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Bad Hair Days? Chemistry to the Rescue

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Introduction

Results of the 2009 Program for International Assessment (PISA) released in December 2010 showed that students in the United States came in 17th in science among the 34 member countries of Organization for Economic Co-operation and Development (OECD). [1] There are several factors that could be identified to explain why our students are lagging behind. Maybe our science classes are designed to be too "academic" and far removed from everyday life so students simply lose interest and end up just memorizing the lesson. No conceptual understanding occurs. And because they memorize the lesson, they forget it as soon as the quiz or test is over.

At the same time, science classes that encourage memorization do not help students develop interest and a positive attitude towards science.

One way to elicit more interest in science, particularly chemistry, is by providing students with learning experiences that enable them to see how chemistry is ingrained in their everyday life and not the inert subject they think it is that they only encounter within the walls of a science classroom.

The majority of my chemistry students begin the school year with the notion that the course is just one of those academic and difficult subjects they have to take and pass if they plan to go to a four-year college. Thus, I make it a point to write lesson plans that show how chemistry is relevant to students' everyday life. I have noticed that the lessons that generate the most interest and active participation are those that can be linked to what teenagers value the most personally.

Young people are very particular about their physical appearance, especially their hair. This is probably the reason why then Senator Hilary Clinton began her Class Day address to the 2001 graduating class at Yale College with the following:

> ''The most important thing I have to say to you today is that hair matters. This is a life lesson my family did not teach me, Wellesley and Yale Law School failed to instill: Your hair will send significant messages to those around you. What hopes and dreams you have for the world, but more, what hopes and dreams you have for your hair. Pay attention to your hair, because everyone else will." [2]

Mrs. Clinton might as well have been talking to high school students because just like college students, they, too, pay a LOT of attention to their hair. Many use their hair to establish and project their identity. It is one part of their body that can readily be changed to reflect their mood, feelings or even their personality. They can have it permed, straightened, braided, colored, etc. And on a day, they wake up to realize their hair "decides" to be stubborn and refuses to look the way it should, a "bad hair day" promptly begins and despair sets in!

This is where chemistry can come in handy to teenagers having a "bad hair day." Whether one has straight, curly, black, blonde or grey hair can be explained by chemistry. Chemistry can also explain why hair is easy to manage one day and becomes unruly the following day.

Various hair products and treatments that students use to transform hair texture and appearance from dull to shiny, curly to straight or brown to green are based on basic chemistry concepts.

In other words, whether one will have a good or bad hair day all depends on chemistry!

This unit will be implemented in my college prep chemistry classes composed mostly of sophomores and a sprinkling of juniors and seniors. All of them have completed college prep biology, algebra 1 and geometry. A few of the juniors and seniors may be taking physics concurrently. The majority are in the class because they are considering going to a 4-year college.

The unit will be carried out after state standardized testing in late April or early May. By this time, students have gained a basic understanding of atomic structure, chemical bonds, intermolecular forces, types of chemical reactions including redox, shapes and polarity of molecules, acids and bases and polymers – concepts needed to make sense of the unit.

The unit is divided into three parts. Part 1 focuses on the structure of proteins. Part II deals with the relationship between the physical structure and chemical composition of hair and hair properties, shape and color. Part III covers the chemistry behind perming, straightening and coloring.

Instructional Objectives

The unit is an opportunity for students to further experience the nature of science that I emphasize throughout the course. Students will engage in activities where they will evaluate arguments based on scientific evidence, communicate ideas about chemistry, see the application of chemistry in business and industry and describe the relationship between science, technology and society. [3]

This unit will also help them acquire and develop specific science process and inquiry skills which include observing, measuring, classifying, inferring, predicting, communicating, making models, collecting and interpreting data, hypothesizing and experimenting. [4]

Finally, the unit will address content specific objectives listed below:

1. describe amino acids as the building blocks of protein.

2. discuss the various functions of proteins in organisms.

3. differentiate among the primary, secondary and tertiary structure of proteins.

4. describe the three layers that make up the hair shaft and relate it to some properties of

hair which include texture, shape, strength, permeability and elasticity.

5. describe how the tertiary structure of keratin explain hair shape and color.

6. explain the chemistry behind shampoos and conditioners and three hair treatments:

perming, straightening and coloring.

Background Information

Proteins

What do nails, hair, tendons, antibodies and hemoglobin have in common? They all contain protein. Proteins are natural polymers that make up 15% of our bodies. These are very large macromolecules – their molar masses could be from 6,000 to no more than 1,000,000 grams.

There are two kinds of proteins. Those that serve a structural function such as keratin in nails or collagen in bones are called fibrous proteins. Globular proteins are those that do not provide structural integrity. Examples include hemoglobin which helps transport oxygen throughout the body and most enzymes which catalyze cellular reactions.

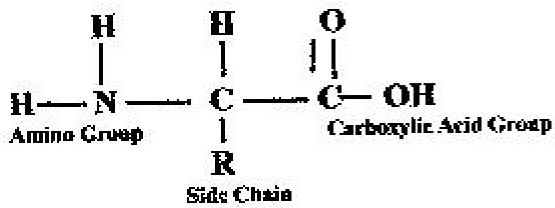
Proteins have many functions. As mentioned above, they provide structure. Proteins facilitate movement. As major components of muscles, they are responsible for the ability of muscles to contract. Most enzymes are proteins. Without enzymes, many chemical reactions in our body such as the breakdown of carbohydrates to generate energy will not readily take place.

Proteins like hemoglobin transport molecules from one part of the body to another. Hormones are proteins that regulate growth or control the activities of organs –oxytocin triggers milk secretion and contraction of the uterus. Antibodies are proteins that protect the organism from foreign substances.

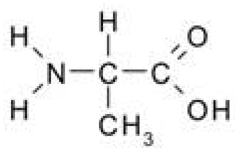
Some proteins have a storage function – ferritin stores iron in the liver, spleen and bone marrow. Other proteins regulate the cell's ability to respond to its environment - rhodopsin is a protein involved in the vision process.

The building blocks of proteins are amino acids. There are over 100 amino acids but only 20 are commonly used to make proteins.

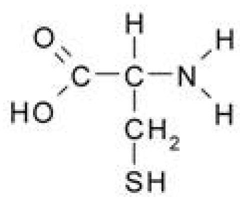
Amino acids have a common structure. Each amino acid has a carbon atom that forms a bond with an amino group (—NH_2), a carboxylic group (—COOH), hydrogen and a side chain referred to as R group. What makes the 20 amino acids different from each other is the type of R group present.



