to X-rays can do one of three things: it can absorb the rays, it can reflect or scatter the rays, or it can allow the rays to pass through. Metals (of which guns and knives are made), typically have heavier atoms and more protons in their nuclei. Their larger nuclei will absorb the X-rays. Organic material (comprising body parts, drugs and plastic explosives), composed of lighter elements with smaller nuclei, will usually be transparent to X-rays and let them pass through.

Carry-on bags are usually scanned using dual-energy X-ray systems. In these systems, after the single, fairly intense beam of emitted X-rays interacts with the objects in the bag, the rays reach three barriers: the first detector that detects the pattern made by both the high and low energy absorption by the object and the rays that passed through the object. Then, an electronic filter removes the lower-energy X-rays, and next, a high-energy detector picks up the high-energy absorption and the rays that passed through. Computer software then compares the images of the two detectors and provides a clear, color-coded image of the different types of materials in the bag. The final image is actually a comparison between the image from the first detector, that picks up everything—high- and low-energy rays, and the image from the last detector, that picks up only the high-energy rays. This allows the final image to highlight the "low-energy" materials, mostly organic items, in the bag. (Source: http://science.howstuffworks.com/innovation/science-questions/backscatter.htm)

More on X-Ray backscatter scanning

While travelers' bags are scanned by X-rays that detect materials by differences in transmission through the bag, people are not scanned this way because it would mean exposure to large amounts of X-ray radiation. Instead, people are scanned using X-ray backscatter devices. Backscatter radiation detects X-rays that are *reflected from* or *scattered by* the person, rather than *penetrating through* the person. This process utilizes much less X-ray radiation than normal X-ray detection devices. The X-ray beam is a narrow, low-intensity beam scanned over the body at high speed. These X-rays are reflected back from the body and any other objects on the body; then, they're converted to a computer image displayed on a remote monitor.

The reflected radiation forms an image on the computer screen. The pattern of backscatter depends on the properties of the material, and it can differentiate organic material. X-ray backscatter only produces a 2-dimensional image, unlike millimeter wave technology, which can produce a 3-dimensional image.

Scattering of X-rays produces a pattern that is more specific than the normal absorption pattern alone, especially for organic materials. The scatter pattern depends on the elements with which it interacts. Higher atomic number elements, with more protons, tend to absorb more X-rays than they scatter, while lower atomic number elements, like those involved in organic material; e.g., carbon, hydrogen, nitrogen and oxygen, tend to scatter X-rays well, providing brighter images of the organic material, including body parts, drugs and plastic explosives. The original narrow X-ray beam also results in very accurate and life-like images, part of the controversy of their use. (Source: http://science.howstuffworks.com/innovation/science-questions/backscatter.htm)

More on advanced imaging technology and our privacy

Millimeter wave technology detection devices used by the TSA now show a generic outline image of the body on the computer screen, rather than an actual picture of an

individual's body. Any potential threat items are indicated as anomalies on that generic body outline. This is in contrast to the X-ray backscatter technology, which does show the actual image of the body. TSA anticipates testing of new software for these X-ray backscatter units that would create a generic body outline, like the millimeter wave units, in the near future.

More on advanced imaging technology and our health

Millimeter wave technology uses non-ionizing radiation and thus is seen as no threat to the health of an airline passenger. The energy of millimeter wavelength electromagnetic radiation is too low to break chemical bonds, and thus too low to cause cellular damage.

X-ray backscatter technology, on the other hand, uses X-rays, which are ionizing radiation. Their energy is sufficiently high to cause cellular damage by breaking chemical bonds. The amount of X-ray radiation used in an individual backscatter scan, however, is so low that experts have stated that the health risk of backscatter radiation to humans is negligible. The amount of radiation to which a person is exposed in an X-ray backscatter scan has been set by the TSA to be less than the amount of radiation a passenger would be exposed to (from normal background radiation at high altitudes) in two minutes of actual flight time (more restrictive than the FDA requirement of four minutes of flight time). The actual radiation limit per scan is 0.25 μSv or 25 μrem. The annual dose limit for the general public is 250 μSv or 25,000 μrem per person.
(Source: FDA, at http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/SecuritySystems/ucm227201.htm.)

There is some debate among scientists, though, about the safety of these scans. Wikipedia's Web site discusses some of the debate at http://en.wikipedia.org/wiki/Backscatter_X-ray#cite_note-41. Scroll down to "Health Effects".

More on energy's effect on matter

Here's a good, basic explanation of how and why energy (radiation—light) interacts (or doesn't interact) with matter. Although it uses infrared light as its example, similar explanations work for other areas of the EMS also.

> **Why molecules like N_2, O_2, and Ar are "transparent" to light**
>
> Light consists of an electric and magnetic field that is transmitted through space. The electric field increases and decreases in magnitude (as does the magnetic field)—that's what's "waving" when we say light is a wave. When light passes over a molecule, the electric field can interact with the molecule if there is a separation of positive and negative charge in the molecule. Let's take a simple example. In a molecule like HF, the fluorine atom will be slightly negatively charged and the hydrogen atom slightly positively charged, because fluorine exerts stronger attraction on the bonding electrons. When a given wavelength of light passes over this molecule, its electric field will interact with the charges on the atoms. The "waving" electric field will push the atoms in one direction (positive and negative in opposite directions) and then the other.
>
> The atoms in the molecule of HF are bonded together, and the bond can be thought of as if it were a spring connecting the two atoms. This "spring" will have a natural frequency of vibration, just like a real spring.

A strong bond, like a strong spring, will tend to vibrate quickly—we say it has a high frequency of vibration. A weak bond will tend to vibrate slowly.

If by chance the frequency of the light passing over the molecule happens to match its frequency of vibration, the molecule will absorb the light, and its energy will be converted into energy of vibration. The analogy of pushing on a swing is a good one. To have the energy of your "push" absorbed by the swing, you must push at the same frequency as the swing is swinging.

Molecules can often vibrate in several different ways. If you imagine a central ball connected by springs to several others, you can probably imagine many different ways that this conglomeration could vibrate. Frequencies of light that do not match one of the natural frequencies of vibration of a molecule are not absorbed to any extent. Frequencies that do match are absorbed.

It turns out that the natural frequencies of vibration of most molecules are about the same as the frequencies of some wavelengths of infrared light.

If a molecule is polar, it will absorb infrared light at some frequencies specific to that particular molecule. That's how molecules can be identified by their IR spectrum.

If a molecule is nonpolar, it may still have an IR spectrum because some "modes of vibration" will produce atomic arrangements that are not symmetrical and therefore will have a dipole moment—the charges will not be arranged symmetrically in the molecule as it vibrates in that manner. For example, the arrangement of atoms in carbon dioxide is:

O=C=O

Consider the type of vibrational motion where the two oxygen atoms both move away from the central carbon and then back towards it. There is no way that the waving electric field of light could move one oxygen atom in one direction while at the same time moving the other oxygen atom in the opposite direction, since they both carry the same negative charge. Although this frequency of vibration will match some frequency of IR light, it will not be able to absorb that frequency.

But if the two oxygen atoms were to vibrate by both moving toward the top of the page and then toward the bottom, this would produce structures that were not symmetrical, the charges would not be distributed evenly as it vibrated, and it would absorb IR light that had the same frequency as this particular frequency of vibration.

But the charge in molecules like N_2, O_2 is always arranged symmetrically no matter how they vibrate, and a monatomic gas like Ar doesn't vibrate at all, so these kinds of molecules are basically "transparent" to infrared light.

(Source: *ChemMatters* Teacher's Guide, October 2003, pp 46–7.)

The idea of radiant energy interacting with matter is at the very heart of the global warming scenario. Carbon dioxide, water and methane absorb infrared energy because IR

frequencies match the vibrational frequencies of stretching or bending of bonds within those molecules. But because oxygen and nitrogen molecules are diatomic, they can only stretch and, since these stretching vibrational frequencies are not in the IR range of frequencies, oxygen and nitrogen do not absorb IR energy and are therefore transparent to IR radiation. See "Life in a Greenhouse", *ChemMatters*, October 2003, 21 (3), pp 18-21 for more information on the greenhouse effect and vibrational frequencies.

More on types of explosives

The February, 2003 *ChemMatters* Teacher's Guide section on the "Explosive History of Nitrogen" contains much material on explosives. Here is an excerpt:

> Explosives can be classified by their sensitivity. Sensitivity refers to the amount of energy needed to initiate the reaction. The energy required to initiate the explosion can be delivered in a variety of ways. These include:
> Shock
> Impact
> Friction
> Electrical discharge
> Detonation of another explosive
>
> Based upon sensitivity, explosives can be divided into two categories, Low Explosives and High Explosives. The terms "low" and "high" refer only to sensitivity, and should not be interpreted as being an indication of the potential destructive capacity of each type.
>
> ***Low Explosives:***
> Low explosives consist of a mixture of substances detonated by heat. The mixture must be confined to explode. They cannot support a **detonation wave**. A detonation wave is the key feature of a violent explosion. It represents the most severe example of combustion consisting of an exceptionally strong shock wave transmitted at supersonic speeds. The shock wave is closely followed by an exothermic reaction that provides sufficient energy to maintain the wave. The wave compresses and heats the gases immediately behind the front of the shock wave and the explosive reaction of these gases perpetuates the wave.
>
> **High Explosives:**
> High explosives will explode without confinement. They are compounds. Their explosion, initiated by shock or heat, will support a detonation wave Explosives can also be classified by the composition of the material. They can consist of a mixture of an oxidizer and a fuel. Examples of these kinds of explosives include:
> Gunpowder—a mixture of potassium nitrate, charcoal and sulfur
> Ammonal—a mixture of ammonium nitrate and aluminum powder
> ANFO—ammonium nitrate and fuel oil
> Cheddites—chlorates or perchlorates and oil.
>
> Or, they may consist of pure compounds, possibly mixed with stabilizers. Examples of these include:
> Dynamite—nitroglycerin mixed into a paste with powdered silica, which acts as a stabilizer

RDX, PETN—very strong explosives which can be used pure TNT—trinitrotoluene
C-4—plastic explosive

An explosive can also be classified as a primary explosive or a secondary explosive. A primary explosive is extremely sensitive. Only a small amount of energy is required to trigger its explosion. Typically, primary explosives are used to detonate secondary explosives. Tetryl, lead azide, mercury fulminate, lead styphnate, tetrazene and hexanitromannitol are some examples of primary explosives.

