Nylon Fibers and Bouncing Balls: Polymer Demonstrations at the Museum of Science and Industry

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Background: Currently, MSI runs a demonstration entitled "Polymers, Petrochemicals and You." The demonstration centers around the creation of a polymer "slime" made from Elmer's glue and Borax. Unlike many other MSI demonstrations (which may have 5-10 different possible small experiments) this demo only has one experiment available for the demonstrator to present.

Goal: Create several more experiments to be included within the "Polymers, Petrochemicals and You" demonstration cart that could be used, individually or as a series, at the discretion of the demonstrator.

Target Museum: Museum of Science and Industry. However, each individual experiment could easily be adapted for demonstrations at SciTech.

Target Audience: Grades 6-12

"**Big Idea**:" Polymers are chain molecules, made up of individual monomers, that can be modified into many different forms and used in different practical applications.

Detailed Project Description:

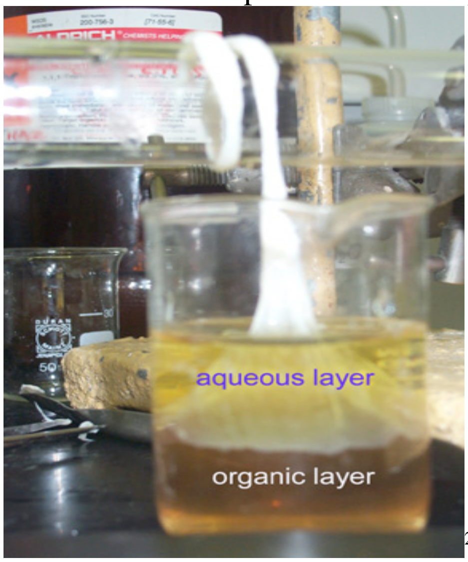
This set of experiments naturally partitions into three different "types" of polymer demonstrations, using different methods and monomers to send the same basic message.[1] For a more detailed description of each demonstration, see appendix 1.

A. Polymer Fibers. (Can also demonstrate Chemical Reactions)

   Two different demos can show the creation of polymer fibers at the interface of the two reactant solutions. In the first, the synthesis of nylon, the demonstrator presents the audience with a beaker of water containing reactant A. The demonstrator then carefully adds hexanes containing reactant B too the first

[1] Many of these demonstrations are modifications of experiments found in Shakhashiri, B.Z. Chemical Demonstrations: A Handbook for Teachers of Chemistry. University of Wisconsin Press, Madison WI 1983 and Summerlin, L.R. and Ealy, J.L. Chemical Demonstrations: A Sourcebook for Teachers; 2nd Edition vol 2.

beaker. At the interface between water and hexanes, a layer of nylon forms, which can then be pulled out with a pair of tweezers into a long continuous string.



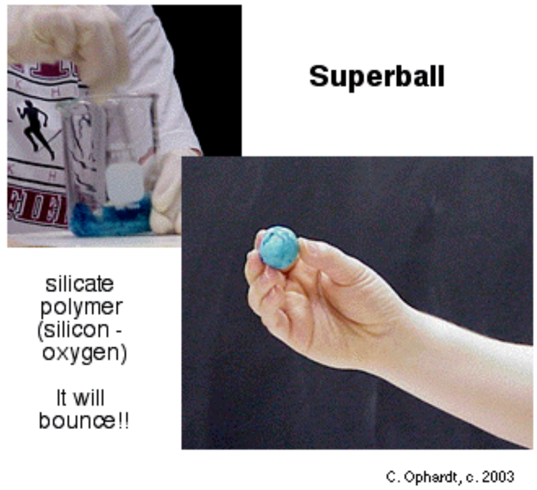
[2]

In the second demonstration of polymer fibers, crosslinked polymeric alginate 'snakes' form when an alginate (a food thickener derived from seaweed) solution is squeezed by syringe into a calcium chloride solution. The crosslinked alginate snakes are safe for handling by the audience.

B. The properties of a polymer depend on the monomers used.

In this demonstration, two different "rubber balls" are created in front of the audience by the demonstrator. The demonstrator mixed the necessary chemicals and the audience (if provided with gloves) can roll the balls themselves. One ball (made of latex) is malleable and bouncy, the other (made of silicone) is bouncy but can crumble.

[2] http://www.kcpc.usyd.edu.au/discovery/9.5.2/9.5.2_nylon66.html



[3]

C. Polymers can do strange things!

This series shows that polymers have strange, unexpected qualities. In one demonstration,"the rod-climbing polymer", there are two bowls: one contains water and the other contains the rod-climbing polymer. When a rod is spun in the bowl of water, the water spreads away as it is flung towards the edges of the bowl. When a rod is spun in the polymer, it does not spin away, but starts to climb the rod against gravity. (This can be related to how dough gets stuck on the mixing paddles of a hand blender).