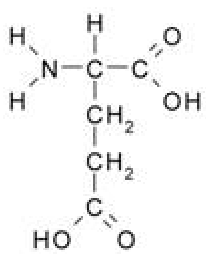
Based on the R group, amino acids may be classified into 4 categories. Nonpolar amino acids have a side chain composed mostly of carbon and hydrogen, making their R group nonpolar and insoluble in water; hence, these amino acids are described as hydrophobic. In an aqueous medium, the nonpolar side chain turns away from water. An example of a nonpolar amino acid is alanine:



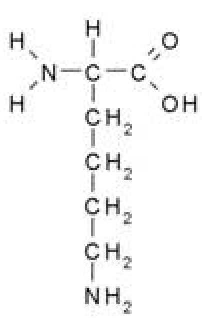
Polar amino acids have a polar side chain, making them soluble in water. They are also called hydrophilic amino acids. An example is cysteine.



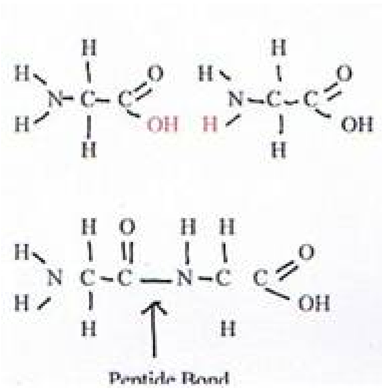
Aspartic acid and glutamic acid make up the 3 rd category. The side chains of these two amino acids contain another carboxylic (—COOH) group. Shown below is glutamic acid.



Alkaline amino acids have a basic group that can accept a hydrogen ion. In lysine, the amino group in the side chain changes into an ammonium ion when it accepts a hydrogen ion.



Amino acids combine to form proteins. Two amino acids can react to form a dipeptide. A bond forms between carbon of the carboxylic end of one amino acid and nitrogen of the amino end of another amino acid. A side product of the reaction is water. The resulting amide group that now links the two amino acids is called a peptide linkage.



Note how the dipeptide has an open amino end and an open carboxyl end. This means that additional amino acids can react with the chain, making it longer, creating a polypeptide and eventually a protein.

The structure of a protein is described in terms of three levels. The primary structure is the order of sequence of amino acids in the polypeptide chain. This sequence is very importance because it determines the identity and function of the protein. For example, the hormones oxytocin and vasopressin have nine-unit polypeptides but two of their amino acids are different. As a result, they show two different functions. Oxytocin triggers uterus contraction and milk production while vasopressin affects blood pressure and moderates kidney functions.

Oxytocin: cys-tyr-ile-gln-asn-cys-pro-leu-gly

Vasopressin: cys-tyr-phe-gln-asn-cys-pro-arg-gly

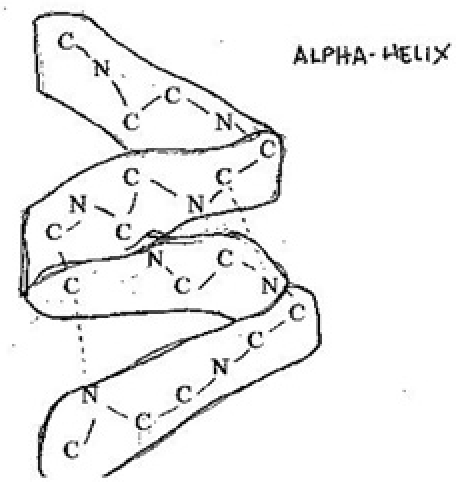
Peptide linkages are rich sites for hydrogen bond formation. Because a polypeptide has several peptide linkages, it is possible for hydrogen bonds to form between peptide linkages within a chain. This causes the chain to fold or bend resulting in a secondary structure for the protein. The secondary structure of a protein is the configuration in space of the protein chain.

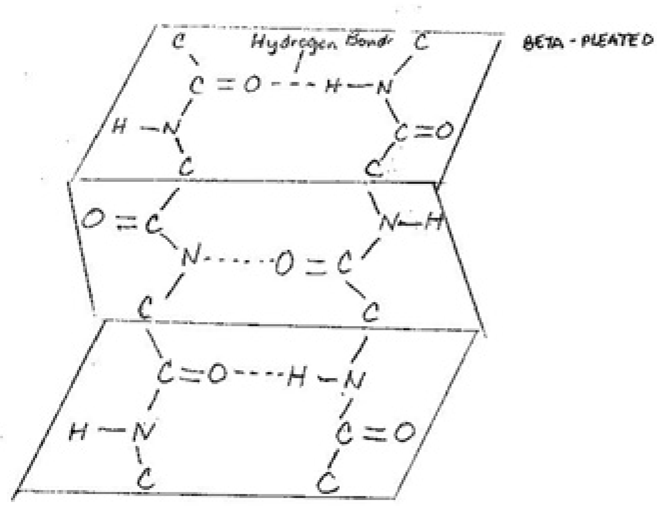
There are two common secondary structures: alpha-helix and beta-pleated sheet. In an alpha-helix, hydrogen bonds twist the polypeptide chain into a spring or spiral-like configuration in such a way that each turn is composed of 3.6 amino acid residues. Hydrogen bonds form between residues that are 4 spaces apart so that every peptide bond is involved in two hydrogen bonds: one from NH to a neighboring CO and one from a nearby CO to another NH. [5]

The spring-like structure makes the resulting protein elastic. Keratin, the protein in hair, and collagen found in tendons have this structure.

The beta-pleated sheet involves two or more protein chains linked together by hydrogen bonds. The proteins in silk and muscles have this structure resulting in fibers that are flexible but show great strength and resistance to stretching.

The over-all structure of a protein is its tertiary structure. So a protein could either be globular or elongated and narrow. Think of a telephone cord as the secondary structure and when some parts of the cord get tangled or form knots with its other parts, the over-all shape of the cord is no longer a nice spiral. The resulting shape with all the knots and tangles is the cord's tertiary structure. Hydrogen bonds, ionic/salt bonds and disulfide bonds between different sites of the secondary structure result in the protein taking a specific shape in space or tertiary structure. The detailed formation of these bonds is discussed in the next sub-section.