Secondary explosives require more energy for detonation, although they are much more powerful once detonated. Common examples are TNT, RDX, PETN, HMX, NH4NO3 and nitrocellulose.

More on explosive detection systems (EDS) and magnetic resonance imaging (MRI)

As the article states, “EDS machines work the same way as a medical imaging technique called Magnetic Resonance Imaging (MRI).” Magnetic resonance imaging is based on nuclear magnetic resonance (NMR), an analytical tool of chemists that has been in use since the late 1940s. NMR uses a very powerful magnetic field to align hydrogen (and other elements’) atoms within the magnetic field.

All nucleons in atoms, protons and neutrons, spin on an axis. In atoms with an odd number of protons and/or an odd number of neutrons, there is a non-zero spin, while in atoms with even numbers of protons and neutrons have a total spin of zero. Hydrogen atoms have only one proton in their nucleus (and most have no neutrons). Hydrogen nuclei (H-1) therefore have a net non-zero spin and are affected by an external magnetic field. They absorb and re-emit electromagnetic radiation when exposed to the external magnetism. This energy corresponds to a specific resonance frequency that is dependent on the magnetic field strength and the magnetic properties of the nucleus itself. Thus the frequency of resonance can be used to help identify the structure of a specific substance. Usually these resonant frequencies correspond to energies in the radio frequency range of the EMS.

The reason the term changed from nuclear magnetic resonance to magnetic resonance imaging was at least in part due to the term “nuclear” in the former process. It was feared people would not accept or allow themselves to be exposed to a machine to which was attached the term “nuclear”, so MRI was born.

In MRIs used in the medical field, the hydrogen atoms to be aligned in the magnetic field are mostly attached to water molecules. Radio frequency electrical fields then systematically change the magnetic alignment. This results in the hydrogen nuclei producing a rotating magnetic field that the instrument’s scanner can then detect. This information is then recorded and used to build an image of the area of the body that has been scanned. Gradients within the magnetic field cause nuclei in these areas to rotate at different speeds. Viewing these gradients in different directions can result in 2-dimensional or 3-dimensional images that can be viewed in any chosen orientation.

MRI images provide good contrast among the different soft body tissues. This makes MRI particularly useful in imaging specific areas of the body, compared to other imaging

techniques, such as CT scans (computed tomography) or X-rays. And an added benefit is that MRI imaging does not use ionizing radiation, as do the other two methods.

Explosives can be detected using this same methodology. The substances under scrutiny can be identified based on their radio frequency signature.

More on Ion mobility spectrometry (IMS)

Among many other uses, ion-mobility spectrometers can detect the chemical tags that manufacturers attach to plastic explosives. These IMS devices work on principles similar to those of other separation devices, yet they have unique properties as well.

In order to analyze the identity of individual molecules in a sample, the material must first be ionized, by one of several methods, including radioactive sources, as mentioned in the article. In the presence of an electric field, the newly-formed ions will move through a tube toward a detector. This is the basis for separation and analysis in many spectrophotometric methods. In the IMS, another variable is added: a drift gas or buffer gas, which is inert (to the sample), and which flows in the opposite direction to the flow of the ions, thus opposing their flow. Typical drift gases include nitrogen, air, carbon dioxide, helium and argon. Choice of buffer gas can affect the optimal separation of ions in the drift tube.

The size and shape of the ions affect how they behave with respect to the buffer gas. Larger ions will be subjected to more resistance by more buffer gas molecules, thus slowing them down and requiring longer travel times through the drift tube.

The rate of flow of the sample ions is controlled by the magnitude of the electric field, and the rate of opposing flow of the drift gas. Temperature also plays a role. The ion's charge, mass, and size and shape (the *ion mobility* part) all contribute to the time it takes for them to traverse the sample tube. This time is characteristic of specific ions. Based on the drift time, chemists' are able to differentiate among and identify various ion species.

A disadvantage of IMS arises as a result of a limitation of the technique. Since drift time is related (inversely) to mass and size of molecules, substances with similar masses and molecular sizes will have similar drift times and will therefore be identified as the same substance; e.g., oil or wintergreen (MW = 152) and mustard gas (MW = 158) will both be identified as mustard gas. Thus, further analysis to conclusively identify a substance will need to be done.

The principal advantage that IMS has over other separation techniques is the speed of separation of the ions in the sample. Results can typically be obtained in tens of milliseconds. Add to this that it is easy to use, has relatively high sensitivity and has a very compact design, and it is easy to see why it has become routinely used by airport screeners to improve security and assure our safety aboard airplanes.

There are many variations on the IMS process, which extend the scope of the instrument and increase its effectiveness. Examples include DMS, differential mobility spectrometry and DMA, differential mobility analysis. IMS can also be used in conjunction with other separation methods, improving analytical results obtainable from either method separately. Examples of this include IMS-MS, ion mobility spectrometry combined with mass spectrometry; LC-IMS, liquid chromatography combined with IMS; and GC-IMS, gas chromatography combined with IMS.

Although ion mobility spectroscopy seems to be the answer to our explosives detection problem, the devices are large, expensive and complex. There is still a need for a smaller, simpler device that could be made portable.

More on research on devices to replace ion mobility spectrometry

Science Daily reports (November 10, 2010) that Prof. Fernando Patolsky of Tel Aviv University and his team of researchers have developed an electronic sensor that can detect multiple kinds of explosives, including TNT. According to Patolsky, the sensor is small, portable, and more reliable and sensitive at detecting explosives than sniffer dogs. This instrumentation could be used in handheld devices to "quickly, reliably and efficiently" detect explosives.

The device is composed of an array of silicon nanowires, coated with a substance that can bind to explosives molecules to form a nanotransistor. Two hundred individual sensors work together to detect various types of explosives. The device is extremely portable, and can work from a distance, so security officers would not have to bring it in contact with items in order to detect the explosive. The extra benefit to this device is that it can identify the type of explosives it detects.

An added aspect to the explosives sensor is that the same device can be adapted to detect not only explosives, but also biological threats and toxins, such as cholera and anthrax.

Science Daily also reports (July 26, 2011) that material scientists at the Technical University of Darmstadt have announced the development of extremely sensitive explosives sensors that are capable of detecting extremely small traces of PETN, the highly explosive chemical pentaerythritol tetranitrate, used by terrorists in some attacks on commercial aircraft.

Prior to this discovery, PETN could only be detected by wipe tests, using ion mobility spectroscopy. But this method requires a considerable amount of time for airport security to run the test, so it is only used for spot-checking bags. Scanners and even dogs trained to sniff out explosives can't easily detect PETN.

PETN is a very powerful explosive, requiring only a few grams to totally destroy a car. Combine this with the fact that PETN is not very volatile, producing very few molecules into air, and you have a substance that is favored by terrorists. PETN was used in the package bombs that were meant to explode cargo planes recently and by the "underpants bomber" in his attempt to blow up a passenger plane in 2009.

The nanosensor developed at TU Darmstadt can detect a single molecule of PETN in 10 billion air molecules. And the only requirement for detection is that ambient air be passed over the sensor. It is conceivable that this detection system could be added to the present walk-through detectors at airports to check every passenger—and their baggage—for explosives.

(Source: *Science Daily* "Science News", "Nano Sensor Detects Minute Traces of Plastic Explosives: Scientists Enable Inexpensive, Reliable Checks for Explosives", July 26, 2011) (http://www.sciencedaily.com/releases/2011/07/110726092952.htm)

More on PI (Pulse Induction)

In PI technology, a single coil of wire can be used as both a transmitter and receiver, although some devices may use two or three coils in tandem. PI sends short, powerful bursts (hence, “pulse”) of current through the wire coil. Each burst of electricity induces a magnetic field. At the end of the pulse the polarity of the magnetic field reverses and the field collapses suddenly. This results in a sharp electrical spike, lasting a few microseconds, causing another current to run through the coil (the “reflected pulse”). This current is also very brief, lasting on the order of 30 microseconds. At the end of this cycle, another burst of electricity is sent through the wire and the process begins again. A typical PI device emits about 100 pulses per second, although that number can vary from twenty to more than a thousand, depending on manufacturer and model.

If the device encounters a metallic object, the pulse induces an opposite magnetic field in the object. When the magnetic field from the electric pulse collapses, causing the reflected pulse, the object’s induced magnetic field causes the reflected pulse to take longer to disappear. Inside the detector, a sampling circuit monitors the duration of the reflected pulse. Comparing this time to the expected time, without a metallic object present, the circuit determines whether there is another magnetic field present, indicating a metal object.

PI devices are one of three metal detecting devices used by hobbyists. The other two are very low frequency (VLF) detectors and beating-frequency oscillator (BFO) devices. All of these are small enough to be portable, hand-held devices.

More on ionizing radiation vs. non-ionizing radiation

Wavelengths of the EMS the length of visible light radiation or longer is considered to be non-ionizing radiation. This means that the energies of these wavelengths are smaller than those needed to break chemical bonds or release electrons from atoms, forming free radicals—highly reactive atoms or molecules containing unpaired electrons. As a result, when electromagnetic radiation of these wavelengths impinges on molecules, no chemical changes occur and no ions are formed (hence, “non-ionizing” radiation). Therefore, no damage is done to living cells and this radiation is not considered a threat to life.

