Playing with Polymers

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GRADE LEVEL / SUBJECT: Chemistry (9-12), adaptable to all grade levels.

Objective:
Although these lessons are geared toward the High School Chemistry level, they can be adapted and made appropriate for grade Middle School or Elementary School activities. Students will be able to: 1) understand the meaning of a polymer and how they are synthesized, 2) observe and compare the properties and phases of both synthetic and natural polymers, 3) describe the chemical reactions involving the individual molecules (monomers) that lead to the formation of large polymer molecules, 4) explore common uses of polymers, 5) conduct experiments in which they synthesize a variety of polymers, 6) present their findings in a group Power Point presentation.

This lesson is divided into a number of different activities which—for the sake of time constrains and content-- can be separated into individual lessons or used in their entirety.

Teacher Notes and Information

Pages 1-6 contain teacher notes and information. Pages 7-11 contain student hand-outs for the Slime and Gack lab activities.

This lesson is divided into a preliminary class discussion, two polymer demonstration activities, two lab activities, a library and web based activity, and a computer activity in which the students compile and present their information. These activities be separated into individual lessons or used in their entirety for the sake of time constrains and content matter.

Materials needed for the combined activities and demonstrations:

Samples of various polymers
Balance
Elmer's or other white glue
Borax
Polyvinyl alcohol
Sodium polyacrylate
Salt
Sugar
Baking soda
Sebacoyl chloride
Hexaminediamine
Paper clip
Glass stirring rod
Beakers, 150 mL and 400 mL, 1L

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Water, tap and distilled
Paper or plastic cups (smallest size available)
Wooden stir sticks
Graduated cylinders
Plastic bags with "zip-type" closure

Introduction Activity: What are Polymers?

Students will be introduced to Polymers with a 'show and tell' discussion of some common polymers (objects, such as Kevlar, Nylon, Plastics, Starch, Proteins, etc…, will be on display for students to pass around the room). I will explain how all the materials are made of small units (monomers) that are joined together in long chains to form a polymer, each of which has distinct characteristics. I will discuss addition and condensation reactions that take place in the synthesis of polymers, and the topic of cross-linking. In addition, I will briefly discuss some of the different types of monomers that make up these polymers, pointing out how the units bond together to form chains . I will discuss the different phases (solids, liquids, and the 'in-between phases').

I will invite students to bring in a few polymers from home that can be passed around. Class members will try to identify the polymers and determine what units they consist of and how they are produced.

Student Presentations:

Objective: Using information from the class textbook, other books, the library, the World Wide Web or first person interviews with scientists who work in polymer research develop a presentation for the class on polymers. Students may work with a partner or partners (3 people is the largest group allowed). I prefer that students present their information using a Power Point Presentation, however, this certainly can be altered to accommodate resources.

Possible Topics:

- Plastics and Recycling
- The discover of various polymers--polyester, Nylon, Rayon, Acrylonitrile or synthetic rubber
- The Polymer Industry--historical or economic approach
- Uses of polymers in industry, consumer goods, biomedical reseach
- Natural polymers--DNA, starch or vitamins

Possible Grading Guidline:

_____ Completed on time (5 points)

_____ Thoroughness of research (10 points)

_____ Bibliography or citations from the World Wide Web (5 points)

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_____ Creativity (5 points)

_____ Accuracy of information (5 points)

_____ Organization and completeness (3 points)

_____ Participation in group (2 points) (To be scored by members of the group.)

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Nylon Rope Demonstration

The Condensation Polymerization Reaction Used in the Creation of Nylon 6-10 (or Nylon 6,6)

Objective: The objective of this demonstration is to show the formation of a condensation polymer.

Review of Scientific Principles:

The various nylons are described by a numbering system that indicates the number of carbon atoms in the monomer chains. Nylons from diamines and dicarboxylic acids are designated by two numbers, the first representing the diamine and the second the dicarboxylic acid. Thus nylon 6-10 is formed by the reaction of hexamethylenediamine and sebacic acid. In this demonstration the acid chloride, sebacyl (or Sebacoyl) chloride, is used instead of sebacic acid. The equation is:

$$H_2N(CH_2)_6NH_2 + Cl\overset{O}{\overset{\|}{C}}(CH_2)_8\overset{O}{\overset{\|}{C}}Cl \longrightarrow -[-\overset{H}{\overset{|}{N}}(CH_2)_6\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}(CH_2)_8\overset{O}{\overset{\|}{C}}-]- + 2\,HCl$$

Many diamines and diacids (or diacid chlorides) can be reacted to make other condensation products that are described by the generic name "nylon." One such product is an important commercial polyamide, nylon 6-6, which can be prepared by substituting adipoyl chloride for Sebacoyl chloride in the procedure described here. The equation is:

$$H_2N(CH_2)_6NH_2 + Cl\overset{O}{\overset{\|}{C}}(CH_2)_4\overset{O}{\overset{\|}{C}}Cl \longrightarrow -[-\overset{H}{\overset{|}{N}}(CH_2)_6\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}(CH_2)_4\overset{O}{\overset{\|}{C}}-]- + 2\,HCl$$

Time: About 20-30 minutes of class time.

