BEAM Fall 2011 Lesson Plan

Chemistry – Fun with Polymers!

Type: Exploration + Activity

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Overview

This lesson plan will introduce students to the chemistry of polymers, including their synthesis, properties, and various uses in our day-to-day lives. Four self-contained modules are available for students to explore depending on their level of interest and the available resources and time.

Modules 1 and 2 both provide hands-on experience with synthesizing polymers using common household ingredients such as borax and glue to make fun bouncing balls, or a combination of salts found in kelp to produce an edible polymer caviar! **Module 3** explores the properties of commonly encountered plastics by having students inspect the recycling symbols found on different plastic bottles and containers, and facilitates discussion on the environmental impact of using plastic. Finally, **Module 4** demonstrates an application of polymers in hydrogels, which are designed to absorb water and are used in many fields of engineering.

These modules are flexible and can be mixed and matched to form a complete lesson plan for students of a given level. For example, for elementary school students, the main activity could be making bouncing balls out of borax and glue and feeling a chemical reaction (a gooey one at that) take place right in front of them in a cup. This can be followed with a demonstration of the edible polymer caviar and diaper hydrogels as both reactions are visually impressive to students. Alternatively, an exploration of different types of recyclable plastic could precede a session of hands-on experimentation in which students synthesize their own polymers (in the form of edible caviar, yum) in different shapes and flavors. For high school students, a more in-depth look at the chemistry behind alginate caviar or diaper hydrogels could be both fun and fruitful, followed by an inspection of different plastics and a discussion of the environmental impacts of the plastics industry.

It's surprisingly fun to talk about all the different polymers that we encounter in our lives! Plastics such as PVC, polyethylene, polystyrene (Styrofoam), and Teflon (non-stick coating), rubber, paper (cellulose), silicones, PDMS, synthetic fibers like nylon, Bakelite, spider silk, and even DNA, all of these are polymers consisting of many smaller bonded subunits and have played an important role in the development of civilization up to the modern era.

Background for Mentors

A polymer is a large macromolecule consisting of smaller repeating, bonded subunits (monomers). For the chemistry savvy, they are produced via addition (chain) reactions in the case of polyethylene (plastic bags) or condensation reactions in the case of nylon or natural polymers such as cellulose, starch, and DNA. Multiple polymer chains can be crosslinked with each other (think the rungs of a ladder) to derive addition properties such as the elasticity and durability of rubber, and as we shall see, the bounciness of a ball composed of crosslinked glue polymers!

There are natural polymers such as the cellulose found in paper products and the proteins and DNA molecules that are essential for our bodily function. There are also synthetic polymers such as the nylon fibers in our clothing and the vulcanized rubber in car tires and shoe soles. So as you can see, polymers do have an amazing range of properties! For example, rubber is stretchy and durable, nylon is silky and smooth, plastic is hard and waterproof, and glue is sticky and viscous. The list goes on!

What are some specific uses and applications for these polymers? Polymers are found in adhesives, lubricants, and structural materials (toys, bags, foam, and aircraft parts), they are used in biomedical devices, for controlled drug delivery, and in dielectric materials, and when dawdle we at cash registers, do we really have a choice when we're prompted with, "Paper or plastic?" They're both polymers!

Polymers are an important topic for our society to understand and discuss in the context of protecting the environment from waste byproducts in polymer production and the widespread use of non-biodegradable plastics. These are topics that chemical engineers and chemists will have to address in the near future. On the other hand, it is in polymers that unbounded potential for engineering next generation biocompatible medical devices and energy-efficient fuel cells is presented! There are both advantages and disadvantages for our unprecedented use of synthetic polymers, but it is undeniable they will remain an integral part of our society for as long as we can anticipate.

For Students

- Christmas lights or paper clip analogy—take a box of paper clips and tell the students that each paper clip represents a monomer that has the potential to form into a longer polymer chain. String together several chains of paper clips to represent polymers and show that a clump of entangled "polymer" chains tends to stick together whereas a handful of individual paper clips acts more like a scattered liquid. Simply stringing the paper clips together has vastly altered their collective properties!

- Name some cool properties that polymers have that might be useful (stretchy, water resistant, tough, stiff, etc.) What are some examples of polymers in the room? What properties do they have?

- What do you think happens when we recycle plastics? How long does it take for plastics to decompose in the environment? What are some of the environmental concerns of using plastics? What are some solutions to these concerns?