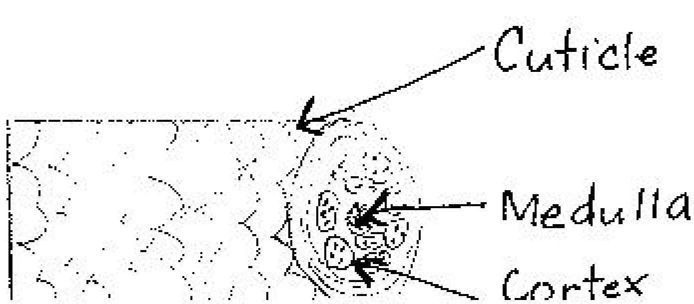


A few proteins would have one part showing an alpha-helix structure while another part would show a beta-pleated sheet configuration. An example is hemoglobin.

The presence of nonpolar and polar sections in a protein "forces" it to take a specific tertiary structure. For example, most proteins are found in an aqueous environment. Recall that water is polar. The tendency of the nonpolar side chains of the protein is to turn away from water because water is polar. At the same time, the polar and ionic side chains tend to turn towards water. This causes the protein to bend or fold in such a way that the nonpolar side chains of the protein are more in the interior while the polar chains are protruding outwards towards the water.

Hair Structure and Composition

Hair on the scalp grows out of a sac-like hole called a hair follicle. Special cells found at the bottom of the follicle reproduce to form new cells. These new cells push dead cells upward, causing hair to "grow" and come out of the scalp as hair shaft. The hair shaft is composed of three layers: the cuticle, cortex and medulla.



The cuticle is a smooth, outermost layer composed of a transparent, scale-like single layer of overlapping cells.An intercellular, lipid-rich cement is responsible for fusing together the colorless cells which are 50-70 microns long, 5-10 microns wide and at most 1 micron thick. [6] This layer serves as the protective barrier for the cortex and medulla.

The sheen and texture of hair depend on the conditions of the overlapping scales in the cortex. Healthy hair feels smooth to the touch because the scales are smooth, regular and lie flat. Hair feels rough because scales in the cuticle have been eroded, scratched and are now disjointed. Even the texture of a single strand of hair could vary. Closer to the root, scales are smooth since they have not been eroded, while farther away from the root, the hair strand may feel rough because the scales are more worn out.

Hair sheen depends on how the cuticle reflects light that strikes it. A smooth layer of scales in the cuticle reflects light evenly and hair appears shiny. A layer of worn out scales reflects light unevenly resulting in hair that appears dull.

Tangles are also due to worn out scales in the cuticle. Disjointed scales get caught with scratched scales in nearby strands, creating knots that tighten as the hair is combed.

The cuticle responds to pH changes. In a basic or alkaline environment, the cuticle layer swells as the scales open up which enables liquids to penetrate into the next layer. The cuticle shrinks and hardens in an acidic environment.

The cortex is a thick, middle layer composed of spindle-like cells filled with the protein keratin and melanin pigment. This is the layer that gives hair its strength, elasticity and tenacity, and color. Chemical changes take place in the cortex. Just like the cells in the cuticle, these elongated cells are held together by an intercellular cement rich in lipids.

The innermost layer is called the medulla or medullary canal. This central portion of the hair shaft has a diameter between 10-20 microns. [7] It is composed of cube-shaped cells that disintegrate fast, leaving behind pockets of air. The medulla may disappear along certain parts of the hair strand and may even be absent in the entire strand. Thick or coarse hair usually contains a medulla. Fine hair for the most part lacks a medulla, as does naturally blonde hair. The role of the medulla in human hair is not completely understood.

Normal hair on the average is50.65 % carbon, 20.85% oxygen, 17.14% nitrogen, 6.36% hydrogen, and 5.0% sulfur. [8]

A type of keratin called "hard" keratin is the protein in hair that gives it structural integrity. Keratin is a fibrous, insoluble protein. This protein polymer contains 18 amino acids, the majority of which are cysteine. The amino acids present in hair include cysteine, serine, glutamic acid, aspartic acid, alanine, proline, isoleucine, tyrosine, phenyalanine, threonine, glycine, valine, histidine, phenylalanine, methionine, leucine, threonine, and arginine.

Keratin is responsible for giving hair its strength. It is organized into protofibrils, each of which is composed of 4 spiral chains of keratin twisted together. These spiral chains are cross-linked by hydrogen, ionic/salt, and disulfide binds just like the sides of a ladder held together by rungs. Where some of these bonds are found determines whether the hair is straight or curly. Changing the shape of the hair (e.g. curly to straight and vice-versa) involves manipulating these bonds.

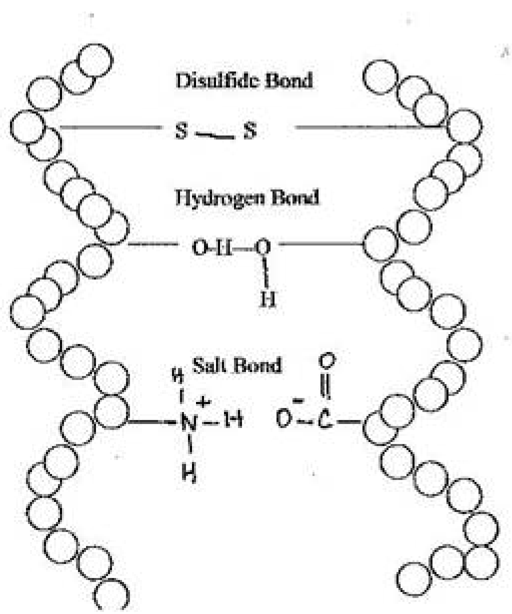
How does each of these bonds form? One end of a keratin chain contains the amino group or $–NH_2$ while the other end has the carboxyl group, —COOH. In hair, these groups have been ionized. The carboxyl group becomes a negative ion because it loses its H^+ while the amino group is now a positive ion because it gains a H^+. The attraction between the two opposite charged ions from neighboring chains creates an ionic or salt bond that helps hold the protein strands together.

Hydrogen bonds can also form between keratin chains. Hydrogen bonds are intermolecular forces that form between the positively charged H of one molecule covalently bonded to a small but quite electronegative atom such as F, O, or N and a negatively charged atom such as F, O or B of another molecule covalently bonded to H. Even though hydrogen bonds are weak, keratin has numerous sites in which hydrogen bonds form not only within but also between molecules. This makes hydrogen bonds a significant cross-link force.

But hydrogen bonds can be broken by water. Water itself forms hydrogen bonds with sites in the protein chains that used to be connected by hydrogen bonds. This enables water molecules to insert themselves between the protein chains. Hair, which is already 30% water by weight, absorbs more water, causing the hair shaft to swell and open up the cuticle.