In contrast, ionizing radiation involves wavelengths of the EMS shorter than visible light—those of ultraviolet light and beyond, into x-rays, gamma rays and cosmic rays. These rays contain enough energy to break chemical bonds and disrupt biological processes within cells, resulting in DNA damage, cancer or worse.

Of the detection devices discussed in the article, here is a breakdown in terms of their wavelengths:

Non-ionizing radiation

Type of device	Type of radiation	Wavelengths	Frequencies
Pulse Induction	electrical pulses	NA	NA
EDS (MRI)	radio frequencies	4.6–3.5 m	6.3–8.5x 10^{7} Hz
Millimeter wave	microwaves	1.2–1.0x10^{-2} m	2.4–3.0x10^{10} Hz

Ionizing radiation

Type of device	Type of radiation	Wavelengths	Frequencies
Ion mobility spectrometer	UV–X-ray	1x10^{-7}–1x10^{-10} m	3x10^{15}–3x10^{18} Hz
X-ray backscatter	"soft" X-rays	1x10^{-8}–1x10^{-10} m	3x10^{16}–3x10^{18} Hz
X-ray machines for bags	"hard" X-rays	1x10^{-10}–1x10^{-11} m	3x10^{18}–3x10^{19} Hz

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Electromagnetic spectrum—**This is an opportunity to discuss the electromagnetic spectrum with students and to show them real-life applications of various sections of the EMS.
2. **Mass spectrometry—**Isotopes were discovered using mass spectrometry, and it is still used today to separate and identify ions and segments of ions in real-life samples of materials. The mass spec is frequently used in conjunction with other devices, like the ion mobility spectroscope, to enhance the "powers" of both instruments.
3. **Radiation—**Ionizing and non-ionizing radiation are both part of this article
4. **Radioactivity—**Nuclear radiation may be used to ionize vapors that are to be subjected to ion mobility spectrometry (although the vapors may be ionized by other methods).
5. **Ionizing vs. non-ionizing radiation—**Millimeter wave technology involves non-ionizing radiation, radiation of low enough energy that it cannot cause damage to cells because it can't break chemical bonds; x-ray backscatter technology involves ionizing radiation, radiation of sufficiently high energy that chemical bonds can be broken and therefore can cause cellular damage. This would be a good time to discuss the differences in energies in wavelengths of the EMS, and to relate these energies to the energies involved in chemical bond-breaking and bond-forming.
6. **Activation energy—**In discussing the interaction of energy and matter, it would be useful to tie in to this discussion the idea of activation energy, which is sometimes provided by radiation (of the ionizing kind, high enough to break bonds and form free radicals).
7. **Technology—**The need for technology often drives scientific research, although scientific discoveries sometimes result in useful technology. Science and technology go hand-in-hand.
8. **Safety—**The TSA needs to be concerned with the safety of airline passengers, both from the viewpoint of terrorists, and from the viewpoint of its own detection systems; it needs to assure travelers that its scanners do not emit harmful radiation, or at least that travelers are not exposed to any harmful radiation.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"Airport scanners cause cancer."** *Actually, there is a tiny bit of truth—and a lot of untruth—in this statement. Truth: the X-ray scanners that are used to scan luggage, laptop computers and the like probably do emit enough X-ray radiation to cause cancer—IF humans were exposed to the radiation, which they are not. Untruth: although X-rays can cause cancer, the short focused bursts of X-ray radiation used in whole-body X-ray backscatter scanners have been shown to be very low levels of radiation, equivalent to the amount of radiation a passenger would receive in less than five minutes of high-altitude flight. And millimeter wave radiation (using radio waves,) used in the most recently-developed whole-body scanners, emits radiation at such long wavelengths and such low energy that it is stopped by the top layers of the skin, and it is low-level and non-ionizing radiation, so it doesn't alter DNA.*
2. **"We see objects because of the light they give off that reaches our eyes."** *Again, there is a bit of truth and a lot of untruth here. Truth: we see <u>some</u> objects because of the light they give off. Such objects include: the Sun and stars, light bulbs, fire, and computer monitors and television screens. All these objects actually <u>emit</u> energy in the form of visible light. Untruth: most other objects we can "see" are visible to us because they <u>reflect</u> energy in the visible region of the electromagnetic spectrum; e.g., the moon, deer in our headlights at night, paper books we read (maybe not Nooks of Kindles). In order for them to reflect light, they must be exposed to a source of light; i.e., one of the objects listed above that emit light. The visible light (or perhaps ultraviolet light) emitted by the source hits the object and is reflected back to our eye, allowing us to see the object. Without the energy source, we would not see the receptor object at all. To test this, look at an object in a lit room, and then take the object to a dark closet, shut the door and view the object again. You won't "see" it because no light is hitting it that can be reflected back to our eye.*
3. **"X-rays can penetrate right through atoms."** *X-rays can penetrate electron clouds surrounding the nucleus, but they cannot penetrate nuclei. If an X-ray is on a collision course with a nucleus, it will be reflected by the dense nucleus. If an X-ray comes close enough to an electron in an atom, the energy of the X-ray can be transferred to the electron, either raising it to a higher energy level within the atom, or removing the electron completely from the atom, thus changing that atom into an ion (hence the term, ionizing radiation).*
4. **"These new whole-body scanners are getting way too personal!"** *Although many people feel this way (and it may be true), the technology has several safety mechanisms built in to minimize the invasiveness of the scan. First, the person on the outside, directing the passenger to pose for the scan never sees the image. A separate person in an enclosed booth views the computer monitor on which the image appears. Second, although the image could appear in very sharp detail, it is blurred out or distorted enough to hide details of the body. This is done automatically by an algorithm in the computer software before the image*

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

1. **"Are X-rays bad for us?"** *X-rays can be harmful to living tissue. If X-rays interact with genetic material, they can cause damage to DNA, which can then be reproduced in growing, replicating cells. This can result in cancer. If an X-ray should pass through the body without colliding with any cellular material, it will cause no harm. The problem is that we can't control a beam of X-rays to that level of precision to guarantee they don't impact cellular material;*

and truth is, it is their interaction with matter; e.g., bone, that makes them useful to us, in differentiating details of parts of the body, and in detecting foreign objects on the body.

2. **"Are radio waves safe?"** *We are exposed to radio waves incessantly, not only from radio stations broadcasting their signals, but also from stars, and even lightning storms. The millimeter-wave scanners utilize the lowest wavelength radio waves. Their energies are far below those of ionizing radiation waves. As far as we know, they cause no adverse health effects to humans upon exposure; however, research is ongoing.*

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

1. The Environmental Protection Association, EPA, has a Web page dealing with natural background radiation. Called Radtown, USA, the page, designed for students, is an animated town (requires Flash) that has a large number of natural and man-made radiation sources that students can click on to find more information. Find it at http://www.epa.gov/radtown/. There is also a text version of the page, and the site contains an extensive background page on radiation, as well.
2. Here's another source for background radiation: NOVA produced a video, *Dirty Bomb*, that dealt with various natural and man-made forms of radiation: http://www.pbs.org/wgbh/nova/dirtybomb/sour-nf.html. This Web page shows a map with various sites that, when clicked upon, will provide more information about the type of radiation source at that specific site.
3. Students can perform a virtual lab involving spectroscopy at http://mrpalermo.com/Virtual_Spectroscopy_Lab.html. The lab involves photographs of both line spectra and flame tests for various elements. Students complete a downloadable lab sheet as they progress through the experiment, and they answer questions posed at the end of the lab.
4. To present a lesson the electromagnetic spectrum (EMS), you could find some ideas on this *Windows to the Universe* Web page: http://www.windows2universe.org/sun/spectrum/multispectral_sun_overview.html. It describes the "multispectral sun", showing the various wavelengths of radiation emitted by the sun.
   You might also want to combine images of the spectrum (e.g., http://www.arpansa.gov.au/radiationprotection/basics/ion_nonion.cfm) that include the types of *sources* of the various ranges of wavelengths on the EMS with those (e.g., http://oceanservice.noaa.gov/education/yos/resource/JetStream/remote/remote_intro.htm) showing the *sizes of the objects/particles* that match those wavelengths, to give students a better idea of the range of sizes of wavelengths involved in the EMS. These charts even relate temperatures to the EMS: http://ngst.gsfc.nasa.gov/exhibit/emspectrum.html and http://en.wikipedia.org/wiki/File:EM_Spectrum_Properties_edit.svg.
   Here's another source for sources of EMS radiation, in the form of electronic "cards": http://ds9.ssl.berkeley.edu/LWS_GEMS/2/emspe.htm. This comes from the GEMS "Living with a Star" module and the NASA *Living with a Star* booklet (http://ds9.ssl.berkeley.edu/LWS_GEMS/pdfs/lws.pdf). You can order the GEMS book for $31.00 here: http://lawrencehallofscience.stores.yahoo.net/liwistbfrsut.html.
5. A good 6-mnute introductory video on the electromagnetic spectrum (EMS) from NASA can be found here: http://www.youtube.com/watch?v=cfXzwh3KadE. The last 2 minutes describe how NASA scientists use EMS to learn more about the world around us. A second NASA video focuses on radio waves as part of the EMS, and what we've learned about our world and space using radio waves. (http://www.youtube.com/watch?v=al7sFP4C2TY) A

third NASA video focuses on microwaves: http://www.youtube.com/watch?v=YgQQb1BVnu8.