Module 1: Bouncing Borax Balls

(20 to 30 minutes)

Background

Glue is made up of a polymer called polyvinyl acetate or PVA (shown below) that is designed to dry when applied between two surfaces and bind the surfaces together. When mixed with borax or boric acid in an alkaline environment, the PVA chains in glue start to crosslink with each other and form networks of branched chains much like a spider's web, giving the PVA a slimy, gooey texture. Corn starch can be added to the mixture to make the product more stretchy or bendy and to create a bouncing ball. The ball becomes bouncy because the starch (a polymer itself) gets trapped between the crosslinked chains and helps to keeps the ball compact and cohesive inside.

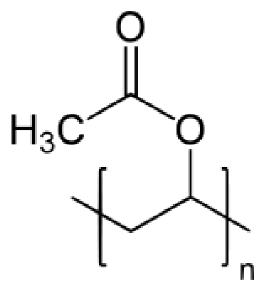


Figure 1. Polyvinyl acetate polymeric unit

Figure 2. Making bouncing balls from borax and glue!

Materials (each student should be able to make his or her own bouncy ball)

Name of material	Amount	Price
Borax (powdered)	1/2 tsp.	
Corn starch	2 tsp.	
White or transparent glue	4 tsp.	
Water (warm)	3 tsp.	-
Plastic cups (clear)	2	
Plastic spoons for mixing and measuring	2	
Food coloring	-	
Ziploc bag	1	

*Tip: Tsp. measures are not necessary—plastic spoons will do fine, it's the ratio of ingredients that counts!

Procedure

1. Prepare a clean work surface by laying down sheets of newspaper and towels in anticipation of spills. Prepare two clear plastic cups and spoons for mixing and measuring.

2. Add <u>3 teaspoons of warm water</u> and a <u>½ teaspoon of borax</u> to a clean plastic cup. Label this cup "borax solution". (Optional.) Add drops of <u>food coloring</u> to this solution for a colored ball!

3. Prepare a second cup labeled “ball solution” and add 4 teaspoons of glue into it. White glue will result in a solid ball whereas transparent glue will result in a clear ball. Be careful to keep the solutions separate as the glue will react upon mixing with the borax!

4. When ready, mix 2 teaspoons of corn starch into the “borax solution”, then pour the “borax solution” into the “ball solution”. Wait 10 to 15 seconds before beginning to stir—the borax will react with the glue during this time to begin crosslinking the chains of the PVA polymer.

5. Stir until the mixture thickens and becomes difficult to stir. Remove the mixture from the cup and try to work it with your hands. The mixture should initially be wet and sticky but solidify over time. If it does not solidify over time, try to add some more glue to the ball surface to fill in the “cracks”.

6. To finish, smear a small amount of glue on the outside of the ball. This glue will react with the remaining borax on the surface to produce a smooth, hard shell for the bouncing ball.

7. Now the ball is ready for bouncing! Try to bounce the ball off different surfaces and observe its behavior. Store the ball in a plastic bag to prevent it from getting dirty. Experiment and create more balls using different amounts of glue, water, and corn starch. Test the new creations and write down any observations.

Troubleshooting

If the ball remains slimy despite additional stirring, try to add more glue (gradually) into the mixture to react with the residual borax. If it looks like nothing is happening to the glue, try to add more borax to catalyze the crosslinking reaction. If the ball isn’t bouncing very well, try to vary the amount of corn starch!

Post Discussion

Have the students experiment with different amounts of the various ingredients and record their observations. Were the students impressed with the radical transformation of the gloopy glue? Is there a difference when more or less glue, water, and corn starch is used? What if corn starch isn’t added to the mixture? What if you don’t add enough borax?

Adding more glue should produce a slimier ball, whereas adding cornstarch should make the ball more elastic (easier to bend and stretch). Interestingly, failing to add corn starch will produce a regular ol’ slime which is also fun to mess with!

