Polymer Properties

Introduction

Polymers are very large molecules that are formed from linking repeating units of atoms called **monomers**. You encounter polymers daily in a variety of contexts. The plastics that we use to package food, make waistbands stretchy, make cell phone cases and many other things are all different types of polymers. The starch in a potato or the cellulose in a lettuce leaf are also polymers. The DNA that codes your generic information and the proteins that are responsible for keeping you alive are also polymers. Different polymer structures are what give these materials their wide range of properties, from rigid polymers in chairs to stretchy and flexible polymers in clothing. These properties depend on many factors, starting with the structure of the monomer building blocks and the bonds that connect monomers to form long chains. Interactions between these long polymer chains also lead to the polymer's properties. For instance, polymer chains that are rigid like uncooked spaghetti interact with one another much differently than chains that are more flexible, like cooked spaghetti that can bend and twist and intertwine with other chains. In this experiment, you will explore the impact of temperature on the properties of a polymer and explore the interesting properties of a polymer suspension.

The flexibility of a polymer is heavily influenced by the ability of individual chains to move relative to one another. One way to make polymers more rigid is to chemically bond chains together so that they cannot move easily. Alternatively, small molecules called plasticizers can be added to serve as a lubricant to allow polymer chains to slide more easily against each other, leading to less rigidity. Even something as simple as temperature changes can influence properties. Some polymers undergo dramatic physical property changes as temperature decreases. If the temperature of those polymers is lowered below a particular value, called the glass transition temperature (T_g), the polymer will undergo a change from a rubbery to a glassy state. Above this temperature, the polymer will be flexible and rubbery, but below the glass transition temperature, it will be hard, rigid, and glassy. In this experiment we will take a polymer that are rubbery and flexible at room temperature and cool them in liquid nitrogen to 77K, or -196^{o}C, which is well below their glass transition temperature.

Polymers can also be used in conjunction with other materials to produce polymer solutions or suspensions that have interesting properties. A **colloidal suspension**, or simply **suspension**, consists of solid particles that have at least one dimension in the range of 3 nm to 1000 nm dispersed in a liquid. Polymers and polymeric solutions and suspensions of polymers frequently show deviations from the simple Newtonian behavior we would expect from most liquids, where the stress applied to the liquid is directly proportional to the resulting strain. For example, if you apply twice as much force to a paddle in water, the Newtonian behavior of water allows the paddle to move twice as fast. Paints, for example, are formulated to be non-Newtonian; that is, they exhibit a decrease in viscosity as the rate of force increases. As you apply paint with a brush or roller, you quickly apply much force or stress, and the paint flows easily. Then you look at the paint on the ceiling or walls and hope that it does not flow to the floor. Acted upon only by the weak constant force of gravity, the viscosity is now too high to allow flow. In this experiment, you will observe a non-Newtonian property called **dilatancy**, an increase in viscosity as the rate of applied force increases. After you do this experiment, you should understand why dilatancy would be a terrible property for paint.

Experimental Procedure:

A. The Glass Transition[1]

CAUTION: Handle liquid nitrogen and any items that have been immersed in it with care! Liquid nitrogen (N_2) can cause frostbite, avoid skin contact! Never pick up anything frozen in liquid nitrogen with your bare hands, use tongs or heavy gloves!

Instructor demonstration:
Your instructor will obtain a hollow rubber ball, like a racquetball, and bounce it several times to demonstrate its properties at room temperature. They will then cool the ball in liquid nitrogen to bring it below its glass transition temperature. Upon carefully removing the ball using tongs, your instructor will throw it against the floor to demonstrate the properties of the polymer at a temperature below T_g. You should make careful observations at all stages of the demonstration.

Procedure for observations below T_g (aka fun with liquid nitrogen!)
Working with your partner(s), complete the following.

1. Obtain a solid rubber ball (such as a small Superball). Bounce it on the benchtop and make observations on its physical properties and behavior.
2. One partner should hold a meter stick vertically on the floor and drop the ball from a height of 100 cm. The other partner closely observes the return bounce height in cm and records it.
3. Carefully place the ball in the liquid nitrogen. Allow the ball to cool for 20-30 minutes while you complete the remainder of part A and part B.
4. Obtain a piece of adhesive tape about 3-4 inches (7-10 cm) long.
5. Using tongs, dip adhesive tape into liquid nitrogen until you think the tape has cooled to 77 K. Remove the tape from the liquid nitrogen and test its stickiness by placing it on paper immediately after removal from the liquid nitrogen. Note any observations.
6. Note the flexibility of a latex lab glove at room temperature. Cool it in liquid nitrogen for about a minute. Describe the physical properties of the glove now.
7. Complete part B
8. Prepare to use tongs to remove the ball from the liquid nitrogen. Before removing the ball you should be prepared to measure the bounce height as you did in step 2, with one partner holding the meter stick and dropping the ball and the other measuring the return height.
9. Immediately upon removing the ball with tongs from the nitrogen, one partner drops the ball from a height of 100 cm. The other partner observes and records the bounce height in cm and observations related to the sound of the bounce. Record this as the bounce height at time = 0
10. Repeat this bounce height measurement once a minute (or more often) for the first 10 minutes and then less frequently as the bounce height approaches the pre-cooled value.
11. Plot "bounce height" vs "elapsed time" starting with time = 0. (See http://chemlab.truman.edu/DataAnalysis/PreparingGraphs_files/PreparingGraphs.htm) You may wish to compare your plot to the curve in reference 1.

B. Dilatancy (shear thickening) of a corn starch suspension[2]

Procedure:

1. Add 21.5 ml of water to 25.0 grams of powdered corn starch and stir together until a uniform suspension is obtained which shows no indication of settling.
2. Stir the suspension slowly and then quickly, noting the difference in viscosity.
3. Pour the suspension into a petri dish. Throw a small solid rubber ball onto the suspension at an angle and observe. Contrast this behavior to that which you observe when you gently set the rubber ball on the suspension.
4. Complete the remaining steps in Part A of the experiment.

References:

1. L.H. Sperling, *Introduction to Physical Polymer Science*, New York: Wiley Interscience, ©1986, pp. 299-300, or 2nd ed., ©1992, pp. 380-1.
2. F. Rodriguez, Polymer Preprints 27 (April 1986), #1, 4023.
3. R.B. Seymour and C.E. Carraher, Jr., *Polymer Chemistry: An Introduction*, New York: Marcel Dekker, ©1981, or 2nd ed., ©1988, ch. 3.