6. If you want to show students how objects can absorb certain wavelengths of EMS, like bonds absorb X-rays (in this case, ultraviolet radiation), visit http://www.chemistryland.com/CHM107Lab/Exp08_UV/Lab/Exp08_UV.html. This Web page shows an experiment done by the teacher involving ultraviolet beads to show how efficient sunglasses are at blocking UV radiation. The beads in this case are the absorber of the radiation, while the UV-protection sunglasses may absorb or reflect some of the UV rays impinging on the glass. The bead activity shows that UV light has sufficient energy to change chemical bonds in the beads that result in the color changes they see, versus visible light, which is lower in energy, and cannot change the colors, hence cannot break and re-form chemical bonds.
7. You can calculate the speed of light using a microwave oven and a chocolate bar (well, many bars). See the Arbor Scientific demonstration at http://www.youtube.com/watch?v=cZ3X3ppLKrM as an example of the experiment and calculations.
8. You can do a demonstration of how a mass spectrometer operates by rolling steel balls of various masses down an inclined plane and onto a Plexiglas surface. Place a very strong magnet under the Plexiglas at roughly a 90 degree angle to the path of the steel balls. Balls of different masses will undergo different degrees of deflection, much as charged atoms or molecules of different masses undergo different amounts of deflection in a mass spectrograph. Such a demonstration apparatus is contained in Talesnick, I. *Idea Bank Collation, A Handbook for Science Teachers;* S17 Science Supplies and Services Co.: Kingston, Ontario, 1984; Vol. I. (Source: *ChemMatters* Teacher's Guide, December 2000). Talesnick also sells a mass spectrometer demonstration kit at http://www.s17science.com/. Go to the bottom of the homepage and click on "Model for Mass Spectrometer".
9. A simulation activity which shows students how molecular masses are determined from mass spec data is found in "Mass Spectra," *Journal of Chemical Education*, 2003, *80,* 176A.
10. NASA provides an entire 1-week curriculum on the topic of mass spectrometry. (The actual mass spec activity only requires 1 day.) The lessons are based on Genesis, a probe that measured solar wind. The mass spec is used to analyze the data from the probe. Both student and teacher versions are provided. Find it at: http://genesismission.jpl.nasa.gov/educate/scimodule/sims_mini-mod.pdf.
11. You can discuss with students the ability of electromagnetic radiation to initiate chemical reactions, using these examples: visible light initiating photosynthesis; ultraviolet light initiating chemical reactions resulting in the formation of ozone in the stratosphere; Sun Print paper (http://www.stevespanglerscience.com/product/sun-sensitive-paper (this paper changes color with sunlight, but it's only the UV rays that cause the change) (there's a video here showing it in action); and, if you're daring, you can demonstrate that visible light in the red-green region of the spectrum will not initiate the photochemical reaction $H_2 + Cl_2 \rightarrow 2\ HCl$, while blue and violet will do the trick. BEWARE: this is truly an explosive reaction! If you do it once for yourself (practice first, right?) you might want to just videotape it and show students the video. At the very least, use an explosion shield. A camera flash will trigger the reaction, and you can use varying color filters to span the spectrum. OK, if I have you sufficiently worried, you can just go to this site and view the reaction, along with a variety of colored LED light sources used to attempt to initiate the reaction, and a slow-motion video of the explosion...cool!
12. Another way to show how energy interacts with matter, you could do an activity to determine the energy needed to produce the photoelectric effect in various metals (called the "work function of the metal". Here, from the Canadian Space Agency, is an activity and question and data sheets to accomplish that task, geared to 11th graders in the Canadian school

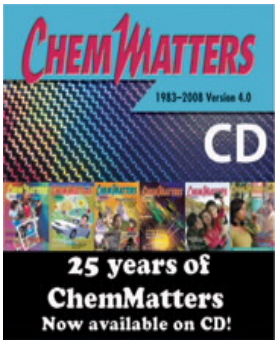
system: http://www.asc-csa.gc.ca/eng/educators/resources/evarm/grade11/electromagnetic.asp. The site also contains extensive background information for the student about radiation.

13. You can use a cloud chamber to show students how radiation interacts with matter. Here is a "do-it-yourself" experiment to make a cloud chamber from an aquarium: http://www.thenakedscientists.com/HTML/content/kitchenscience/garage-science/exp/cloud-chamber/. The page also shows a brief video clip of particle tracks in the author's aquarium cloud chamber. And this Web site shows a collection of actual photos of particle tracks in a cloud chamber: http://www.practicalphysics.org/go/Experiment_584.html;jsessionid=albbHPt2TGV9?topic_id=$parameters.topic_id&collection_id=%24parameters.collection_id. A video from "Frostbite Theatre" from Jefferson Labs shows students how to make their own cloud chamber. (http://education.jlab.org/frost/cloud_chamber.html) You might want to show students just the last half of the video, where the ion tracks are shown and their source is discussed.

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

1. Students can research about and report on the various types of airport security scanners and compare and contrast them, focusing on their method of operation, features, cost, efficiency, safety, privacy, etc.
2. Students can learn more about the visible spectrum and various light sources through a Web page discussion involving the use of a simple spectroscope (ostensibly supplied by the teacher). The discussion is followed by an assignment for the student to take the spectroscope home and experiment with various light sources there to discover more about light. (http://www.chemistryland.com/CHM107Lab/Exp7/Spectroscope/Spectroscope.html)
3. Students concerned with the safety of the various scanning technologies used in airports might want to do online research to determine for themselves how safe these devices really are.
4. Students might want to research and file a brief report on the differences between ionizing and non-ionizing radiation, why these differences exist, and their effects on living organisms.

References (non-Web-based information sources)



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. (Part way down the Web site screen, click on the *ChemMatters* CD icon like the one shown here at the right.)

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 *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Some of the more recent articles (2002 forward) referenced below may also be available online at the URL listed above. Simply click on the "Past Issues and Teacher's Guides" button at the right. If the article is available online, that will be noted.

Goldfarb, B. The Canine Cocaine Caper. *ChemMatters* **1993**, *11* (3), pp 14–15. Cocaine smugglers actually dissolve and mold cocaine right into the plastic used to make dog carriers. US Customs drug-sniffing dogs are unable to detect the scent.

Rohrig, B. Radioactivity—It's a Natural. *ChemMatters* **2000**, *18* (2), pp 6–9. The author discusses the sources of "natural" radioactivity in our daily lives, and on the last page of the article he offers students a chance to estimate their own personal radiation dose.

More information about natural radiation can be found in the Teacher's Guide for the April 2000 issue of *ChemMatters*.

Morton, R. Drug Detection at the Olympics—A Team Effort. *ChemMatters* **2000**, *18* (4), pp 7–9. The article discusses the gas chromatography and the mass spectrophotometer as methods of analysis of drug use by Olympic athletes.

Senkowsky, S. Biosensors: Early Warnings of Unseen Enemies. *ChemMatters* **2002**, *20* (4), pp 7–8. This article discusses the use of biosensors as detection devices for various biological agents, and the possibility of their use in airports as walk-through sensors.

The February, 2003 *ChemMatters* Teacher's Guide section on the "Explosive History of Nitrogen" contains much material on explosives.

The April, 2007 *ChemMatters* Teacher's Guide section on "The Death of Alexander Litvinenko" contains a lot of background information about radiation, how it's measured and its biological effects.

Vos, S. Sniffing Landmines. *ChemMatters* **2008**, *26* (2), pp 7–9. The author discusses the role of canines in detecting landmines, based on volatile TNT, or rather, DNT. She also discusses scientists' attempts to create a detector that will work better than a dog's nose.

Jacoby, M. Keepers of the Gate. *Chemical and Engineering News*, **2009**, *87* (22), pp. 10–13. In this article, the author discusses the state of TSA's security measures in airports.

Web sites for Additional Information (Web-based information sources)

More sites on the history of airport security

For a somewhat light-hearted look at a timeline of airport security ("Airport Security? More Like TSA Gone Wild!"), visit http://gizmodo.com/5696276/the-history-of-airport-security-visualized.

For a rather detailed timeline on the history of airports worldwide, see *Airports International*'s June/July 2003 article, "35 Years of Airports International" at http://www.nesdb.go.th/specialWork/suvarnabhumi/ceo_talk/35%20Years%20of%20Airports%20International.pdf.

In 2006 the *Heritage Foundation*, a Republican think tank, published an 8-page report entitled, "Time to Rethink Airport Security". The article critiques the present TSA structure and suggests alternatives that could provide more security at lower cost. You can access the article at http://www.heritage.org/research/reports/2006/07/time-to-rethink-airport-security. It can be read online or downloaded as a pdf file.

More sites on airport security

TSA's Web site provides information for the traveler about its efforts to ensure passenger safety: http://www.tsa.gov/approach/tech2/index.shtm.

Airsafe.com has a nice Web site that covers all aspects of airline safety, for the lay person. View it at http://www.airsafe.com/.

Millimeter wave technology and X-ray backscatter detection systems are described briefly in a 4-minute TSA video. The description is directed at the lay person in preparation for using these systems at the airport. (http://en.wikipedia.org/wiki/File:TSA-_How_It_Works.ogv)

Metatube presents a very short (29-second) video clip that shows an animation that describes X-ray backscattering and millimeter wave detection devices: http://www.metatube.com/es/videos/42720/How-TSA-Scanners-work/. (The unavoidable video advertisement that precedes the clip is as long as the clip itself.)

For an article from *Time* magazine that describes the conditions of airport security just two weeks after 9/11, visit http://www.airsafe.com/frames/apt_sec.htm.

This site general description of "How Airport Security Works", from the How Stuff Works Web site, was referenced in the article: http://science.howstuffworks.com/transport/flight/modern/airport-security.htm.

More sites on sources of radiation

The National Earth Science Teachers Association has a nice Web site dealing with the Sun, part of which deals with how the Sun radiates its energy, via the proton-proton chain mechanism of fusion. You can view the site at http://www.windows2universe.org/sun/Solar_interior/solar_furnace.html.