References

1. http://portal.acs.org/portal/fileFetch/C/WPCP_011041/pdf/WPCP_011041.pdf?guest=true

Module 2: Sodium Alginate and Molecular Gastronomy

(20 to 30 minutes)

Background

Alginate is a natural polymer that is derived from the cell walls of sea kelp and has a sticky, slimy, and gel-like texture when mixed with water. Indeed, alginate is added to many well-known commercial food products such as ketchup, Jell-O, and ice cream to serve its purpose as a thickening agent. In our experiment, we will mix dry alginate with water and/or fruit juice and observe what happens when drops or streams of these mixtures are added to a solution containing calcium ions. It turns out that the calcium ions help to crosslink the individual alginate polymer chains (see below), resulting in the formation of an insoluble layer of gel on the outside of the juice beads. This **may or may not** yield an appetizing polymeric caviar! Eat if you dare :)

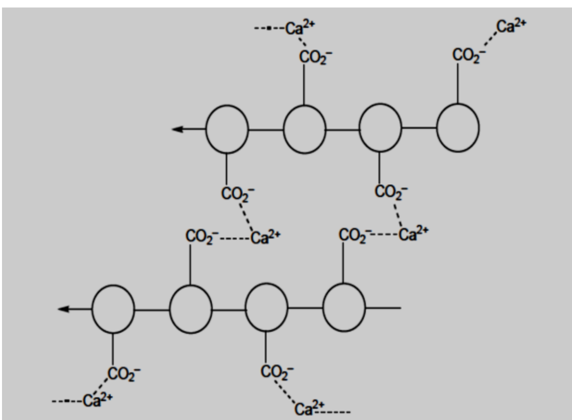


Figure 3. Crosslinking of alginate polymer chains with Ca^{2+}.

Figure 4. Polymer caviar experiment!

Materials (each group of 5 students can make their own caviar)

Name of material	Amount	Price
Sodium alginate	3 grams	
Calcium chloride	2 grams	
Water	300 mL	-
Fruit juice	150 mL	-
Food coloring	-	
Cups and bowls	3	
Plastic syringe (cut off end with scissor)	1	
Plastic spoons for mixing	3	
Whisk (optional)	-	
Strainer (optional)	1	
Newspaper, towels	-	

*Note: An empty milk carton with a funnel made of Al foil is provided for waste collection. All reagents are biodegradable.

Procedure

1. Split the students into groups of four or five each. Lay out newspaper sheets to create a work surface and pass out paper towels in case cleanup is required. Prepare the milk carton for waste collection.

2. Prepare the calcium solution. Add <u>2 grams of calcium chloride</u> (the little white balls) to an empty cup. Now add a little water to the cup. What do you observe? (The cup should heat up due to the calcium chloride dissolving in the water.) Now fill the cup with water up to the ¾ mark. Stir to dissolve.

3. Add <u>water or fruit juice</u> to a second clean cup (a wide brim is recommended to facilitate stirring). Add about <u>half of the sodium alginate</u> (white powder in a vial) to the water or fruit juice and try your best to incorporate the alginate via mixing with a spoon or whisk. The solution should start to become more gel-like with continued mixing (keep at it, as this process may take up to 5 or 10 minutes). If colored caviar is desired, add food coloring to this mixture after it is fairly homogenous.

4. Pour about half of the calcium solution into a paper bowl.

5. This is the fun part! Using a spoon or a plastic syringe, drop beads or streams of the alginate mixture into the bowl with the calcium solution. Observe the reaction that occurs and try to pick up the polymer beads after they have stabilized in solution.

6. Remove the beads from the solution with a strainer and lay them on a separate plate. If you want to try eating the "caviar" beads, it is recommended to rinse them with water first or they will taste salty!

Figure 5. Alginate beads and worms colored with food coloring.

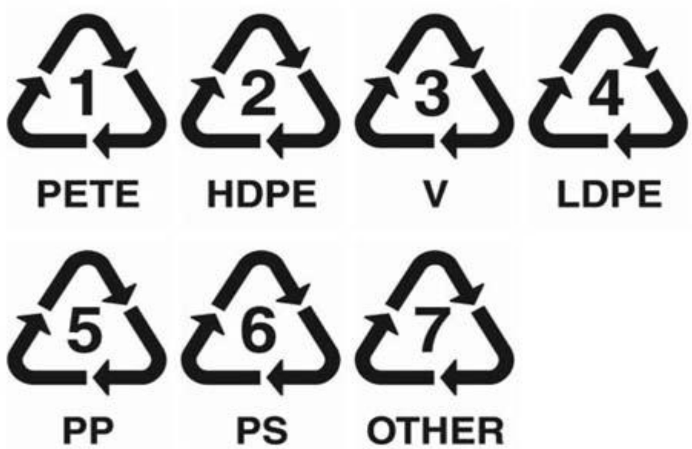
References

1. http://toastable.com/2010/08/watermelon-caviar-an-introduction-to-molecular-gastronomy/
2. http://gelfand.web.cmu.edu/scimodules/2._Gel_Beads_and_Worms.html
3. http://www.youtube.com/watch?v=xeP01iqQxi0 (video)

Module 3: Investigating Recyclable Plastic Types

(15 to 20 minutes)

Bring a bunch of different plastics to class and have the students investigate their different properties. Maybe try to identify common properties and classify the plastics accordingly. Students could play a game where after they have seen some examples of the different plastics, they are shown a new plastic container and they have to guess which recycling number it has!