The strongest cross links are called disulfide bonds. These are covalent bonds that form between two cysteines that are found in different parts of the twisted keratin chains.

Cysteine is an amino acid which has a –SH part protruding from the protein backbone. When two cysteines from neighboring protein chains react, the hydrogen from the SH of each cysteine is lost. Now without their hydrogen, the two sulfur atoms form a covalent bond with each other. This bond is called disulfide bond or disulfide linkage. The most abundant amino acid in keratin is cysteine; thus, disulfide bonds play a major role in giving hair its strength.



Among the three bonds, hydrogen bonds are the easiest to break. Water, for instance, can break hydrogen bonds. This explains why curly hair becomes temporarily straight when it is wet. But once it dries, new hydrogen bonds form between adjacent keratin strands and the hair turns curly again.

An acidic or basic solution can break ionic bonds; hence, hair products that are too acidic or basic can make hair weaker and brittle.

Because disulfide bonds are a lot stronger, a redox reaction is needed to break them. It is these bonds that must be broken when hair is permed or relaxed.

In straight hair, atoms found at more or less the same sites on adjacent keratin chains form the bonds that hold the chains together. This results in straight hair.

In wavy or curly hair, most of the bonds are formed between atoms located along different sites of nearby chains. This causes keratin to fold and bend a lot, resulting in curly hair.

Two types of melanin pigment in the cortex account for natural hair color. Brown to black color is due to the pigment eumelanin. Red and yellowish colors are due to phaeomelanin. How light or dark hair color is depends on the density of distribution of the melanin granules. When skin cells grow old and stop producing eumelanin or pheomelanin, a person's hair turns gray or white.

Hair produces its own natural conditioner in the form of sebum, an oil-like material. Sebum is produced by sebaceous glands found next to the hair follicles. It coats the hair shaft, serving as a protective barrier for the cuticle. It also traps moisture in which makes hair soft and smooth. The smooth and even surface it creates on the cuticle makes the hair shiny. Finally, the waxy coating prevents bacteria from growing on the hair shaft.

But sebum can trap dirt. Sebum and dirt build up makes hair not only unhygienic but also dull.

Water alone is not effective in removing dirt from hair. Water and sebum do not mix because water is polar while sebum is nonpolar. Hence, shampoo is used to wash hair.

Shampoos contain detergent. A detergent molecule has both polar and nonpolar components. Sebum and dirt stick to the nonpolar end of the detergent. Water is used for rinsing because water attracts the polar end of the detergent. As water pulls out the polar end of the detergent, sebum and dirt dissolved in the nonpolar side of the detergent are pulled away, leaving the hair clean.

Shampoo is better than soap in washing hair. Soap is basic which will cause the scales in the cuticle to swell and open up. Shampoo has a lower pH which makes the cuticle cells lie flat.

Most shampoos have a built-in conditioner. Conditioners, whether they are part of the shampoo formulation or separate, coat the hair shaft with a waxy material. Just like sebum, a conditioner serves as a protective layer, smoothens the rough edges of cuticle scales and traps moisture in, preventing hair from tangling and getting dry and rough.

But there is also danger to using too much conditioner. Residue from over conditioning builds up and weighs the hair down, making it limp.

Hair Treatment

Permanent Waves

Turning straight hair to curly is a matter of breaking the cross linkages in keratin. This can be done by using a permanent wave solution. A typical permanent wave solution contains 7% ammonium thioglycolate, 3% ammonium hydroxide and water. [9]

Hair is first dampened so that water can break the hydrogen bonds between keratin chains. When the permanent wave solution is applied, the alkali in the solution, ammonium hydroxide, breaks the ionic/salt bridges. The –OH of the ammonium hydroxide reacts with the positively charged amino group ($—NH_3^+$) . The amino group then loses its positive charge. Its attraction for a neighboring negatively charged carboxyl ion dissipates and the ionic bond between the ionized amino and carboxyl groups collapses.

The only bonds left in the cross linkages are the very tough disulfide bonds. The base in the permanent wave solution is not even strong enough to break the disulfide bonds. A redox reaction does the job.

Ammonium thioglycolate serves as a reducing agent. It adds hydrogen to the sulfur atoms that make up the disulfide bond. This is the reduction part of the reaction. This breaks the bond between the two S atoms.

$$\text{Chain—S--------S—Chain} + 2\text{HS—CH}_2\text{COO}^- \rightarrow$$
$$\text{Chain—SH} + \text{HS—Chain} + {}^-\text{OOCCH}_2\text{—S---------S—CH}_2\text{COO}^-$$

With the three bonds forming the cross linkages broken, the hair can now be reconfigured. Sections of the hair are carefully coiled around rollers. Hair readily takes the shape of the curlers because the cross linkages have collapsed.

At this point, oxidation, the other half of the reaction, is ready to be carried out. After the hair is rinsed with water to remove the excess ammonium thioglycolate, hydrogen peroxide, which hairdressers call a neutralizing agent but is really an oxidizing agent, is applied. The oxygen of hydrogen peroxide removes the hydrogen atoms that were added to the sulfur atoms of the cysteine residues, forming water. The sulfur atoms, now free of hydrogen, connect with each other, to form disulfide bonds. These new disulfide bonds lock the keratin chains in the new "curly" position.

$2e^- + H_2O_2 + 2H^+ \rightarrow 2H_2O$

The permanent wave solution has a pH ranging from 8 to 9.5. The high pH opens up the cuticle, allowing the chemicals to go in and react with the keratin faster.

The base in the permanent wave solution can be replaced by an acid but it does not open up the cuticle so the process takes longer.

Hair Straightening

Hair straightening can be done using heat or chemicals. Heat from a flat iron (with a temperature range between 170 ^{0} C - 230 ^{0} C) breaks some of the hydrogen bonds that comprise the cross linkages in keratin. [10]

Brushing the hair then stretches the protein strands and new hydrogen bonds form in new positions in the now straighter hair. This is, however, a temporary configuration. Water can easily break these hydrogen bonds and the protein strands go back to their old configuration.

Chemical straightening is a more permanent way of having one's hair straightened. The principle is the same as getting a permanent wave. The three bonds that form the cross linkages need to be broken so that hair can be reshaped.