The US Nuclear Regulatory Commission's Web site contains a 12-page article on "Natural and Man-Made Radiation Sources'. It contains several graphs to show the sources. The last two pages are a "Compute Your Own Radiation Dose" (paper & pencil) worksheet. (http://www.nrc.gov/reading-rm/basic-ref/teachers/06.pdf)

Students worried about their exposure to radiation might be interested in a Web page from the EPA that provides an online "Calculate Your Radiation Dose" at http://www.epa.gov/radiation/understand/calculate.html.

TSA's Web site has a page, http://www.tsa.gov/approach/tech/ait/safety.shtm, on which they cite the safety of their advanced imaging technology, both millimeter wave and x-ray backscatter (which they call, simply, backscatter). They provide URLs for several other sources that agree with their findings.

NOVA has a very simplistic “interactive” diagram that lists some of the natural radiation sources around us (within the context of their video on a dirty bomb). The Web page also contains a very short background essay and five student review questions. View it at http://www.teachersdomain.org/resource/phy03.sci.phys.energy.radsource/.

The NRC Web site contains a page on the biological effects of radiation, for students worried about radiation exposure: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html.

More sites on the electromagnetic spectrum

You can view animations of the interaction of electrical and magnetic waves in light waves at the following sites:
http://www.youtube.com/watch?v=oZZ4wKYtVl8&NR=1&feature=endscreen
http://www.youtube.com/watch?v=Qju7QnbrOhM&feature=related
http://www.youtube.com/watch?v=Fxr3xTlFi-o&feature=related

An interesting discussion of visible light as only a small part of the entire electromagnetic spectrum, written for high school students, can be found at http://www.chemistryland.com/CHM107Lab/Exp7/Spectroscope/Spectroscope.html.

A few diagrams of the entire electromagnetic spectrum can be found here: http://ngst.gsfc.nasa.gov/exhibit/emspectrum.html) and here http://www.windows2universe.org/physical_science/magnetism/images/em_spectrum_berkeley.jpg). The first site shows waves related to NASA space probes, sizes of waves as related to sizes of real objects, and also types of waves related to temperature.

The Department of Defense Web site includes a page showing the EMS and the various wavelengths used in the broadcast industry, from Extra Low Frequencies (ELF) all the way to Super High Frequencies (SHF), along with some of the military uses for these ranges. (http://www.ee.bgu.ac.il/~waveprop/Handouts/EM_Spectrum.jpg)

Another, more complete chart from the US Department of Commerce, National Telecommunications and Information Administration, diagrams all the available frequencies of the EMS: http://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf. Note that this chart is from 2003, before the television broadcast frequencies were changed.

A YouTube video shows by analogy with a reel of movie film just how small the video spectrum portion of the entire EMS really is (1 frame [1 inch] on the film in >2000 miles of film). (http://www.youtube.com/watch?v=kfS5Qn0wn2o)

NASA’s “Imagine the Universe!” Web site has a page on the EMS: http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html.

More sites on PI (pulse induction)

The *How Stuff Works* Web site has more background on metal detectors, including VLF and BFO, as well as PI devices, on this page: http://www.howstuffworks.com/gadgets/other-gadgets/metal-detector.htm.

More sites on MRI (magnetic resonance imaging)

To see a video on how an MRI works, visit the Mayo Clinic's Web page at http://www.mayoclinic.com/health/mri/MM00395. The video is directed at the prospective MRI patient, so it shows what you can expect for your MRI, but it also shows how the MRI device works.

How Stuff Works has a 6-page section on the MRI at http://www.howstuffworks.com/mri.htm. This page may take awhile to load, as there is a video attached that begins as soon as the page appears. The video shows various real objects cut in cross-sections, analogous to the images taken and sequenced by an MRI.
The video by itself can be viewed at http://videos.howstuffworks.com/discovery/45162-the-ge-show-presents-analog-slices-video.htm#mkcpgn=snag1 or at http://www.ge.com/thegeshow/visions-of-health/?utm_source=Discovery%26utm_medium=Banner%26utm_campaign=Visions-of-Health.

For a primer on nuclear magnetic resonance (NMR), the process upon which MRI is built, see this page from the Hebrew University: http://chem.ch.huji.ac.il/nmr/whatisnmr/whatisnmr.html, and for a bit more detailed account, see this page from Michigan State University: http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/Spectrpy/nmr/nmr1.htm. Wikipedia also provides fairly detailed description of NMR at http://en.wikipedia.org/wiki/Nuclear_Magnetic_Resonance.

For a really detailed, college-level coverage of the "Basics of NMR", visit this site from the Rochester Institute of Technology's Dr. Hornak: http://www.cis.rit.edu/htbooks/nmr/.

More sites on IMS (ion-mobility spectrometry)

For more, basic information on IMS, visit Wikipedia's site: http://en.wikipedia.org/wiki/Ion_mobility_spectrometry.

For a more detailed description of IMS and its uses (2008), see http://www.sensorsmag.com/networking-communications/government-military/on-site-trace-chemical-detection-part-1-understanding-ion-mo-3950. This page contains a few simple diagrams of the IMS internal workings.

For more information on the development of IMS, see http://www.chemistry.nmsu.edu/~research/ion_mobility/moreims.html.

A report on research to determine how choice of buffer gas can affect selectivity of ions in ion mobility spectrometry can be found at http://www.wsu.edu/~hillh/Hill%20scan%20papers%20pdfs/2002%20JASMS%20Matz%20Investigation%20of%20Drift%20Gas%20Selectivity.pdf.

Another application of IMS is real-time detection of underground pollutants. This site, http://ces.boisestate.edu/imssensordevelopment.htm, describes the use of IMS to test groundwater.

More sites on X-ray backscatter imaging

Wikipedia's Web site contains a page dealing with X-ray backscatter imaging. View it at http://en.wikipedia.org/wiki/Backscatter_X-ray.

The FDA has set limits on exposure to radiation in backscatter devices. You can read their report at http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/SecuritySystems/ucm227201.htm.

Go to another page on *Wikipedia*'s Web site to view scientists' debate about the safety of backscatter scans: http://en.wikipedia.org/wiki/Backscatter_X-ray#cite_note-41.

More sites on plastic explosives

Did you ever wonder how safety officers could be trained in detecting the various types of explosives, without endangering their lives in the process? Visit http://www.aiexplosives.com/inspections_articles.asp?id=21 for information on the use of simulated explosives for training of security agents in the detection of plastic explosives.

More sites on mass spectroscopy

A tutorial to help one learn about mass spectrometry is available from the American Society for Mass Spectrometry: http://www.asms.org/whatisms/index.html.

Teacher tools for mass spectrometry contains several tools: a complete list of all isotopes of all elements, an interactive periodic table that shows all isotopes of each element, and a simulated spectrogram ("mass spec plotter") of any compound you input: http://www.sisweb.com/mstools.htm.

The ChemGuide Web site has a useful page on the mass spectrometer at http://www.chemguide.co.uk/analysis/masspec/howitworks.html.

The American Society for Mass Spectrometry provides a short slide show to explain how mass spectrometry works at http://www.asms.org/Education/ExplainingMassbrSpectrometry/tabid/304/Default.aspx. You might want to start with the slide labeled "Concept 1".

Unwrapping the Mystery of Mummies

Background Information (teacher information)

More on mummification

The Washam article states that Egyptians mummified an estimated 70 million bodies, with the treatment of a body taking approximately 70 days. A beginning question might be why Egyptians went to such lengths to preserve their dead. Reasoning behind this is described in the October 1999 *ChemMatters* Teacher's Guide: "Ancient Egyptians believed in an afterlife. They believed that after death, a person split into three parts—the body, the ba (personality) and the ka (spirit). In order to go into the afterlife, it was necessary to have a body. If the body decayed, then there would be no afterlife. Thus the process of mummification was developed." (p 8)

There are no definitive records of how the Egyptians carried out the process of mummification. An interesting modern-day foray into learning more about the process involved a pair of researchers mummifying a body in 1994. Ronn Wade, director of the Maryland State Anatomy Board and director of the Anatomical Service Division of the University of Maryland collaborated on the project with Bob Brier, a professor of philosophy and Egyptology at the C.W. Post campus of Long Island University in New York (http://discovermagazine.com/2000/mar/featmaking). A past *ChemMatters* article (Touchette, N. Mumab: The Making of a Modern Mummy. *ChemMatters* **1996**, *14* (1), pp 4–7) describes their project in detail, interspersing comments about their modern-day mummification with a description of what the Egyptian mummification of Tuthmosis III may have been like. Information from that article includes:

> In an attempt to unravel some of the mysteries of mummies, Wade and Brier conducted a reasonable, yet rather macabre experiment—they created a mummy of their own using ancient Egyptian methods. Before embarking on their embalming mission, Brier and Wade commissioned a silversmith to make replicas of Egyptian embalming tools, enlisted a master woodworker to construct an authentic Egyptian embalming table, visited Cairo street markets to collect special spices and oils, and ventured to the river Nile to gather natron, a mixture of chemical salts that for thousands of years has been deposited along the riverbed. The final requirement—a suitable body—was filled by Mr. M. who had directed that his body be donated to science. (p 4)

The possible process for the mummification of Tuthmosis III in approximately 1450 B.C. is described:

> …it is likely that the body of Tuthmosis was brought to the ibu—the "tent of purification"—to begin the 70-day process. There, it was washed with a solution of water and natron. Next, his brain was removed through the nostrils. The Egyptians considered the brain to be of no special significance with little use in the afterlife. According to Herodotus' account, the brain was extracted by poking a hole in the ethmoid bone, a thin bone at the top of the nostrils. The Egyptian embalmers used large bronze needles with hooked or spiral ends to perform this procedure;

> however, it was not clear how they managed to remove such a large organ through such a small opening. … the Egyptian embalmers removed all of his internal organs through a small incision on the left side of his abdomen. Only his heart, which was considered to be a person's essence, was left untouched. … the Egyptian embalmers washed the interior of Tuthmosis' body with the spices frankincense and myrrh and palm wine. The liver, spleen, intestines, and kidneys were then covered with white crystals of natron. After being preserved individually, each organ was stored in a special canister called a canopic jar. The lids of canopic jars were shaped like the heads of Egyptian gods—the four sons of Horus—who are the guardians of the entrails. After mummification of the body, the canopic jars with dried viscera were placed with the mummy at burial. … Finally the Egyptian embalmers wrapped Tuthmosis' body in long strips of flaxen fabric. With elaborate ceremony, the body was carried to its final resting place. (pp 4–6)

Wade and Brier worked to match their modern conditions with those from ancient times: "Next they covered the entire body with 270 kilograms (600 pounds) of natron and placed it in a special room maintained at about 46 °C (115 °F) with less than 30 percent humidity—conditions designed to mimic those at which mummification was carried out in ancient Egypt. … After spending 35 days buried in natron, Mr. M. lost 100 pounds of water, out of his original body weight of 160 pounds. … The entire wrapping process took several days and required more than 6 layers and 9 kilograms (20 pounds) of linen." (pp 5–6)

A major part of mummification was the treatment of corpses with natron. A more in-depth description of natron and reasons for its use were part of a past *ChemMatters* article (McKone, H. T. Embalming—Chemistry for Eternity. *ChemMatters* **1999**, *17* (3), pp 12–13).

