Slime

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Just in time for Halloween, we'll make some slime. Everyone has a feeling about how slime should act; of course, it should be slimey! It should stick togther and drip, but it should not come apart. So there should be something about slime that keeps it stuck together, but still allows it to move and sag. The principle of slime is in the cross-linking, or connecting, of molecules that are long "chains" to begin with. Gelatin (the stuff used to make Jello) is a good example of a long chain molecule. In this case, the cross-linking agent is heating/dissolving in water, followed by cooling. The water used in the mixing of Jello is suspended within a matrix of cross-linked gelatin molecules, and does not easily evaporate as it would if it were simply sitting in a cup.

Another useful long chain is Poly Vinyl Acetate, contained in conventional "white glue" or "Elmer's" glue. In this case, a chemical additive - simple, supermarket-style "Borax" (sodium tetraborate decahydrate, $Na_2B_4O_7.10H_2O$) - serves as the cross-linking agent. And again, water is entrapped, or suspended within the matrix of cross-linked Poly Vinyl Acetate molecules.


(photo: see reference 6)

Steps to Slime

1. Thoroughly mix ½ cup of water and ½ cup of white glue ("Elmer's School Glue") in a tall paper or plastic cup.

2. Add a few drops of food coloring to the water/glue mixture, again mixing thoroughly. This will be your "Glue Solution".

3. In a separate cup, mix 1/2 cup of water and 1/2 teaspoon of "Borax". The objective is to make a saturated Borax solution, that is, one in which the Borax will not continue to dissolve after mixing. This will be your "Borax Solution". See the notes below in the "chemistry" section regarding the borax solution.

4. Now you are ready to slimify. Get ready to pour a small amount of Borax Solution into your Glue

Solution, being prepared to mix the two very rapidly with a big flat tongue depressor or similar flat stirrer.

5. For very firm slime, add a large amount of Borax Solution to your Glue Solution. For drippy slime, add a small amount of Borax Solution to the Glue Solution and mix very rapidly and thoroughly.

Some Observations

1. Place the slime in a bowl and let it sit overnight. It will most likely be a lumpy mess when you place the slime in the bowl, but by morning, the slime will have settled nicely into the bowl, forming a level surface, with a collection of surface bubbles from air that was trapped within the slime when it was mixed.

2. Gently lay a fork (prongs down) onto the surface of the slime. In several hours, the fork will have sunk into the slime, and the slime will encapsulate the fork. The fork will tear the slime if it is removed rapidly. Similarly, if pulled slowly, slime can be stretched into thin sheets or strings. But if pulled quickly, the slime can be forced to break or fracture along a relatively flat plane.

3. The biochemist in our group contends that the cross-linking reaction is endothermic; that is, that the linking reaction sucks energy from the surrounding volume of slime and making the slime cool to the touch. However, the physicist in our group points out that the whole blob of slime is largely water, imperfectly trapped within a matrix of polymer, so water evaporation goes on continuously over the surface of the slime, cooling the surface. Additionally, because of the high water content of the slime, the thermal conductivity of the slime is essentially that of water, and feels cool to the touch, even if it is the same temperature as the ambient. So, like good scientists, we'll have to get out our thermometer and actually TEST the temperature of the slime to see if it ended up at a lower temperature than when it started.

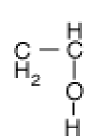
Some Chemistry

Now that we've made a mess, let's see if there is some science behind all of this. The chemistry that we'll describe is complicated, but some of our readers will want to read about all of these details. What is nice about this is that there is a little bit of science for younger children, while there is also some considerable detail left open for study by even the most advanced chemists. None of us are organic chemists, so we're depending on the literature and the web for accurate information, hopefully derived from more-or-less primary sources. There is a lot of "vapor" on the web, so we've tried to filter out most of it in our search. We would appreciate corrections and comments from our readers.

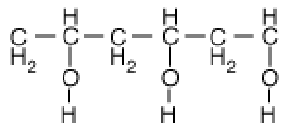
First we see that we've been a little lax about our nomenclature. The long-chain, cross-linked polymer that we've made from PolyVinyl *Acetate* is actually called "Gluep" or "Gack", while the polymer made from Poly Vinyl *Alcohol* is called "Slime". Volumes have been written about the mechanism responsible for the cross-linking of PVAlcohol, while the web is substantially less complete about the details of the chemistry responsible for cross-linking PVAcetate.

Cross-Linking PolyVinyl Alcohol

So we start with the single Vinyl Alcohol molecule (called an *alcohol* by the addition of the hydroxyl group OH- to the vinyl group CH_2-CH)



and string a bunch of them together to form *Poly* Vinyl Alcohol.



Now we have some polymer ready for cross-linking. Our objective will be to add something that will bind several of these long molecules together side-by-side, something like the rungs of a ladder. We start by dissolving some Borax ($Na_2B_4O_7.10H_2O$) in water, which dissociates into sodium ions and tetraborate ions.

The tetraborate ion reacts with water (hydrolyzes) to produce boric acid and the OH^- ion.