One of the more common techniques uses Japanese thermal straighteners. Just like permanent wave solutions, one of its active chemicals is ammonium thioglycolate which, as described above, breaks disulfide bonds in a reduction reaction. A flat iron is then used to reshape the keratin strands into a straighter configuration after which an oxidizing agent like hydrogen peroxide or sodium bromate establishes new disulfide bonds in new sites that will keep the strands straighter.

Another technique called the Brazilian blow-out involves adding amino acids from keratin to the protein fiber in hair. A cross-linking reagent is used to stick the extra amino acids to the keratin strands in hair after which the hair is stretched and heated with a flat iron. This technique has generated controversy because one of the cross-linking reagents used is formalin, which is considered a carcinogen when inhaled. [11]

Hair Coloring

A conventional permanent hair dye solution contains hydrogen peroxide, ammonia, dye precursors and a surfactant. The hydrogen peroxide and ammonia react to form perhydroxyl ion and an HO radical which raise the pH of the solution between 10-11. The very high pH lifts and opens the scales of the cuticle as the hair fiber swells. It is necessary to open up the cuticle because the molecules that make up the dye precursors are too large to go through the cuticle. Once the cuticle opens up, the dye precursors are able to go in and reach the cortex.

The perhydroxyl ion has two functions. It oxidizes the dye precursors which enable them to fuse together to form the desired color. At the same time, it reacts with the melanin, bleaching it in the process. The surfactants keep the hydrogen peroxide and ammonia dissolved in the solution and make the chemicals stick to the hair while the treatment is being done.

The last step involves the use of an appropriate shampoo or cream rinse to close up the scales of the cuticle, trapping the new color inside the cortex. This allows the hair to keep its color for a long time. The color is not washed off by shampoo.

Though the term used is permanent hair coloring, the color does not stay permanent. The new hair that grows from its root will have the original color.

One trade off of using this combination of permanent hair dye solution is the damage the hair suffers from the high alkalinity of the solution. To lessen hair damage due to high pH, chemists from Proctor and Gamble came up with a formula that lowers the pH and eliminates the formation of the HO radical which causes a lot of hair damage.

In 2008, the company launched a new line of permanent hair dyes that uses ammonium carbonate, hydrogen peroxide, and the amino acid sodium glycinate. The reaction produced a new set of reactive species: a peroxymonocarbonate ion (HCO_4^-) and a carbonate radical (CO_3^{2-}). The peroxymonocarbonate ion permits the bleaching and coloring to occur at pH 9, causing less damage to the hair. Further damage is reduced by the addition of sodium glycinate which removes the carbonate radicals as they are formed. [12]

Semi-permanent hair coloring involves the use of a colorant and not a dye precursor so there is no oxidation involved. The colorant's pigment molecules are small enough to penetrate the cuticle and settle around the cortex but they do not react with the melanin. The color gradually fades and may be gone after 5-10 shampoos.

Temporary hair coloring also uses a colorant. Because the colorant molecules are large, they cannot go through the cuticle. Instead they just coat the cuticle and the color washes out after 2-3 shampoos.

Teaching Strategies and Classroom Activities

In selecting strategies to implement this unit, I considered two things. They must demonstrate the nature of science – science is not only a body of knowledge but is also a way of doing and a way of thinking.

At the same time, the strategies must also cater to varied learning styles of my students who, as part of the net generation or millenials, are digital natives whose major way of gathering information and interacting with other people and the environment is through social media and digital devices. Millenials also prefer to learn by working collaboratively with their peers and appreciate structured activities that allow creativity.

Part I. Proteins

A discrepant event demonstration called Skewered Balloons will be used to set the tone for this sub-unit. Student volunteers will be challenged to stick a bamboo skewer that has been dipped in baby oil through a balloon without popping it. The demonstration will be used to review our past lesson on polymers and how a lot of polymers, including the latex the balloon is made from, have cross linkages. If none of the students are successful, have them push the skewer gently through the end where the knot was tied until the tip reaches the opposite end. Asking probing questions such as those listed below will help students explain why pushing the skewer through the knot and nipple end does not make it pop while puncturing it though the middle will.

- Why does the balloon stretch when inflated? (Latex is made up of intertwined polymer chains that are elastic.)
- Where is the balloon most stretched? (middle) least stretched? (ends)
- Why does the balloon pop when the skewer is pushed through the middle? (The chains are already stretched and the skewer breaks the cross linkages.)
- Why does the balloon not pop when the skewer is pushed through the ends? (The polymer chains stretch around the skewer which gets in between the molecules.)

Direct teaching using PowerPoint will be used to provide input about amino acids as the building blocks of protein and the 1^0, 2^0, 3^0, and 4^0 structures of proteins. Models of these structures using simple materials such as pop beads, chenille stems, plastic beads, slinky, folded paper and the like will be used to help students visualize the structures.

Examples of real life applications (e.g. lactase and lactose intolerance, cysteine in hair contributes to the strength of hair) will be interspersed throughout the presentation.

Working in collaborative groups, students will construct their own models using common materials of their choice to illustrate how the amino acid cysteine, an important component of keratin, the protein found in hair, can form disulfide bonds. They will also construct models to show the difference among the primary, secondary, tertiary and quartenary structures of protein in general. Each group will present and explain their model to the class.

A mini-lab activity entitled Protein in Hard Tissue will serve as closure. In this activity, students will learn the role of a structural protein in hard tissue. Working in pairs, students will observe and compare the properties of cooked chicken bone before and after it is soaked in 1 M HCl overnight. In their lab write up, students will be asked to record their observations and describe what happened to the mineral salts of the bone, explain why the soaked bone is easier to twist and bend, hypothesize what could be the insoluble protein left in the soaked bone and the possible role of this protein in the formation and maintenance of healthy bones. (The acid reacted with the minerals in the bone to dissolve them and what is left is the insoluble protein collagen. Collagen gives bones strength and resilience.)

Part II. Physical Structure and Chemical Composition of Hair and Its Properties

I will begin this sub-unit with a hands-on activity. Working in pairs, students will construct a hair hygrometer using a shoebox and a long strand of hair. Some of them may have done this in middle school so they can be tapped to share that a hygrometer measures humidity or the amount of water vapor in the air. A detailed procedure on how to make the hygrometer is found in Appendix A. Draw out from students how a hair hygrometer works by asking what happens to their hair when humidity changes. Their own personal experience of a "bad hair day" should prompt them to respond that curly hair frizzes and straight hair becomes limp when humidity increases so when humidity is high, the hair strand in the hygrometer lengthens while at a lower humidity, it contracts and shortens. This change in length moves the pointer in the hygrometer.

