# Lab 29: Cross-Linking of a Polymer

## Goals

1. To observe the cross-linking of a polymer

2. To better understand the process of solidification of a material by cross-linking

3. To observe a non-Newtonian fluid

4. To better understand a hydrogen bond

## Materials and Equipment

150-mL beaker
30-mL beaker
Polyvinyl alcohol (*PVA*)
Sodium tetraborate
Wooden stir stick
Measuring spoon, 1.0 mL

## Materials Not Included

Paper plate
Food coloring (optional)
Source of heat

## Introduction

Many common materials solidify by forming cross-links between molecules. Examples include epoxy and ordinary silicon caulk. Cross-linking is the bonding together of adjacent polymer molecules, often by smaller molecules of another material. Cross-linking occurs in all directions and usually forms a three-dimensional network. Polymers can have thousands of monomers in a single atom, and one polymer molecule can cross-link to many other molecules.

Most vinyl polymers are not water soluble. Polyvinyl alcohol (*PVA*) is soluble, however, because it has ($OH^-$) hydroxyl groups. This allows the *PVA* to form a colloidal suspension in water because the hydroxyl ($OH^-$) groups are ready acceptors for hydrogen bonding. (See the introduction for Lab 26: Organic Chemistry Models for more information about hydrogen bonding.) This allows *PVA* to interact with polar water molecules and makes *PVA* soluble. Because of the hydrogen bonding, *PVA* molecules will also interact slightly with each other. This increases the viscosity in the solution, depending on the concentration.

Borate ions, $B(OH)_4^-$, are formed in stepwise reactions when sodium tetraborate dissolves in water. The first step is the formation of boric acid:

(1) $Na_2B_4O_7 + 7H_2O \rightarrow 4B(OH)_3 + 2NaOH$

Boric acid then accepts a hydroxide from water:

(2) $B(OH)_3 + 2H_2O \leftrightarrow B(OH)_4^- + H_3O^+$

Borate ions, $B(OH)_4^-$, can form hydrogen bonds with all four of its hydroxyl groups between adjacent *PVA* polymer molecules. This is a hydrogen bond cross-link. Although these hydrogen bonds are relatively strong, they are also dynamic, so they are constantly forming and dissociating. This gives slime the ability to flow or ooze while still having some strength and elasticity short-term.

Slime is a good example of a non-

Newtonian fluid. A non-Newtonian fluid is a fluid in which the viscosity changes with the applied strain rate. It stretches when pulled slowly, but breaks when pulled quickly. As a result, non-Newtonian fluids may not have a well-defined viscosity.

## Devotional

*"As you come to him, the living Stone—rejected by men but chosen by God and precious to him—you also, like living stones, are being built into a spiritual house to be a holy priesthood, offering spiritual sacrifices acceptable to God through Jesus Christ."*
*1 Peter 2:4-5*

*"Dear friends, let us love one another, for love comes from God. Everyone who loves has been born of God and knows God." 1 John 4:7*

**Principle: The strength of community comes from relationships.**

When a polymer cross-links, the physical properties can change dramatically. Without the cross-links, some polymers are very fluid. But once the linkages are in place, this same substance can be a rigid solid. Epoxy is like this. The strength of the cross-linked polymer comes from both the number of linkages and the strength of the linkages. In Peter's illustration of the house given above, the building materials are added to one another to make a structure. If the structure were of stone, the stones would be cut and fit into place so that they interlocked with each other. Once interlocked, the stone walls could stand for centuries, or even longer.

Communities gain their strength from relationships. In some communities, people know each other for a lifetime. They have been through storms and through stress. They may have helped and served each other. All this makes a relational linkage between the people. These are bonds of community. The same can be true in the family as well. In the church, there is an additional element that binds people together. The Holy Spirit acts as an agent to bring the community together in love. Again, it is through common ministry together or by serving one another that bonds of friendship and love are established. Sometimes these bonds are so strong that they can be sensed by those who enter from the outside. Those who don't have love in their lives may be drawn to this love. Sharing why we love is a wonderful way to bring people into the kingdom of God.

## Procedure

***Note: Sodium tetraborate is slightly toxic (it is used as a laundry detergent enhancer). Do not ingest the slime, and wash your hands after handling it.***

***Note: Heat the water <u>before</u> you add the PVA.***

***Note: You may use the digital balance to measure the reagents.***

1. Put 50 mL of hot water in the 150-mL beaker (or heat the water to about 85° C in a microwave). Use the 1-mL measuring spoon to add 3 scoops (about 2.1 g) of polyvinyl alcohol (*PVA*) to the 50 mL of hot water in the beaker. Stir this with the stir stick to dissolve the *PVA*. Allow this to cool until it is comfortable to handle.

***Note: It might take some time to dissolve all the PVA, and you may need to reheat the water.***

2. Observe and record the properties of the *PVA* solution (question 1 in the questions section). Add a drop or two of food coloring if you desire to have the slime colored.

3. While the *PVA* solution is cooling, stir one half (½) to three fourths (¾) of a scoop (about 0.4 - 0.6 g) of sodium tetraborate into 10 mL of warm water in the 30-mL beaker.

4. Stir the sodium tetraborate solution

into the *PVA* solution. While stirring, lift the stir stick out of the solution several times to observe the viscosity and other property changes. Record this in the questions section.

5. It may take several minutes for the cross-linking to occur and for the material to become more solid. This result is slime.

6. Put the slime on a paper plate or other clean surface.

7. Remember to clean up.

# Lab 29

## Questions for Cross Linking of a Polymer

1. Describe the properties of the *PVA* solution before you mixed it with sodium tetraborate. What was the viscosity? Was it sticky?

2. How do the properties of the *PVA* change when the sodium tetraborate is added? What did you observe as you lifted the stir stick out of the solution as you were mixing the two solutions?

3. What causes the change in the properties of the solution when the sodium tetraborate is added?

4. The formula of a monomer of *PVA* is $C_2H_4O$. Find the molecular mass of the monomer.

5. The molecular mass of the *PVA* in this solution is roughly 100,000 amu. How many monomers are in the *PVA* chains?

6. A non-Newtonian fluid is a fluid in which the viscosity changes with the applied strain rate. If pressure is applied quickly, it acts differently than if pressure is applied slowly.

a.) Pull the material apart quickly. What happens? Put the material back together and slowly pull it apart. What is the difference? What effect do the molecular mass of the *PVA* and hydrogen bond cross-links have on its physical properties?

b.) Roll a small piece of slime into a ball and drop it. What happens? Place that ball onto the counter for a few minutes. What happens? Is slime a non-Newtonian fluid? Why or why not? You might want to do more research about non-Newtonian fluids on the Internet.



7. The cross-linked polymer initially contains a high percentage of water (about 96% water). How do the properties of the material change as the water evaporates out of it? You may want to leave a piece of the material uncovered overnight to observe how it changes when the water it contains evaporates.