In the second demonstration, the "tubeless siphon," the demonstrator begins pouring a polymer fluid from a higher cup to a lower cup, then tilts the higher cup upright again. If this were water, the fluid flow would stop. With this polymer, the fluid continues to siphon over the edge of the higher cup into the lower cup.


[4]

[3] http://www.elmhurst.edu/~chm/demos/
[4]http://genchem.chem.wisc.edu/demonstrations/Gen_Chem_Pages/22organicpage/organic main.htm)

Evaluation Plan: Thanks to our earlier evaluations, we already have an idea of the type of polymer-related demonstrations that MSI audiences want to see. The Nylon demonstration scored particularly high in our evaluation. In order to evaluate these demonstrations, we would design each individual experiment and then test them on the museum floor to gauge audience responses. Based on these tests, we would continue to revise the demonstration manuals until we were satisfied.

Appendix 1: Detailed Descriptions of each experiment

Nylon Demonstration

Description

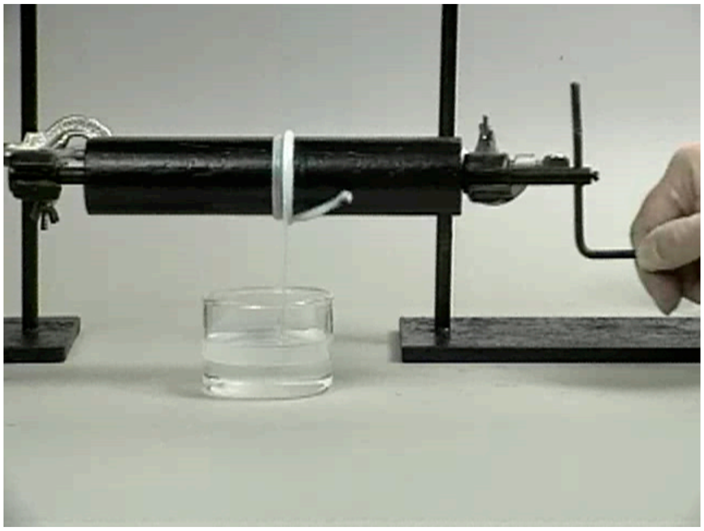
Upon engaging an audience, the demonstrator would first walk them through a background info introductory conversation that includes the idea that polymers are molecular chains, what is an example of something made of nylon, and that chemical reactions happen when two reactants get close together. The demonstrator would then prepare a small beaker with the bottom water layer already in place, and would invite the audience to watch as the top hexanes layer was added, forming a nylon layer in the middle. Due to the mild toxicity of the ingredients, the audience wouldn't be able to pull out the nylon themselves, but hopefully we can design a device that would allow them to turn a winch to reel the nylon out of solution after the demonstrator sets the system up.

Next, the demonstrator would use another beaker to shake the two components together, producing nylon powder. On the demonstration cart, we will have vials containing washed and dried samples of both the nylon string and the powder for the audience to examine.