Later in this sub-unit, have students refer back to this activity to explain the relationship between humidity and hair behavior. Water molecules not only break the hydrogen bonds that hold the coiled chains of keratin together in the cortex of the hair shaft but also form hydrogen bonds themselves with the keratin chains. This allows water molecules to wedge themselves between the protein chains causing hair to expand.

Teacher input using PowerPoint presentations on the three layers of the hair shaft and the organization of keratin and melanin in the cortex, and how the three layers respond to pH and water will provide students with background information to help them construct models of the cross linkages in keratin chains. The model should clearly identify the three bonds (hydrogen, salt/ionic and disulfide bonds) that hold the chains together. This will be done in groups of 3. Examples of materials students could use include Chenille stems for the keratin chains and colored paper clips for the bonds. A different color is used for each of the three bonds. Students will be encouraged to use their creativity in exploring other materials they can use to construct their model.

Using the model they made and their notes from the PowerPoint, students will explain the shape (curly or straight), texture (coarse or smooth), sheen (dull or shiny) and color of their hair. The group output is a pyramid foldable ™ . [13] in which each side contains an explanation of each student's hair. Instructions on how to make a foldable are included in Appendix A.

A micro scale lab activity comparing the pH of different kinds of shampoo (pH balanced, shampoo with built-in conditioner, shampoo without conditioner, anti-dandruff, clarifying, baby, etc.) will serve as closure for this sub-unit. A pH meter or pH paper will be used to measure the pH of undiluted and diluted samples of shampoo. Careful measurements of pH should show that pH balanced shampoos have a lower pH than regular shampoos while baby shampoos have a pH close to neutral (hence Johnson baby shampoo's slogan of no more tears). In their lab write up, each student will decide the best type of shampoo for their hair based on the results of the activity.

Part III. The Chemistry Behind Hair Perm, Straightening and Coloring

In the third and final sub-unit, students will have guided reading activities using articles from ChemMatters and other publications and internet access to learn how perm, straightening and coloring work. They will summarize their findings in the form of a three-tab foldable ™ . [14] Their foldable must show that curling and relaxing or straightening hair involve breaking not only the hydrogen bonds between protein strands but the disulfide bonds as well and creating new cross linkages in new locations of the keratin chains. The third section of the foldable must show that permanent coloring involves altering the melanin pigments in the cortex while semi-permanent and temporary coloring do not affect the melanin. In semi-permanent coloring, the dye settles around the cortex while in temporary coloring, the dye simply coats the cuticle.

Students will also test the effects of solutions with different pH on hair. This activity will be combined with a Predict, Observe, Explain (POE) strategy. I will make arrangements with a hair salon near the school to collect cut hair from one individual with straight hair. Bundles of hair containing 10-15 strands each will be coiled around wooden splints and held in place by rubber bands. These bundles will be soaked in 3 different solutions for 15 minutes and 10 minutes for the fourth one. The first 3 solutions are vinegar with a pH of 4, clear window cleaner with a pH of 8, and permanent wave solution, while the fourth is permanent wave solution followed by neutralizer. For the fourth solution, the hair sample will be removed from the permanent wave after 10 minutes, rinsed with tap water and then soaked in the neutralizer for 5 minutes. Students will then predict which solution is the most effective in making hair curly before and after the samples get wet and which one makes the hair easier to split or become more damaged.

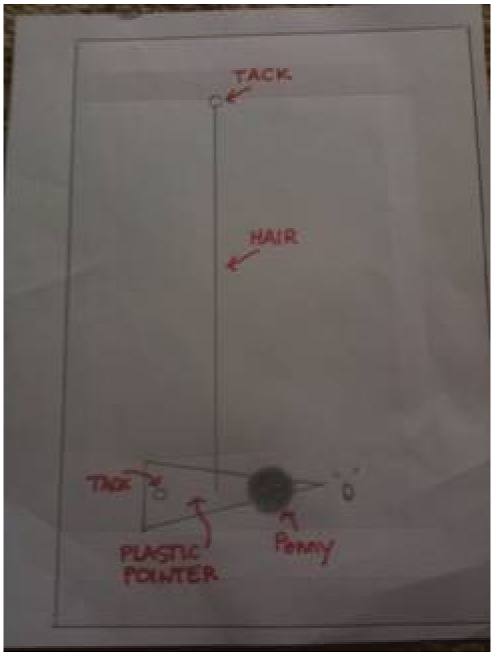
The 4 hair samples will be removed from the solution after 15 minutes and allowed to dry partially. After removing the rubber band carefully, students will observe and rank the degree of curling shown by each hair bundle. The strength of each hair sample will be tested by removing one strand of hair from each sample and stretching it gently from each end.

Students will then rinse with tap water, dry completely and compare the amount of curling of the 4 hair bundles after which another stress test is performed. The students' lab write ups must show each POE component. In their explanation, they should compare their observation with their prediction and explain their observation in terms of the cross linkages in keratin. Their explanation must also include that basic solutions are more damaging than acidic solutions because the former opens up the cuticle of the hair shaft.

A group project will be used to synthesize what students have learned from this unit. Working in collaborative groups of 4-5, they will create a 3-5 minute video presentation on how chemistry leads to a "good hair day."

Appendix A. Worksheets

Making a Hair Hygrometer (adapted from a worksheet provided in a workshop I attended entitled Climate Change Institute given by Chabot Space Science Center. According to the facilitator, he got the procedure from http://www.education.noaa.gov).



1. Cut a small piece of plastic such as an old identification card into a triangle as shown in the diagram. This will serve as the pointer.

2. Poke a thumb tack through the pointer near the base of the triangle. Turn the tack around until the pointer moves freely around the tack.

3. Tape a penny onto the pointer near the tip of the triangle.

4. Glue three hair strands, which are about 8 inches long, onto the plastic between the tack hole and the penny.

5. Use a thumb tack to fasten the pointer to one of the long sides of a shoe box about ¾ of the way down the side, making sure the pointer can still move freely around the tack.