> The mixture of salts that make up natron comes from some naturally occurring river chemistry. Riverbed erosion contributed a variety of dissolved minerals to the flowing Nile River. During the hot summer months, the receding waters left large salt deposits in flats along the banks. The ancient Egyptian embalmers gathered these salts to make their effective dehydrating agent.
>
> For these ancient embalmers, removing water from tissues was a critical step. Without water in the tissues, bacteria and fungi—organisms of decay—were unable to thrive. Tissues that would have broken down rapidly in that equatorial climate were effectively preserved by the dehydrating action of natron. (p 12)

The chemistry involved in the geological formation of natron is summarized in a past *ChemMatters* article (Touchette, N. Mumab: The Making of a Modern Mummy. *ChemMatters* **1996**, *14* (1), pp 4–7):

> $CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$
> $CaCO_3 + H_2O + CO_2 + 2NaCl \rightarrow 2NaHCO_3 + CaCl_2$
> $2NaHCO_3 + Heat \rightarrow Na_2CO_3 + H_2O + CO_2$
>
> Limestone (calcium carbonate, $CaCO_3$), in the presence of heat and humidity, reacts with salt (sodium chloride) to produce sodium carbonate (Na_2CO_3). Limestone can also react with salt in the presence of carbon dioxide and water to produce sodium bicarbonate ($NaHCO_3$). As the waters evaporate, natron, containing carbonate and bicarbonate, is deposited. The leftover calcium chloride dissolves in water and

> percolates into the ground. The essential ingredients of natron are sodium carbonate and sodium bicarbonate; sodium chloride and sodium sulfate are impurities. (p 7)

The article also describes action of the natron as a dehydrating agent:

> Solid salts normally contain positive and negative ions in a highly structured crystalline form. When exposed to water vapor, the charged ions can attract and interact with the polar water molecules. Some salts incorporate H_2O molecules into the crystalline structure, forming solid "hydrates." In natron, sodium carbonate, Na_2CO_3, can change in this way to the water-containing hydrate $Na_2CO_3 \cdot H_2O$, as well as $Na_2CO_3 \cdot 7H_2O$ and others. Even though they contain considerable water, these hydrates remain solid and dry to the touch. In contrast, when water vapor interacts with sodium chloride, NaCl, the solid salt dissolves to form a liquid solution. The resulting sodium ions, Na^+, and chloride ions, Cl^-, become "hydrated"—the positive hydrogen end of the water molecule is attracted to negative chloride ions, and the negative oxygen atom is attracted to positive sodium ions.
>
> Some researchers believe that the sodium bicarbonate is especially effective in suppressing bacteria. When dissolved, the bicarbonate increases the pH, making it more difficult for bacteria to grow. In addition, sodium bicarbonate may help liquefy, or emulsify, the fats of the body, which are later removed during the cleansing process. (pp 6–7)

The terms embalming and mummification tend to be used somewhat interchangeably. The difference between the two is described in the "Anticipating Student Questions" section below. Outside of Egypt, techniques had been developed to preserve bodies, although not necessarily to the elaborate extent of the Egyptian methods. Some of the techniques are described in the *ChemMatters* article "Embalming—Chemistry for Eternity".

> The advent of Christianity brought gradual changes in burial customs to the Greco–Roman world. Christians, emphasizing the spiritual aspect of death and resurrection, had little interest in the preservation of the body. However, in the 15th century, there was renewed interest in body preservation, partly the result of a desire to learn more about human anatomy by dissecting human remains. … William Hunter, an 18th century Scottish anatomist, published a method of embalming using a mixture of turpentine and camphor. John Hunter, using his brother's methods, embalmed the body of the wife of Martin van Butchel, a famous London citizen. Mr. van Butchel proudly kept the embalmed body of his wife on display, dressed in fine clothes, in a glass case in his sitting room.
>
> By the early 19th century, as it became customary to view the body during the mourning period before burial, Americans looked for improved methods to preserve the remains. By 1850, several patents had been issued for embalming fluid formulations. These formulations often contained salts of toxic metals such as arsenic, antimony, lead, mercury, and copper to inhibit bacterial growth. Laws prohibiting the use of these toxic metals in embalming began to appear in the early 20th century. Formaldehyde soon became the compound of choice. Formaldehyde, chosen for low cost, availability, and simplicity of use, remains the most common preservative in embalming fluids. … There are several health

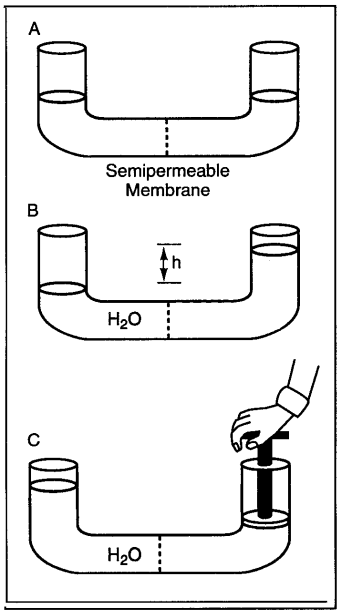
> concerns associated with formaldehyde. Besides being a known carcinogen, it is found to cause occupational asthma and contact dermatitis. Consequently, researchers continue to seek a formaldehyde replacement. (p 13)

As stated above, laws prohibiting the use of certain chemicals for embalming were introduced. The selection of chemicals used can have an effect long after the embalming is finished (December 2005 *ChemMatters* Teacher's Guide):

> Prior to the Civil War, most bodies were simply buried, without the benefit of embalming. But the preponderance of bodies from the Civil War, and the desire of relatives to have the bodies returned "home" to be buried, resulted in the rapid growth of the embalming industry. Bodies were embalmed using arsenic compounds that kept the bodies supple and the skin an acceptable white color. After the end of the war, between 1880 and 1910, the embalming business flourished. After 1910, embalmers turned to formaldehyde as their preservative agent, but prior to that, arsenic was the embalming chemical of choice. Those embalmed bodies were buried in wood or metal coffins. Over the years, both types of coffin deteriorate, and soon, as the arsenic used in the embalming of all those bodies leaches out of the deteriorated coffins into the groundwater, we may experience our newest ecological disaster. (p 54)

More on osmosis

As the Washam article states, osmosis occurs when two solutions of different concentrations are on either side of a semipermeable membrane. Water molecules move to the solution with the greater concentration until both sides have the same concentration. "The tendency for osmotic flow to occur from a solvent to a solution is usually measured in terms of what is called the osmotic pressure of the solution. The osmotic pressure is not a pressure which the solution itself exerts but is rather the pressure which must be applied to the solution (but not the solvent) from outside in order to just prevent osmosis from occurring" (http://chemed.chem.wisc.edu/chempaths/GenChem-Textbook/Osmotic-Pressure-854.html). A common diagram shows the levels of different solutions if they are placed in a U-shaped tube divided by a semipermeable membrane. For example, a past article in *ChemMatters* (Alper, J. Survival at Sea. *ChemMatters* **1992**, *10* (3), pp 4–7) has the diagram and caption below, which also includes an example of reverse osmosis, where with enough pressure the water molecules can be pushed from the side with the higher concentration to the other side to produce pure water.



"When water is added to a U-shaped tube that is divided by a semipermeable membrane (A), the water can pass freely through the membrane, and the height of the water on the left side equals that on the right. If a chemical that cannot pass through the membrane, such as sodium chloride, is added to the right side, the water will flow from left to right. The difference in heights, h, is an indication of the osmotic pressure. A pump can be used to apply external pressure to the right side (C). If the pressure is great enough and the membrane is strong enough, the osmotic flow of water can be reversed, producing pure water on the left from salt water on the right. The pressure required to purify seawater is much greater than a person can produce with a single pump like the one shown." (p 5)

The terms isotonic, hypertonic, and hypotonic are often heard in relation to osmosis. They refer to relative strengths of solutions that are placed on the two sides of the semipermeable membrane. If two solutions are isotonic, the solute concentrations are the same on both sides and no net flow of water will occur. If two solutions of differing concentrations are placed on the two sides, the solution with a lower solute concentration would be hypotonic, while the solution with the higher solute concentration would be hypertonic. If an object such as a red blood cell were placed in a hypotonic solution, a net flow of water would occur into the red blood cell, possibly causing it to burst. If it were placed in a hypertonic solution, a net flow of water could occur out of the red blood cell, causing the cell to shrink. Students can make similar observations in the "Osmosis in an Egg" experiment described in the "In-Class Activities" section below.