Materials and Supplies:

- 50 ml 0.50 M hexamethylenediamine (1,6-diaminohexane), $H_2N(CH_2)_6NH_2$, in 0.5 M sodium hydroxide, NaOH (To prepare: dissolve 3.0 g of $H_2N(CH_2)_6NH_2$ plus 1.0 g NaOH in 50 ml distilled water. Hexamethylenediamine can be dispensed by placing the reagent bottle in hot water until sufficient solid has melted and can be decanted. The melting point is 39-40°C.)
- 50 ml 0.2 M Sebacoyl chloride, $ClCO(CH_2)_8COCl$, in hexane (To prepare: dissolve 1.5 ml to 2.0 ml Sebacoyl chloride in 50 ml hexane.) gloves, plastic or rubber (ones that will not dissolve in hexane)
- 250 ml beaker or crystallizing dish
- forceps
- 2 stirring rods or a small windlass
- food-coloring dye (optional)
- phenolphthalein (optional)

General Safety Guidelines:

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- Hexamethylenediamine is irritating to the skin, eyes, and respiratory system.
- Sodium hydroxide is extremely caustic and can cause severe burns. Contact with the skin and eyes must be prevented.
- Sebacoyl chloride is corrosive and irritating to the skin, eyes, and respiratory system.
- Hexane is extremely flammable. Hexane vapor can irritate the respiratory tract and, in high concentrations, be narcotic.

Procedure:

1. Wearing gloves, place the hexamethylenediamine solution in a 250-ml beaker or crystallizing dish.
2. Slowly pour the Sebacoyl chloride solution as a second layer on top of the diamine solution, taking care to minimize agitation at the interface.
3. With forceps, grasp the polymer film that forms at the interface of the two solutions and pull it carefully from the center of the beaker.
4. Wind the polymer thread on a stirring rod or a small windlass.
5. Wash the polymer thoroughly with water or ethanol before handling.

Food coloring dyes or phenolphthalein can be added to the lower (aqueous) phase to enhance the visibility of the liquid interface. The upper phase can also be colored with dyes such as azobenzene, but observation of the polymer film at the interface is somewhat obscured. Some of the dye will be taken up with the polymer, but can be removed by washing with water.

Disposal:

1. Any remaining reactants should be mixed thoroughly to produce nylon. The solid nylon should be washed before being discarded in a solid waste container.
2. Any remaining liquid should be discarded in a solvent waste container or should be neutralized with either sodium bisulfate (if basic) or sodium carbonate (if acidic) and flushed down the drain with water.

References:

- Cornell University Chemistry 207 Lab Manual
- Sly, I. Lindsay (1998), Department of Materials Science and Engineering, University of Illinois (UIUC)[Online], Available:http://matse1.mse.uiuc.edu/~tw/home.html

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Superabsorbant Polymer Demonstration

Objective: The objectives of this demonstration is to show the ability of a polymer to hydrate and form a gel.

Review of Scientific Principles:

Sodium polyacrylate powder, a super absorbent polymer. Sodium polyacrylate is a polymer, meaning that it consists of chains of identical units, known as monomers.

$$-CH_2-CH(COONa)-$$

When water is added to the white crystalline polymer, they absorb many times their size and a polymeric gel forms. In the absorbing process, the gel that forms swells.

Disposable diapers use small amounts of sodium polyacrylate to absorb baby urine. The more polymer powder in a diaper, the more urine it can absorb.

In addition to its use in disposable diapers, sodium polyacrylate, have many uses.

1. It is found in soil to help soil retain water.
2. It is used by florists as a dirt-free way to store water and to keep cut flowers fresh for a long time.
3. It is used in filtration units that remove water from airplane and automobile fuels such that vehicles perform more efficiently.
4. It is used to make Gro-Creatures, which are toys shaped like dinosaurs, fish, lizards, and other assorted animals that increase in size when placed in water. These critters can be dried out and rehydrated over and over again.

When the sodium polyacrylate is immersed in water, there is a higher concentration of water outside the polymer. When water approaches a sodium polyacrylate molecule it is "drawn" to the center of the molecule by osmosis. The ability of the polymer to absorb excessive amounts of water is due to osmotic pressure (the movement of water through a membrane permeable only to water). The sodium polyacrylate absorbs water until there is an equal concentration of water inside and outside.

Time: About 20-30 minutes of class time.

Materials and Supplies:
Baby diapers
sodium polyacrylate
Sodium Chloride
Food Coloring

General Safety Guidelines:

- The chemicals used in this demonstration should not be ingested.