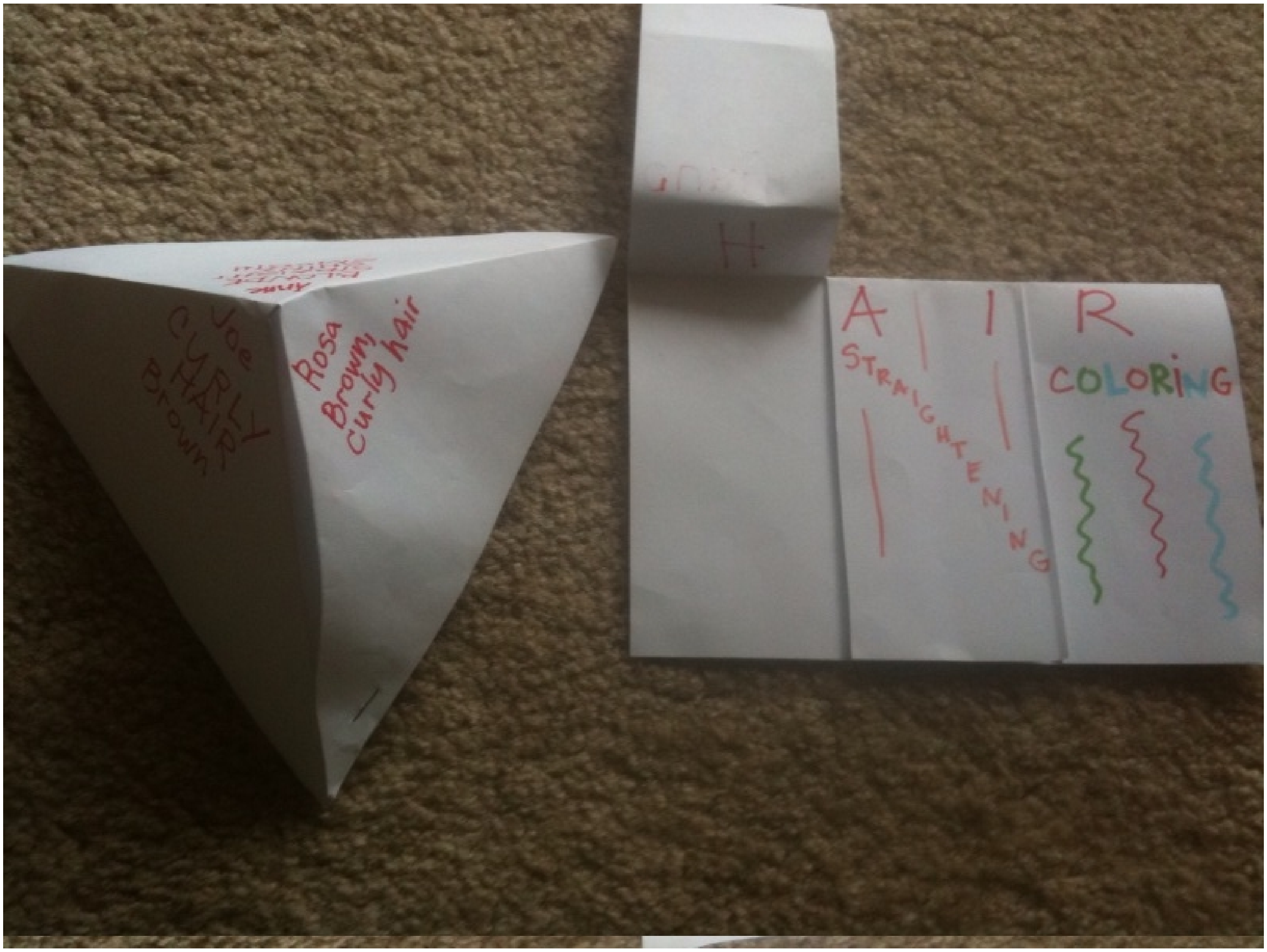
6. Attach a second tack about one inch from the top of the box in line with the spot where the hair is glued to the pointer.

7. Pull the free ends of the hair tight so that the pointer is horizontal. Wrap the hair around the upper tack and glue to hold the hair in place.

8. Mark on the box as "0" where the pointer is pointing at when it is completely horizontal.

9. Observe what happens to the pointer when humidity changes. When the air is humid, hair absorbs moisture and will expand and lengthen, making the pointer move down. When air is dry, hair contracts and shortens and the pointer moves up.

Making Pyramid Foldable ™ and Three-Tab Foldable ™ (These are just two of several foldables developed by Dinah Zike. Foldables are graphic organizers that can be used in the classroom in a variety of ways.)



Pyramid Foldable ™

1. Fold a 8.5 x 11 paper taco style and cut off the extra rectangular portion.

2. Open the paper and fold it taco style again in the opposite way so that the two creases now form an "x".

3. Cut from one end of one valley to the center of the "x". This creates two flaps.

4. Make a pyramid by gluing one flap under the other.

Three-Tab Foldable ™

1. Fold a 8.5 x 11 paper length-wise or hot dog style.

2. Fold the right side toward the center such that half of the paper is covered.

3. Fold the left side over the right side such that there are three equal sized sections.

4. Open the left and right folds and cut along the two valleys to create three windows or tabs.

Appendix B. California Chemistry Standards Covered by the Unit

This unit will be taught after students have gained basic understanding of the following concepts: atomic structure, chemical bonds, intermolecular forces, types of chemical reactions including redox, shapes and polarity of molecules, acids and bases and polymers.

It will be part of the module on organic chemistry and biochemistry. It will address the following California standards in Chemistry:

CA Standards #10. The bonding characteristics of carbon allow the formation of many different organic molecules of varied sizes, shapes, and chemical properties and provide the biochemical basis of life. As a basis for understanding this concept:

a. students know large molecules (polymers) , such as proteins, nucleic acids, and

starch are formed by repetitive combination of simple subunits.

c. students know amino acids are the building blocks of proteins

f. students know the R-group structure of amino acids and know how they combine

to form polypeptide backbone structure of proteins

End Notes

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http://online.wsj.com/article/SB10001424052748704698004576103940087329966.html (accessed July 13, 2011).

[2] Zernike, Kate. "Commencements; At Yale, Mrs. Clinton Ponders Hair and Politics." New York Times (Manhattan) May 21, 2001. http://www.nytimes.com/2001/05/21/nyregion/commencements-at-yale-mrs-clinton-ponders-hair-and-politics.html (accessed July 16, 2011).

[3] National Research Council, (US). *National Science Education Standards: observe, interact, change, learn.* Washington, DC: National Academy Press, 1996.

[4] National Science Teachers Association. "Practicing Science Process Skills at Home." www.nsta.org. www.nsta.org/elementaryschool/connections/200712TorresHandoutParentNSTAConn.pdf (accessed July 16, 2011).