Removal of water from a body that is to be mummified serves to help preserve the tissue for long periods of time. This can be compared to the reason that dehydration of foods such as meat and fruit helps to preserve them. The key is moisture content, as described at http://pubs.ext.vt.edu/348/348-597/348-597.html: "Foods can be spoiled by food microorganisms or through enzymatic reactions within the food. Bacteria, yeast, and molds must have a sufficient amount of moisture around them to grow and cause spoilage. Reducing the moisture content of food prevents the growth of these spoilage-causing microorganisms and slows down enzymatic reactions that take place within food. The combination of these events helps to prevent spoilage in dried food."

More on computed tomography

Computed tomography is a type of x-ray imaging that goes beyond the usual two-dimensional image that can be obtained through ordinary x-rays, such as when a doctor x-rays a bone to identify whether there is a break, or to view the chest cavity. X-rays are passed through the portion of the body to be studied, with different tissues absorbing different amounts of the x-rays, leaving various amounts of x-rays that exit the other side of the body to be captured by a detector. The x-ray images formed are a sort of "stack" of everything that the x-rays passed through. For example, in a chest x-ray image, one can see the ribs, the spine, and other portions in between the two, all layered in one image.

The difference between ordinary x-ray imaging and computed tomography is briefly described at the U.S. Food and Drug Administration website (http://www.fda.gov/Radiation-

EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm115318.htm):

> Although also based on the variable absorption of x rays by different tissues, computed tomography (CT) imaging, also known as "CAT scanning" (Computerized Axial Tomography), provides a different form of imaging known as cross-sectional imaging. The origin of the word "tomography" is from the Greek word "tomos" meaning "slice" or "section" and "graphe" meaning "drawing." A CT imaging system produces cross-sectional images or "slices" of anatomy, like the slices in a loaf of bread. The cross-sectional images are used for a variety of diagnostic and therapeutic purposes.

The site also provides a description of how a CT system works (http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/MedicalImaging/MedicalX-Rays/ucm115317.htm):

> 1. A motorized table moves the patient through a circular opening in the CT imaging system.
> 2. While the patient is inside the opening of the CT imaging system, an x-ray source and detector within the housing rotate around the patient. A single rotation takes about 1 second. The x-ray source produces a narrow, fan-shaped beam of x-rays that passes through a section of the patient's body.
> 3. A detector opposite from the x-ray source records the x-rays passing through the patient's body as a "snapshot" image. Many different "snapshots" (at many angles through the patient) are collected during one complete rotation.
> 4. For each rotation of the x-ray source and detector, the image data are sent to a computer to reconstruct all of the individual "snapshots" into one or multiple cross-sectional images (slices) of the internal organs and tissues.

Computed tomography was invented in the early 1970's by both British engineer Godfrey Newbold Hounsfield of EMI Ltd. and South African-born physicist Allan Cormack of Tufts University, Massachusetts. The two shared a joint Nobel Prize in Physiology or Medicine in 1979 for their invention. The use of CT scanners has become widespread over the past several decades, with improvements in speed and scanning resolution made over time.

> The first clinical CT scanners were installed between 1974 and 1976. The original systems were dedicated to head imaging only, but "whole body" systems with larger patient openings became available in 1976. CT became widely available by about 1980.
>
> The first CT scanner developed by Hounsfield in his lab at EMI took several hours to acquire the raw data for a single scan or "slice" and took days to reconstruct a single image from this raw data. The latest multi-slice CT systems can collect up to 4 slices of data in about 350 ms and reconstruct a 512 x 512-matrix image from millions of data points in less than a second. An entire chest (forty 8 mm slices) can be scanned in five to ten seconds using the most advanced multi-slice CT system. (http://www.imaginis.com/ct-scan/brief-history-of-ct)

More on radiocarbon dating

The Washam article discusses the use of radiocarbon dating to determine the age of the board, bone, and cloth of the mummy. Radiocarbon dating is often used to help date archaeological discoveries. The method was developed by American chemist Willard F. Libby in the 1940's; he subsequently won the 1960 Nobel Prize in Chemistry for his work. The April 2001 *ChemMatters* Teacher's Guide includes a discussion of radiocarbon dating:

> One of the most basic questions surrounding any archaeological discovery is its age. Although ages can be approximated from the nature of the materials found at a site (tools, materials, types of pottery, clothing, etc.), one of the most common analytical techniques involves radiocarbon dating, a technique developed by W. F. Libby.
>
> Radiocarbon dating is used to estimate the age of any object that originally was a living plant or animal. It is based upon the decay of ^{14}C, a radioactive isotope of carbon.
>
> ^{14}C is continually being produced in our atmosphere. Very high-energy cosmic rays cause high-energy nuclear reactions. Some of these reactions produce neutrons, which in turn react with ^{14}N in the atmosphere to produce ^{14}C.
>
> $$^{1}_{0}n + {}^{14}_{7}N \rightarrow {}^{1}_{1}H + {}^{14}_{6}C$$
>
> ^{14}C is radioactive, with a half-life of approximately 5700 years. We assume that ^{14}C has been produced in our atmosphere at a relatively constant rate for the past several thousand years. A relatively recent development shows that there are small variations in the ^{14}C content of living things over time. Modern archeologists compensate by calibrating radiocarbon dating with other methods to account for these variations.
>
> Since ^{14}C decays at a nearly constant rate, we believe that it has reached a steady-state concentration in our environment. A good analogy would be to pour water at a constant rate into a bucket that has a moderately small hole in the bottom. As the water gets deeper, the pressure on the bottom increases, so the water flows out the bottom of the bucket at an increasing rate. When this rate becomes equal to the rate at which water is being added, the level of water in the bucket stays the same.
>
> Plants ingest carbon dioxide from the atmosphere during photosynthesis. Animals consume plants and other animals. The ratio of ^{14}C to the total amount of carbon in any living thing becomes equal to the ratio found in the atmosphere. The amount of ^{14}C present is sufficient to produce a radioactivity equal to 15.3 disintegrations per second per total gram of carbon.
>
> But when a living organism dies, it no longer ingests carbon in any form. As the ^{14}C disintegrates, the amount of radioactivity found in each gram of carbon decreases. For example, when the decay rate reaches one-half of 15.3 disintegrations/s, this indicates that the sample is approximately 5700 years old, the half-life of ^{14}C.
>
> The burning of fossil fuels has increased the amount of ^{12}C in the atmosphere in the last hundred years or so. This may complicate the

application of ^{14}C dating in the future. (p 9)

More on electron microscopy

Students have probably used a light microscope at some time during their studies; a comparison of a light microscope to an electron microscope can be a good starting point, as some of the basic ideas between the two types of microscopes parallel each other. The "Explain That Stuff" website (http://www.explainthatstuff.com/electronmicroscopes.html) outlines four essential parts when one uses a microscope to view a magnified image of a specimen:

1. The source of light.
2. The specimen.
3. The lenses that make the specimen seem bigger.
4. The magnified image of the specimen that you see.

In an electron microscope, these four things are slightly different.

1. The light source is replaced by a beam of very fast moving electrons.
2. The specimen usually has to be specially prepared and held inside a vacuum chamber from which the air has been pumped out (because electrons do not travel very far in air).
3. The lenses are replaced by a series of coil-shaped electromagnets through which the electron beam travels. In an ordinary microscope, the glass lenses bend (or refract) the light beams passing through them to produce magnification. In an electron microscope, the coils bend the electron beams the same way.
4. The image is formed as a photograph (called an electron micrograph) or as an image on a TV screen.

There are different types of electron microscopes such as transmission electron microscopes (TEMs), scanning electron microscopes (SEMs), and scanning tunneling microscopes (STMs), although the basic elements are generally the same.

"Electron Microscopes were developed due to the limitations of Light Microscopes which are limited by the physics of light to 500x or 1000x magnification and a resolution of 0.2 micrometers. In the early 1930's this theoretical limit had been reached and there was a scientific desire to see the fine details of the interior structures of organic cells (nucleus, mitochondria...etc.). This required 10,000x plus magnification, which was just not possible using Light Microscopes." (http://www.unl.edu/CMRAcfem/em.htm) Increased magnification using electron microscopes resulted in the detailed view of the mummy wrapping fibers described in the Washam article.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Environmental chemistry—**The chemicals chosen for use in embalming and their potential effect on the environment, particularly in connection with modern-day methods, can be discussed.
2. **Hydrates—**The description of natron and its component chemicals can be used as an example of hydrates and their ability to incorporate water from outside sources.

3. **Osmosis—**Osmosis is connected to the use of natron to remove water from body tissues during the process of mummification. It could also be linked to a discussion of osmolarity and osmotic pressure.
4. **Isotopes and nuclear chemistry—**The article's section on radiocarbon dating includes information about three different isotopes of carbon, what makes isotopes different from one another, and that ^{14}C undergoes radioactive decay.
5. **Electromagnetic radiation—**The use of x-rays in computed tomography (CT) scans during the study of mummies can be shared as one example of electromagnetic radiation, with a discussion of its associated energy and wavelength and why it is useful in this particular application.
6. **Chemical instrumentation—**The Washam article mentions several high-tech tools used to study mummies, including computed tomography, electron microscopy, and radiocarbon dating.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"It is impossible to study a mummy without unwrapping it."** *Many high-tech tools such as computed tomography, radiocarbon dating, and the use of electron microscopes can be performed without disturbing the mummy or by using very small samples of it, and can reveal a substantial amount of information.*