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- The Polyacrylate solutions can be rinsed down the drain with plenty of water.

Procedure:

1. Fill a liter jar full of water. Add food coloring to make the water more visible—I prefer Yellow.
2. Ask the students to predict how much water can be effectively soaked up by the diaper.
3. Slowly add the colored water to the diaper until you reach the saturation point. Hold the diaper up for the students to view.
4. Next, add a few pinches of sodium chloride to the diaper. Observe.
5. Add between 20-30 grams of Polyacrylate to a 1 liter beaker. Slowly add colered water to the beaker while stirring the solution. Continue to add water until the beaker is full.
6. If you are brave, invert the beaker to demonstrate how thick the solution is.
7. Add a few pinches of salt to the beaker and stir.
8. Flush the solution down the sink with plenty of water.

References:

Mathias, Lon J., University of Southern Mississippi
[Online], Available: http://www.psrc.usm.edu/macrog/index.htm

Chemistry in Action: The Molecules of Everyday life, Morgan, Nina, Oxford University Press, New York, 1995.

Shakhashiri, B.Z., "Chemical Demonstrations", Vol. 3, chapter 9, p. 368.

PVA Slime Activity:
Preparation of the PVA solution should be carried out under a fume hood or in a well ventilated class room. The Polyvinyl Alcohol, as a solid, is mixed in water to make a 4% solution. That means add 40.0 g of PVA to enough water to make a 1.0L solution.. The best results are obtained by heating the water to about 80-90°C on a hot plate. Sprinkle the PVA powder in very gently and slowly on the top of the solution while stirring so as not to cause the mixture to clump together. Temperatures above 95°C may result in decomposition of the PVA and the creation of an odor to the solution. Continue to sprinkle the PVA into the hot solution while it is stirring. After all of the PVA has been added to the water, place a top on the vessel. If the water evaporates off, a skin of PVA will form. Allow the solution to cool, and the resulting solution will be ready for the students to use.

Estimated Time: About 30 minutes of class time.

Gack-Gluep Activity:
This activity can be very messy! You may wish to use plastic or paper cups for measuring the glue and water. A 1:1 glue to water ratio works well. If you decide to use food coloring you

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should also use latex gloves to avoid students staining their hands. I allow my students to mix the colors, creating interesting color patterns. Advise the students to store the Gack material in an air tight container or it will become brittle and lose its elastic properties.

Estimated Time: About 30 minutes of class time.

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PVA Slime

Cross-Linking Poly (vinyl alcohol) with Sodium Borate

Objective: The objective of this experiment is to explore the change in physical properties of a polymer as a result of cross-linking. The result of adding more cross-linking agents to a polymer is considered and another model of cross-linking is viewed.

Applications:

There are a number of uses of the PVA polymer we are studying:

1. They may be used in sheets to make bags to act as containers for pre-measured soap you simply throw into a washing machine.
2. The PVA sheets may be made into larger bags to be used by hospitals as containers for the cotton cloth used in the operating rooms or to hold the bed linen or clothing of infected patients.

Time: This experiment will require approximately 30 minutes to conduct and clean up.

Materials and Supplies:

- 100 ml/group of poly (vinyl alcohol) 4%
- 10 ml of sodium borate 4%
- Styrofoam or plasic cups and wooden stir sticks
- Zip lock bags or plastic 'Easter Eggs'

General Safety Guidelines:

- Laboratory aprons and goggles should be worn in this experiment as in all procedures.
- Both the borax and the PVA will burn the eyes. Hands should be washed at the end of the experiment.

Procedure:

The polyvinyl alcohol and sodium borate are mixed together in approximately a 10 to 1 ratio.

1. 100 ml of the 4% poly (vinyl alcohol) is added to a Styrofoam cup .
2. Food coloring can be added to the PVA in the cups to make different colors. Simple food coloring is recommended. This coloring should be added before any of the borax solution has been added, or it can be added directly to the borax solution.
3. Add 10 ml of the 4% cross-linker (sodium borate) to each cup. Begin stirring the mixture immediately with your wooden tongue depressor.
4. Make observations as to what is occurring as the reaction proceeds.

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5. Within a couple of minutes the slime will be formed. Lift some of it out with the tongue depressor and make your observations. Record your observations on your data sheet.
6. Take some in your hand and stretch the slime slowly. Record your observations on your data sheet.
7. Repeat the stretching exercise only this time do it rapidly. Record your observations on your data sheet. Compare the results of the two tests. The slime is non toxic and is safe to handle, so you can put it in a Zip-lock bag (or latex glove) and seal it to take home.
8. Follow good laboratory procedure and wash your hands with soap and water. It is recommended that this procedure be followed whenever handling this material. Keep it in the glove or bag until it is discarded. The sodium borate or PVA could burn your eyes.
9. Place a small amount of the PVA on a paper towel and set it off to the side to dry until tomorrow. Upon returning to class the next day, record in the data section your observation of the slime.