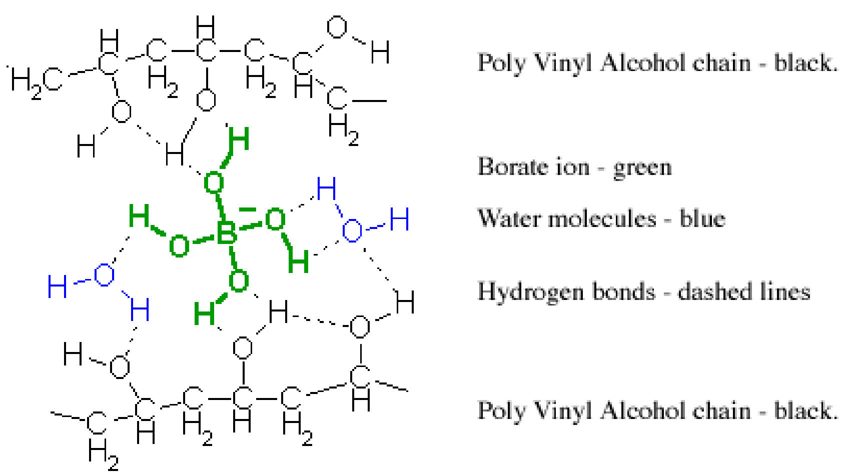
$$B_4O_7^{-2}(aq) + 7\ H_2O \ \longleftrightarrow\ 4\ H_3BO_3(aq) + 2\ OH^-(aq)$$

The boric acid further reacts with water to form the borate anion.

$$H_3BO_3(aq) + 2\ H_2O \ \longleftrightarrow\ B(OH)_4^-(aq) + H_3O^+(aq)$$

So now we have the form of the borate ion that we need. The $B(OH)_4^-$ ion is shaped like a tetrahedron (four sides, each side is an equilateral triangle) with the boron in the center and the OH groups at each corner. *Hydrogen bonds* form between the borate ion and the OH groups on the sides of the Poly Vinyl Alcohol.

These bonds are not very strong, and are broken and reformed easily, allowing the slime to sag and move slowly under stress. A particularly good picture is available in Reference 3.

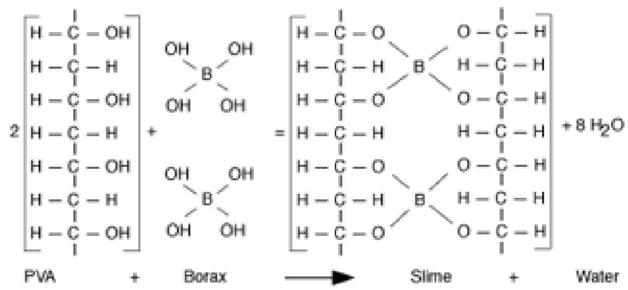


Let's study this scrambled mess. The green borate ion is in the middle, the PVA chains are on the outside and are bent and twisted, water molecules are dispersed randomly throughout the assembly and dotted blue lines (hydrogen bonds) make connections between Oxygen and Hydrogen, especially to those Oxygen and Hydrogen that are paired up and sticking out the sides of the PVA chains. There are some important features in this picture:

a) the polymer chains distort to allow these hydrogen bonds to occur, and

b) water molecules dispersed throughout the mess add to the hydrogen bonding.

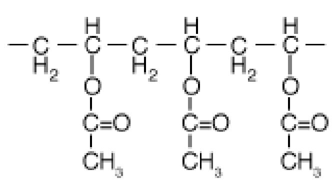
Reference 2 and others describe the cross-linking in a way that does not emphasize the importance of hydrogen bonding, and by imagining that the water remaining in the slime really doesn't have much of a role to play. They draw a simplified picture like this;



Notice that this picture describes the bonding as if a water molecule had simply been removed from each bond site. This treats the bond as a covalent bond, and not the weaker hydrogen bond which we believe is responsible for the true nature of the relatively weak cross-linking. This is supported by the discussion in Reference 1.

Cross-Linking PolyVinyl Acetate

So what about Poly Vinyl Acetate, the long chain that we've used to make our "Gluep", "Gack" or whatever we're calling it? The acetate groups (CH_3-CO=O) attached to the Vinyl groups make the long chains look a little different.



Resources on the web are very vague about what happens to the Poly Vinyl Acetate to allow cross-linking. At least one reference (see Ref. 5) indicates that the Poly Vinyl Acetate (Elmer's glue) in water tends to lose some of the acetate groups into solution, only to have these groups replaced by O-H groups as in Poly Vinyl Alcohol. Then, cross-linking occcurs in the same way as before. However, if this is the case, then Slime and Gluep should be pretty similar to each other. But other sources point out that the borate ion in the middle of everything is still charged, and that adding acid to the cross-linked polymer can pull the borate out of the links (the hydronium ion attracts the borate ion) and dissolve the slime back into an aqueous PVA solution again. So we're going to have to do some experiments to find out what is going on.

Note About the Borax Solution.

At room temperature, a saturated solution is about 4% by weight of Borax to water (the density of Borax is about 1.7 gm/ml; see Ref. 4). As the temperature rises, the amount of Borax that can be dissolved in water will increase. Heating the water (below the boiling point!) will help the borax to dissolve, but make sure you allow it to cool before using it. As the temperature falls, excess Borax will precipiate out of the solution and sit on the bottom of the cup. Use the saturated solution for your experiments and leave the undissolved crystals sitting on the bottom of the cup.

References

Please e-mail us if you cannot find these references.

1. Casassa, E.Z., Sarquis, A.M., and Van Dyke, C.H., "The Gelation of Polyvinyl Alcohol with Borax," *Journal of Chemical Education*, Vol. 63, #1, January, 1986, p.57-60.

2. www.rohmhaas.com/company/plabs.dir/htmldocs/itstheslime.html

3. www.madsci.org/posts/archives/2003-12/1070294201.Ch.r.html

4. www.borax.com/pdfs/dist/Profile_Borax_Decahydrate.pdf

5. www.chemistry.lsu.edu/webpub/demo-2-silly-putty.pdf

6. www.psrc.usm.edu/org/Polymer%20Demos/Pdf/slime.pdf