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

1. **"Are the mummies destroyed when scientists study them?"** *Scientists today have many high-tech tools at their disposal that allow them to study mummies without destroying them, or only using very small samples from the mummy. Previously, mummies could not be effectively studied without unwrapping them; exposure to the air then tended to cause them to disintegrate. In the 19th century, many mummies were destroyed through their use as entertainment for aristocrats, who would purchase mummies, have them unwrapped, and then hold observation sessions (http://www.crystalinks.com/mummy.html).*
2. **"Is mummification different from embalming?"** *The term* embalming *refers to any attempt to keep a dead body from decaying.* Mummification *is basically a subset of embalming techniques and refers to the process by which a body is preserved by being dried out to the point where decay, which requires water, cannot take place." (October 1999* ChemMatters *Teacher's Guide, p 8)*
3. **"Does anyone have their bodies mummified today?"** *In 2011, a taxi driver who was terminally ill from lung cancer signed on to have his body mummified, with the procedure filmed for television (http://newslite.tv/2011/10/18/taxi-driver-mummified-like-tut.html). A 1996* ChemMatters *article (see References section below) describes a modern-day mummification.*

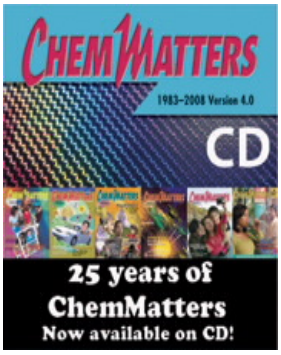
In-class Activities (lesson ideas, including labs & demonstrations)

1. Students can try their hand at mummification using fruit such as apple slices. An apple slice can be weighed, then covered with a mixture of baking soda and salt, which are ingredients in natron, with a second apple slice weighed and left out as a control. Both slices are weighed afterward. Many such experiments are on the web, including variations that use hot dogs and chicken: see http://www.unmuseum.org/exmum.htm, http://www.sciencebuddies.org/science-fair-projects/project_ideas/HumBio_p022.shtml, and http://www.camws.org/CJ/Chicken Mummification.pdf.
2. The February 1996 *ChemMatters* Teacher's Guide suggests demonstrating the general consistency of a mummy by bringing meat jerky to class, since jerky is made by removing moisture in order to preserve the meat. Instructors can either purchase pre-made jerky or make their own. Many recipes are available online, such as http://www.foodnetwork.com/recipes/alton-brown/beef-jerky-recipe/index.html and http://allrecipes.com/recipe/docs-best-beef-jerky/.
3. Sodium carbonate, one of the components of natron, can form various hydrates. A common chemistry laboratory asks students to determine the formula of a hydrate such as copper(II) sulfate pentahydrate, $CuSO_4 \cdot 5H_2O$, which appears blue when hydrated and has a light, whitish color when the water is driven off. Mass data is collected before and after heating the hydrate. One such laboratory online is http://dwb4.unl.edu/chemistry/labs/LABS06.html. The hydrate laboratory found at http://www.frontiernet.net/~jlkeefer/water_of_hydration.doc investigates several different compounds.
4. An experiment included in the *ChemMatters* October 1992 Teacher's Guide (p 3), "Osmosis in an Egg," can be used to demonstrate osmosis by causing water to diffuse in two directions through a selectively permeable membrane (the thin, inner membrane just under the shell of the egg). A raw egg is covered with vinegar and left for 24 hours; the shell dissolves, leaving the intact membrane underneath. The egg is then placed in a solution of 80 mL of colorless corn syrup such as Karo Light Syrup mixed with 200 mL of water for 24 hours. The egg takes on a shriveled appearance as water moves out of the egg to the highly concentrated syrup solution. Various websites also describe similar activities. An extensive example is found at http://www.adamequipment.com/education/Documents/EdExp2c.pdf; others are at http://www.exploratorium.edu/cooking/eggs/activity-nakedexperiment.html, http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/eggosm.html, and http://www.csun.edu/~klb27749/csun_coursework/695/longitudinal_study.htm.
5. Cylindrical samples taken from potatoes using cork borers can be used to investigate osmosis. The samples are placed in different solutions, such as various concentrations of NaCl, sucrose, and water. They are then measured for changes in mass and length. Two examples are http://www.starsandseas.com/SAS Cells/SAS cellphysiol/Osmosis.htm and http://dpbiologyiszl.wikispaces.com/file/view/Sample+Lab+Report-+Potato+Osmosis.pdf.

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

1. Students could investigate whether there are any mummy exhibits at nearby museums and arrange to visit and report back to class.
2. Students could visit a funeral home and learn about modern-day methods used to preserve bodies and report.
3. Students could tour a medical facility that performs computed tomography (CT) scans and report.

References (non-Web-based information sources)



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. (At the bottom of the Web site screen, click on the *ChemMatters* CD image like the one at the right.)

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 *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Some of the more recent articles (2002 forward) referenced below may also be available online at the URL listed above. Simply click on the "Past Issues and Teacher's Guides" button at the right. If the article is available online, that will be noted.

A past *ChemMatters* article focuses on embalming methods from both ancient and modern times. (McKone, H. T. Embalming—Chemistry for Eternity. *ChemMatters* **1999**, *17* (3), pp 12–13)

The October 1999 *ChemMatters* Teacher's Guide for the article "Embalming—Chemistry for Eternity" contains extensive information on mummification. (p 8)

A past *ChemMatters* article intersperses an account of making a mummy in 1994 with a description of likely ancient Egyptian mummification practices. (Touchette, N. Mumab: The Making of a Modern Mummy. *ChemMatters* **1996**, *14* (1), pp 4–7)

The *ChemMatters* article "Survival at Sea" includes a discussion of osmosis. (Alper, J. Survival at Sea. *ChemMatters* **1992**, *10* (3), pp 4–7)

Web sites for Additional Information (Web-based information sources)

More sites on mummification

An article from *Chemistry World* describes some of the chemicals used in mummification and their link to archaeological study. (http://www.rsc.org/images/Archaelogical Analysis - Mummy Mania_tcm18-197541.pdf)

The National Public Radio program "The Art of Mummy Making" has a short text description online with links to the radio clip and a mummy photo gallery. (http://www.npr.org/programs/morning/features/2001/oct/mummy/011025.mummy.html)

The *Discover Magazine* article "The Chemistry of…Mummies" describes some of the chemicals used to help preserve bodies. (http://discovermagazine.com/2002/mar/featchemistry)

The British Museum website has an online tour that was designed to accompany its exhibition "Mummy: The Inside Story". It describes the high-tech study of the mummy using text

and photographs. (http://www.britishmuseum.org/explore/online_tours/egypt/mummy_the_inside_story/mummy_the_inside_story.aspx)

The Spurlock Museum has a home page on Egyptian Mummification leading to information on history, rituals, artifacts, materials, and chronology. (http://www.spurlock.uiuc.edu/explorations/online/mummification/Pages/materials1.html)

More information on the study of a mummy owned by the Spurlock Museum at the University of Illinois is available at http://www.itarp.uiuc.edu/atam/research/mummy/index.html.

More sites on osmosis

An application of osmosis to deliver liquid drugs in the human body is described at http://www.rsc.org/chemistryworld/News/2011/November/03111102.asp.

The McGraw Hill website offers the animation "How Osmosis Works", which is accompanied by a voiceover with an explanation of the process. (http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__how_osmosis_works.html)

The process of reverse osmosis is explained at the HowStuffWorks website. (http://science.howstuffworks.com/reverse-osmosis.htm)

More sites on computed tomography

The Nobel Prize website describes the background of the 1979 Nobel Prize in Physiology or Medicine awarded to Allan M. Cormack and Godfrey N. Hounsfield for the development of computer assisted tomography. (http://www.nobelprize.org/nobel_prizes/medicine/laureates/1979/perspectives.html)

The results of the study of a child mummy are summarized at http://www.medicalmodeling.com/mummy/ChildMummy_ProjectOverview.pdf, with images showing computed tomography data and how it was used.

A mummy at the Smithsonian's National Museum of Natural History was studied using computed tomography (CT); the webpage shows the results of different scans, including a short video that stacks the thousands of layers from a CT scan using a computer program to visually "grow" the mummy. (http://www.mnh.si.edu/exhibits/eternal-life/mummy-science.cfm)

A YouTube video shows a mummy undergoing a CT scan and some of the results obtained. (http://www.youtube.com/watch?v=VTGrHPBEYZ4&feature=related).

The HowStuffWorks website contains the article "How CAT Scans Work". (http://science.howstuffworks.com/cat-scan.htm)

More sites on radiocarbon dating

A series of three short videos describes the science behind radiocarbon dating, along with its use in the laboratory, and potential margins of error. (http://www.pbs.org/wgbh/nova/tech/radiocarbon-dating.html; click "Launch Interactive")

W. F. Libby's 1960 Nobel lecture on radiocarbon dating is available at http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1960/libby-lecture.pdf.

The website http://www.101science.com/Carbon14.htm has a carbon 14 dating calculator along with links to other information on radiocarbon dating.

More sites on electron microscopy

The Nobel Prize website describes the history of Ernst Ruska and his work on the design of the first electron microscope, for which he shared the 1986 Nobel Prize in Physics. (http://www.nobelprize.org/nobel_prizes/physics/laureates/1986/perspectives.html)

The basics of electron microscopy, along with information on the workings of three specific types—transmission electron microscopes, scanning electron microscopes, and scanning tunneling microscopes—is available at http://www.explainthatstuff.com/electronmicroscopes.html.

Numerous websites show collections of images obtained through the use of electron microscopy; a few examples are:
http://www.fei.com/resources/image-gallery/list.aspx?prodtype=sem,
http://www.mos.org/sln/sem/sem.html, and
http://www.dac.neu.edu/biology/em/imagegallery.html.

The document "An Introduction to Electron Microscopy" is an in-depth and extensive "primer on electron and ion beam microscopy and is intended for students." (http://www.fei.com/uploadedFiles/Documents/Content/Introduction_to_EM_booklet_July_10.pdf)

More Web sites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

The learning guide found at http://www.fi.edu/mummies/guides/mow_edguide.pdf was designed to accompany the museum exhibition "Mummies of the World". However, it contains useful information and activities that could be used even without seeing the exhibit, including extensive background information and activities that encourage students to "Think Like a Mummyologist".