[5] Moore, John T., and Richard Langley. "Part II. The Meat of Biochemistry: Proteins." In Biochemistry for dummies. Hoboken, N.J.: Wiley, 2008. 51-83.

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[7] ibid.

[8] "hair biology - hair fiber composition." hair loss and hair growth information. http://www.keratin.com/aa/aa012.shtml (accessed August 15, 2011).

[9] Baxter, Roberta. "Permanent Waves." ChemMatters, April 1993.

[10] Drahl, Carmen. "Hair Straighteners." Chemical and Engineering News 88, no. 45 (2010): 54.

[11] Hess, Glenn. "Formaldehyde Linked to Cancer in Humans." Chemical and Engineering News 88, no. 23 (2010): 30.

[12] Jarvis, Lisa M. "Color Challenge." Chemical and Engineering News 86, no. 6 (2008): 32-33.

[13] Zike, Dinah. *Dinah Zike's Teaching with foldables mathematics; Dinah Zike's Teaching with foldables science*. New York: McGraw-Hill Glencoe, 1999.

[14] ibid.

Teacher Resources

"Cell compounds and biological molecules ch. 2 & 3 flashcards | Quizlet." Flash cards, vocabulary memorization, and study games | Quizlet. http://quizlet.com/2981200/cell-compounds-and-biological-molecules-ch-2-3-flash-cards/ (accessed July 19, 2011).

This is a good reference for structural formulas of organic and biological molecules.

Drahl, Carmen. "Hair Straighteners." Chemical and Engineering News 88, no. 45 (2010): 54.

This is a short and straight forward article that clearly explains how different hair straightening methods work.

Giroux, Robin. "What's That Stuff: Shampoo." Chemical and Engineering News 80, no. 15

A simple article that lists the components found in shampoos and what the function of each component is.

Griffin, John J. , Robert F. Corcoran, and Kenn K. Akana. "pH of hair shampoos. A topical high school experiment." Journal of Chemical Education 54, no. 9 (1977): 53-54.

2002): 42.

This article describes a simple lab experiment that can be performed in a high school chemistry lab to test the pH of various shampoos.

L'Oreal. "Hair Science." www.hair-science.com. www.hair-science.com/_int/_en/home.aspx?tc=ROOT-HAIR-SCIENCE^HOME-HAIR-SCIENCE&cur=HOME-HAIR-SCIENCE (accessed July 19, 2011).

This web site provides a good overview of hair science and a clear and easy to understand discussion of the science behind hair products. Diagrams accompany most sections making the discussion easy to follow.

Jarvis, Lisa M. "Color Challenge." Chemical and Engineering News 86, no. 6 (2008): 32-33.

This article discusses how issues concerning hair coloring are being met.

Moore, John T., and Richard Langley. "Part II. The Meat of Biochemistry: Proteins." In Biochemistry for dummies. Hoboken, N.J.: Wiley, 2008. 51-83.

This offers a good review on biochemistry especially for teachers who do not have a strong background on protein chemistry.

Morel, Olivier J. X., and Robert M. Christie. "Current Trends in the Chemistry of Permanent Hair Dyeing." Chemical Reviews 111, no. 4 (2011): 2537-2561.

This article describes innovations in hair coloring.

Raber, Linda. "What's That Stuff: Hair Coloring." Chemical and Engineering News 78, no. 11 (2000): 52.

This article provides a simple discussion of the chemistry involved in hair coloring.

Wilbraham, Antony, Dennis Staley, Michael Matta, and Edward Waterman. *Chemistry*. Teacher's Edition for California ed. New Jersey: Prentice Hall, 2007.

This is a comprehensive textbook for chemistry. The teacher's edition provides a variety of hands-on activities as well as reinforcement and remedial strategies. Zike,

Dinah. *Dinah Zike's Teaching with foldables mathematics; Dinah Zike's Teaching with foldables science*. New York: McGraw-Hill Glencoe, 1999.

This is a good reference for 3-D graphic organizers which students will find easy to make and use.

Zumdahl, Steven S., Susan L. Zumdahl, and Donald J. Decoste. World of Chemistry. Boston: McDougal Littell, 2002.

This is a good reference on describing proteins in terms of their primary, secondary and tertiary structures. It also provides a lot of real life examples.

Student Resources

Baxter, Roberta. "Permanent Waves." ChemMatters, April 1993.

This article provides a simple but accurate discussion of the chemistry behind a hair perm. Diagrams clearly illustrate the chemical reactions that take place when hair undergoes a permanent wave.

Dombrink, Kathleen J., and David O. Tanis. "pH and Hair Shampoo." ChemMatters, April 2003.

This article describes how shampoos work.

Fruen, Louis. "Natural, Braided, Bleached, Colored, Straight." ChemMatters, October 2008.

This is an easy-to-understand article on the chemistry behind hair products and treatments popular with teenagers.

Gonick, Larry, and Craig Criddle. *The cartoon guide to chemistry.* New York: HarperResource, 2005.

This book explains chemistry concepts through simple and funny cartoon type illustrations.

Murphy, Pat. "Exploratorium Magazine: Hair." Exploratorium. http://www.exploratorium.edu/exploring/hair/ (accessed July 16, 2011).

This online article provides an interesting discussion of the science behind bad hair days and how science/chemistry can be used to do away with common hair problems that teenagers usually face.

BASF The Chemical Company. "Podcast: How does conditioner make your hair soft? - BASF - The Chemical Company - Corporate Website." BASF Global - BASF - The Chemical Company - Corporate Website. http://www.basf.com/group/corporate/en/news-and-media-relations/podcasts/chemical-reporter/conditioner (accessed July 13, 2011).

BASF The Chemical Company. "Podcast: What does actually take place when we color our hair? - BASF - The Chemical Company - Corporate Website." BASF Global - BASF - The Chemical Company - Corporate Website. http://www.basf.com/group/corporate/en/news-and-media-relations/podcasts/chemical-reporter/hair-color (accessed July 13, 2011).

BASF The Chemical Company. "Podcast: What is the chemistry behind a permanent wave hairstyle? - BASF - The Chemical Company - Corporate Website." BASF Global - BASF - The Chemical Company - Corporate Website. http://www.basf.com/group/corporate/en/news-and-media-relations/podcasts/chemical-reporter/perm (accessed July 13, 2011).

These 3-5 minute podcasts about hair products and treatments may be short but they provide good examples of how chemistry is part of students' every day life. Each podcast offers a simple explanation of how hair conditioners work and how chemicals change hair color and transform straight to curly hair.

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