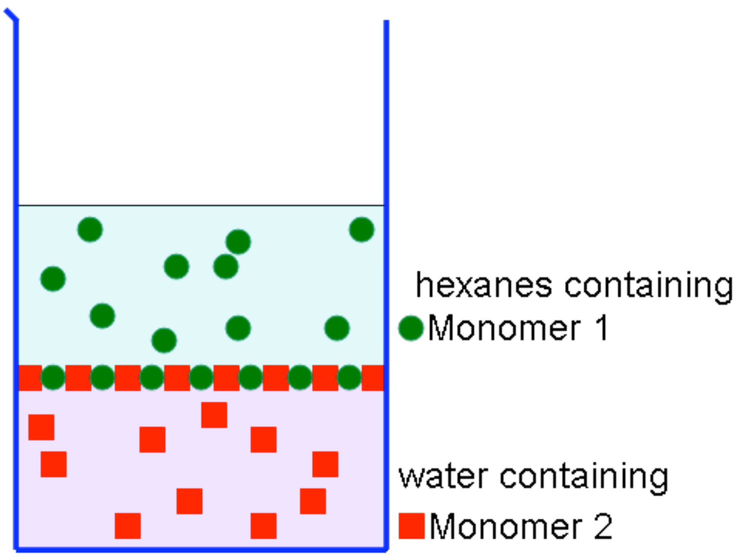
Science of demonstration

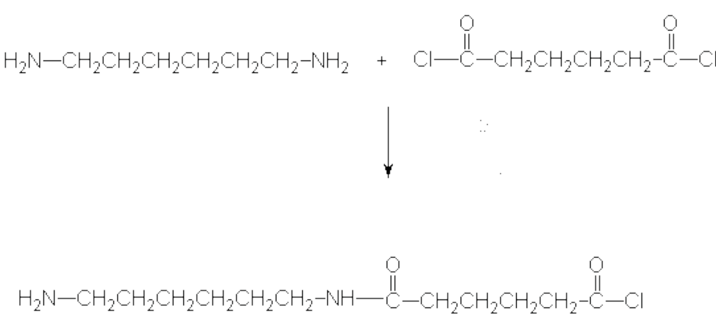
Nylon rope synthesis has the extra potential to be a basic lesson in chemistry: Chemical reactions happen when two reactants mix. Nylon is produced at the interface of two immiscible solutions containing the two required reactants to produce nylon.

Nylon- 6-10, commonly used in clothing and consumer plastics is a polymer of alternating monomers (ABABABA…). One reactant is dissolved in hexanes, and the other is dissolved in water. The two solvents don't mix so the reactants only come into contact at the fluid interface. A layer of nylon forms at this interface and can be pulled out with tweezers to form a slender rope. As the nylon is pulled out it exposes fresh solutions at the interface and adds more and more nylon, forming a continuous string. Alternatively, a nylon powder can be made by shaking or stirring the two solutions together to give an emulsion (like when you shake oil and vinegar before pouring on your salad). Each bead of the emulsion forms a tiny bead of nylon.



The audience can participate by turning crank after demonstrator initializes the string.[5]



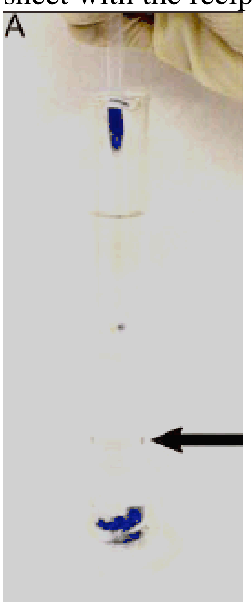

[6]

[5]<http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA5/MAIN/1ORGANIC/ORG16/NYLON/PICTURE.HTM>

Hazards: the two reactants are corrosive and the solutions must be handled with gloves.

Alginate snakes

The demonstrator will again discuss the concept of a polymer as a molecular chain. For the alginate snakes, the concept of crosslinking would be introduced. When polymer strands are 'locked together' at various places in the polymer strand, they are called crosslinked. To demonstrate formation of cross-linked polymers, the demonstrator would prepare a solution of sodium alginate by dissolving 2 grams of alginic acid in water. Alternatively, the commercial antacid Gaviston can be used. Food coloring can be added. The demonstrator next would fill a syringe with the solution. When the alginate solution is squirted with a steady flow into a solution of calcium chloride, cross-linked gel 'snakes' form. When sodium alginate hits the calcium solution, the calcium ions displace all of the sodium ions. Since the sodium ions have a positive one charge, they are only able to bind to one alginate molecule at a time. The calcium ions have a positive two charge, so they can bind to more than one alginate molecule at a time. This is how the calcium ions crosslink the alginate to form alginate snakes. This demonstration is non-toxic and all ingredients are available at the grocery store so the children can take home a sheet with the recipe.[7]



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[6] Images and descriptions from http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA5/MAIN/1ORGANIC/ORG16/NYLON/THUMBS.HTM and Shakashiri, Chemistry Demonstrations vol 1.

[7] For more information, see: http://www.elmhurst.edu/~chm/demos/gavisconsnakes2.htm or Nowick et al. "The Alginate Demonstration: Polymers, Food Science, and Ion Exchange". Journal of Chemical Education, 75 (11), 1998.

“Rubber” Balls

The physical properties of polymers can vary widely depending on the monomers used. The demonstrator can have a couple different rubber balls on display to illustrate this, for example a neoprene bouncy ball and a norbornene non-bouncy ball. Norbornene is a good shock absorber which is why it doesn’t bounce much, while neoprene does not absorb shocks so it bounces back. Car tires are made of a mixture of both polymers to get the benefits of shock absorption from norbornene and the durability of neoprene. This demonstration also includes synthesis of two other types of rubber balls. The latex ball is made by mixing liquid latex solution with vinegar. Liquid latex is made of globules of rubber, as from rubber trees. These globules are kept separated in solution by ammonia. When the vinegar is mixed with latex the vinegar neutralizes the ammonia and the latex rubber polymerizes, allowing it to be molded into a ball that bounces (and is stretchy). The silicone ball is made by mixing sodium silicate (liquid glass) solution with ethanol. The ethanol crosslinks the silicate monomers to form a rigid bouncy ball. This ball, however, does not stretch but crumbles when it is squished.