Why do you think these numbers are located at the bottom of soda bottles and other plastic objects? What happens when we recycle different plastics?

1: PETE (Polyethylene Terephthalate) - Soft drink bottles, water bottles, peanut butter containers, salad dressing containers, vegetable oil bottles

2: HDPE (High Density Polyethylene) - Milk containers, bleach, detergent, and shampoo bottles, trash bags, grocery and retail carrying bags

3: PVC (Polyvinyl Chloride) - Window cleaner bottles, clear food packaging, wire and cable jacketing, medical tubing, building materials such as siding, piping, and windows

4: LDPE (Low Density Polyethylene) - Squeezable bottles, bread bags, frozen food bags, clothing, furniture, dry cleaning bags

5: PP (Polypropylene) - Yogurt containers, syrup bottles, caps, straws, medicine bottles

6: PS (Polystyrene) - Plates, cups, egg cartons, carry-out containers, compact disc jackets

7: OTHER

Module 4: Diaper Hydrogels

(15 to 20 minutes)

1. Diaper Experiment – How do hydrogels work in diapers?

    a. Grab a diaper and carefully cut through the inner lining. Remove the plastic lining and collect the cotton-like material found inside in a plastic bag.

    b. Seal the plastic bag and blow air into it such that it expands. Vigorously shake the bag until you can see powder accumulating at the bottom.

    c. Pour this powder into a cup—you may find it easier to work with only half of it at a time. We have now isolated the secret ingredient…

    d. Add a little water to the cup and observe what happens to the powder. Try to shake the cup a little bit to mix the ingredients. Add some more water until you see a transformation! Pour approximately half a cup of water into the powder, or more to test how much water the powder can absorb!

    e. After 30 seconds, observe that the water has changed—it is no longer a liquid but a gooey solid!

2. Hair Gel Experiment – How can hydrogels be deactivated?

    a. Place a glob of hair gel in a cup.

    b. Add salt to the blob and record your observations. You should see that the hair gel is becoming more and more watery as the hydrogel loses its ability to retain water.

Figure 6. Diaper content after water is added. What a change!

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BOUNCING BORAX BALL – EXPERIMENTAL PROCEDURE

Ingredients
- 3 spoons water
- ½ spoon borax
- 4 spoons glue
- 2 spoons corn starch
- food coloring

1. Add 3 spoons of water and a ½ spoon of borax to an empty cup. Label "Borax Mixture".
2. Add 4 spoons of glue to a second empty cup and label "Ball Mixture".
3. Add 2 spoons of corn starch to "Borax Mixture" and food coloring if you like a colored ball! Mix with a spoon until everything is even!
4. Now pour the "Borax Mixture" into the "Ball Mixture" cup. Wait 10 seconds before stirring! Stir the mixture with a spoon until it becomes more solid and hard to stir. This is a chemical reaction!
5. Remove the ball from the cup with your hands and mold it into a ball with your hands. Add a little glue to the surface of the ball if it is still too slimy!
6. Once it is dry, you can bounce the ball!

Can you invent a better recipe for an even bouncier ball? :)

POLYMER CAVIAR – EXPERIMENTAL PROCEDURE

Ingredients - water or fruit juice - calcium chloride (small white balls) - alginate powder (white powder) - food coloring	

1. Add the calcium chloride to a cup filled about ¾ with water.
2. Add water or fruit juice to another cup, along with about half of the alginate powder!
3. Use a whisk to mix the alginate powder into the water or fruit juice. You should see that the water becomes thicker like a gel!

Keep mixing! It takes a while!

4. Add food coloring to the mixture with the alginate if you want to make it colored!
5. Now, using a spoon or syringe, add drops or streams of the alginate water into the calcium water! What do you see happening? Try to experiment with the mixes!

What happens if you leave the beads in the water for a long time?

Can you improve the recipe to make an even tastier caviar?