

## PVA gelation with Boric Acid and NaOH (degelation with HCl)

Polyvinylalcohol 78,000 g/mole (4 percent solution in water by weight about)

Boric Acid (4 percent solution in water by weight about)

Hot plate and water

(Note: solutions were made by “eyeballing” method, precision is not very important)

- 1) The PVA and boric acid need to be heated to go into solution. We basically brought the water almost to a boil before they went into solution. (You need to melt the crystals of both before they dissolve.)
- 2) Mix a relatively small amount of the boric acid solution into the PVA solution and you make slime. The OH groups of the boric acid seem to bond to the hydroxyl groups of the PVA through the sodium ion. With just boric acid there is, on average, one sodium ion per boron so full crosslinking is not possible. The system can form very high molecular weight molecules but they do not percolate to form a gel.
- 3) To alleviate this situation you can add a 10% solution of NaOH in water. This must also be heated to go into solution quickly. By providing unlimited  $\text{Na}^+$  ions the system percolates in about 10 seconds after adding about 10% of the NaOH solution to the boric acid/PVA/water slime. If you mold the gel with your hands using gloves you can make a nice rubber ball. The rigidity of the ball depends on the amount of boric acid you added at the initial slime stage. More boric acid leads to a tougher ball. This is because the molecular weight between boric acid crosslink sites is the initial molecular weight, 78,000 g/mole, divided by 4 times the number of boron atoms per PVA chain (about 20) since boron is tetrafunctional. You need to play around with the recipe to make a good rubber ball that bounces. Depending on the boron content you can get slime to a hard marble like ball.
- 4) If sodium is the vital ingredient to form a percolated network, it can be removed with an acid such as HCl to form water and NaCl. For this to work well you need to use concentrated hydrochloric acid (in water) since the dissolution of acid into the rubber ball is slow. It is possible to make the rubber ball turn into a fairly low viscosity liquid by soaking it with HCl. Depending on the concentration of HCl and the amount of boron in the rubber ball this can be instantaneous or can take half an hour to fully work.
- 5) The modulus of the rubber ball depends on the molecular weight between crosslink sites,  $n$ , and the absolute temperature,  $T$ ,  
$$E \sim kT/n$$
The degree of swelling of the gel depends on the affinity of the polymer to the solvent through the solvent/polymer interaction parameter,  $\chi$ , which is strongly negative for a good mixing and positive for immiscibility. The degree of swelling is measured by  $Q$ , which is the volume of the swollen gel to the volume of the dry gel. Following Flory-Rehner Theory,  
$$Q \sim (-\chi n/V_1)^{3/5}$$
Where  $V_1$  is the molar volume of the solvent.