Rod-Climbing Polymers

In normal ‘Newtonian’ fluids, the molecules of the fluid can tumble over each other freely. Even in viscous fluids like glycerol or corn syrup, the molecules move freely, albeit slowly, in all directions. Many kinds of polymer liquids, on the other hand, are made of long polymer strands that can tumble freely in all directions until a stress is applied to the liquid, i.e. stirring or pouring. The act of stirring or pouring strains the polymer strands in one direction and the extended network of strands have more difficulty sliding over each other in that direction. Instead the polymer strands get tangled and the fluid viscosity increases. These liquids, ‘Non-newtonian’ fluids, show some very odd properties. One such property is ‘rod-climbing’. It is instructive in each demonstration to compare the polymer fluid with a normal fluid like water. To demonstrate rod-climbing, the demonstrator will have two bowls, one contains water the other contains the polymer fluid (previously prepared and reusable poly(acrylamide)). When a stirring rod (like in the diagram below) stirs the water solution the water flings out towards the sides of the bowl and creates a whirlpool around the rod. When the stirring rod stirs the polymer solution, the fluid climbs the rod in a direction perpendicular to the applied stirring force. When stirring stops, the fluid flows back down into the bowl.

A solution of polyacrylamide in glycerin climbs a vertical rotating rod.[8]

Tubeless Siphon

Another demonstration of the pull of a polymer's extended network is in the "tubeless siphon". Again, the demonstrator would compare the behavior of water with a previously prepared polymer fluid (poly(ethylene oxide)). When one pours water from one beaker to another, then uprights the beaker, the water stops flowing. The polymer fluid, however, has an extended structure that becomes more entangled and resistant to flow in the direction of an applied force. So the polymer strands that have already fallen over the side will continue to exert a pull on the fluid still in the beaker. The fluid continues to siphon over the edge of the beaker.


An aqueous polyethylene oxide solution, once started, will siphon over the edge of a beaker.

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[8] photo from http://genchem.chem.wisc.edu/demonstrations/Gen_Chem_Pages/22organicpage/organicmain.htm

In addition to these two demonstrations, a bowl of cornstarch fluid and some silly putty could be present as examples of Non-Newtonian fluids that are readily available from the grocery or toy stores. If the audience stretches the silly putty slowly, it can stretch into long strands. But if stretched quickly it breaks as if it is very brittle. Cornstarch in water creates 'oobleck' which acts like a solid when it is cut or hit but flows like a liquid.

http://www.science-house.org/CO2/activities/polymer/oobleck.html

Appendix 2: Estimated Costs for All Experiments

	chemical	amount	price	amnt needed for 1 demo		cat no	price per demo
nylon	1,6-Hexanediamine	100g	15.8	3g	fisher	AC12064-0010	$6.25
	SEBACOYL CHLORIDE	25mL	29.15	1.5mL	fisher	S75197	
	NaOH	100g	31.12	1g	fisher	S318-100	
	hexane	1L	74.3	50mL	fisher	H292-1	
polyurethane	kit		33.05		fisher	S73009	$33.05
tubeless siphon	poly(ethylene oxide)	5g	25	5g	aldrich	372773-5G	$25.00
rod climbing	glycerol	1L	69.83	1L	fisher	BP229-1	$92.23
	poly(acrylamide)	5g	22.4	5g	aldrich	181277-5G	
silicone superball	sodium silicate	1L	5.3	10mL	fisher	S93379	$0.09
	ethanol	500mL	6.95	2.5mL		S73979	
						total	
latex ball	liquid latex	473mL	13.95	15mL	liquidlatex.net		$0.50
	acetic acid (white vinegar)	500mL	2	15mL	grocery store		
alginic polymer snakes	alginic acid	100g	28.4	2g	fisher	AC27058-1000	$0.61
	calcium chloride	100g	3.9	1g	fisher	S75069	

Appendix 3: Benchmarks Achieved in the Illinois State Learning Goals for science.
http://www.isbe.state.il.us/ils/science/pdf/goal12.pdf

STATE GOAL 12: Understand the fundamental concepts, principles and interconnections of the life, physical and earth/space sciences.

C. Know and apply concepts that describe properties of matter and energy and the interactions between them.
EARLY ELEMENTARY
12.C.1b Compare large-scale physical properties of matter (e.g., size, shape, color, texture, odor).

LATE ELEMENTARY
12.C.2b Describe and explain the properties of solids, liquids and gases.

MIDDLE/JUNIOR HIGH SCHOOL
12.C.3b Model and describe the chemical and physical characteristics of matter (e.g., atoms, molecules, elements, compounds, mixtures).

LATE HIGH SCHOOL
12.C.5b Analyze the properties of materials (e.g., mass, boiling point, melting point, hardness) in relation to their physical and/or chemical structures.