Data and Analysis:

Observation of the PVA before the sodium borate is added:

Observation of the PVA after the sodium borate is added:

Observation of stretching the cross-linked PVA slowly:

Observation of stretching the cross-linked PVA rapidly:

Observation of the cross-linked PVA left out in the air overnight:

Questions:

1. What are the physical properties that change as a result of the addition of sodium borate to the poly (vinyl alcohol).

2. What would be the effect of adding more sodium borate to your cup (your thoughts only)?

3. After making the observations on the dried PVA, how does the water affect the elasticity of the polymer? What is elasticity?

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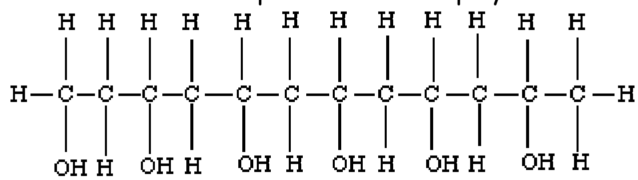
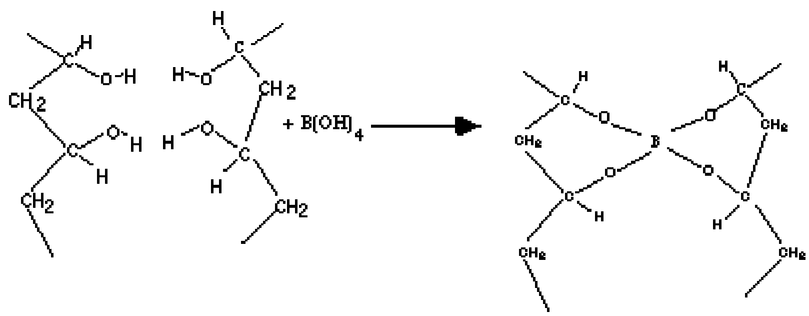
4. Find and circle the repeat unit in the polymer molecule below?



5. What is the formula of the poly (vinyl alcohol) monomer circled above? (Your teacher may want to show you how to alter this slightly after you have drawn the structure.)

6. In the picture below, circle the borax cross-linking agent.



References:

- Cornell University Chemistry 207 Lab Manual
- Journal of Chemical Education, Jan. 1986, #63, pp. 57-60.

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Synthesis of Gack

Cross-Linking a Polyvinyl acetate to make a 'silly putty' type material.

Objective: The objective of this experiment is to cross-link a polymer and observe the changes in the physical properties as a result of this cross-linking. The changes in physical properties of a cross-linked polymer are also studied as the temperature is varied.

Review of Scientific Principles:

If a substance springs back to its original shape after being twisted, pulled, or compressed, it is most likely a type of polymer called an elastomer. The elastomer has elastic properties (i.e., it will recover its original size and shape after being deformed). An example of an elastomer is a rubber band or a super ball.

Elmer's glue contains small chains of hydrocarbons, called polyvinyl acetate, suspended in water. Gack is formed by cross linking the chins to form an amorphous polymer The Gack is held together by very weak intermolecular bonds that provide flexibility around the bond and rotation about the chain of the cross-linked polymer.

Time: A 20-25 minute period is required to perform the mixing/making and cleaning up of Gack.

Materials and Supplies:

- 55 % Elmer's glue solution in water
- 4 % borax solution (sodium borate)
- Styrofoam cups
- zip lock bags
- food colors

General Safety Guidelines:

- Since borax solid and solution will burn the eyes, goggles and aprons should be worn.
- Hands should always be washed after kneading the silly putty and finishing the experiment, especially if food coloring is used.

Procedure:

1. Wear goggles and lab aprons.
2. Pour 20 ml of the Elmer's glue solution into a Styrofoam cup.
3. Add 10 ml of the Borax solution to each cup.
4. Immediately begin stirring the solutions together using the wooden stick.
5. After a couple of minutes of mixing, the Gack should be taken out of the cup and kneaded in the hands. Don't worry about the material sticking to your hands as

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these pieces will soon mix with the larger quantity with which you are working. Continue to knead until the desired consistency is reached.

6. Stretch the Gack slowly from each side.
7. Compress the silly putty back into a ball.
8. Pull the silly putty quickly from each side and compare the results.
9. Wash your hands with soap and water when you have finished the experiment.

Data and Analysis:

Describe what effect the Borax solution had on the glue\water solution.

Describe the transition of the solution material to the more 'solid-like' Gack material.

Questions:

1. How do the physical properties of the glue, water mixture change as a result of adding the sodium borate?

2. What would be the effect of adding more sodium borate solution?

CCMR

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