Intermolecular Bonding in Polymers

Introduction

You encounter **polymers** every day whether you realize it or not. A polymer is a large, long molecule made of repeating molecules linked together in a chain. The molecules that repeat in the polymer are called **monomers**. Polymers such as plastic and styrofoam are made by humans. Polymers are also *part of* humans. DNA, proteins, and many sugars are polymers. Even hair is made up of polymers! You can think of a polymer like a string of beads. Each bead along the string is a monomer. The monomers can be very simple molecules, such as the C_2H_4 molecules that polymerize to make the common plastic polyethylene, or they can be much more complicated. A model of the polymer you will be working with today is shown in **Figure 1**.

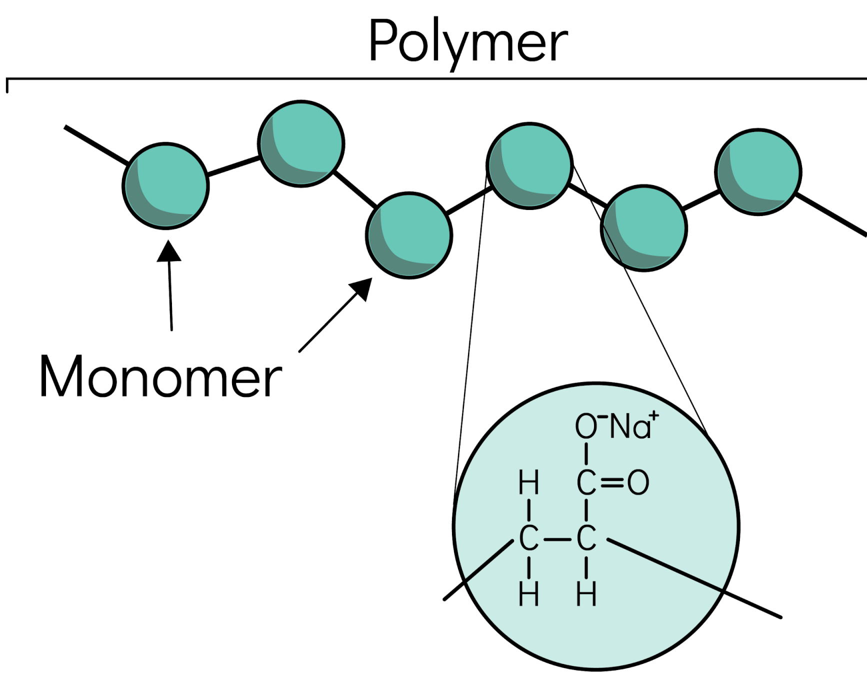


Figure 1. Monomers and Polymers. When many (often thousands and thousands!) monomers are linked together they become a polymer. The chemical structure of monomers vary greatly. Here, the monomer beads represent the monomers of sodium polyacrylate.

In this lesson, you will explore how the chemical bonding and structure of a polymer are key in helping scientists to do something pretty extraordinary: create artificial organs

What To Do

Step 1. Obtain materials from your teacher. In your cup, you have a small amount of sodium polyacrylate. Sodium polyacrylate is a polymer. A model of the polymer and the structure of its monomer are shown in **Figure 1.**

Step 2. Add water to your cup, approximately 10 mL at a time (about one plastic spoonful) and write down what you see and feel in the space below. Discuss with your group.

Step 3. Continue to add water until you run out and write down your final observations.

Step 4. Obtain a second cup of polymer and more water from your teacher. This new polymer is also sodium polyacrylate, but in a slightly different form from the polymer in your first cup.

Step 5. Add water to your cup, about 10 mL at a time (or one spoonful) and write down what you see and feel in the space below. Discuss with your group.

Step 6. Continue to add water until you run out and write down your final observations.

Step 7. How was the second polymer different from the first? Be specific in your comparison, cite your observations.

Step 8. Answer the analysis questions, reading the Bite when instructed.

Analysis Questions

1. The trade name for sodium polyacrylate is “Waterlock.” After seeing it in action, what do you think are some everyday applications of this polymer? How could it be used in real life?

Some polymers are easily shaped into three dimensions because they form **crosslinks.** Crosslinks act like glue, connecting polymer threads and forming a 3D material. A crosslink is often made of multiple molecules, as is the case with the crosslinks that can form in sodium polyacrylate, shown in **Figure 2**.

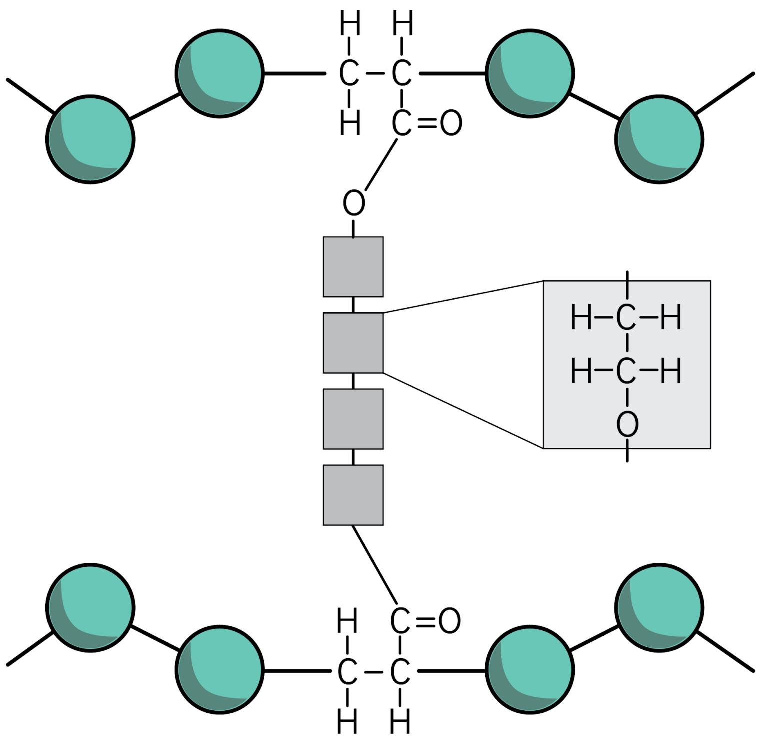


Figure 2. Crosslinks. This chemical structure shows one way in which sodium polyacrylate may be chemically crosslinked. To show the bonds, the structure of the monomer represented by the green beads has been shown for the middle monomer in both the top and bottom chains. Note that several repeats of another molecule (represented by shaded boxes) makes up the crosslink.

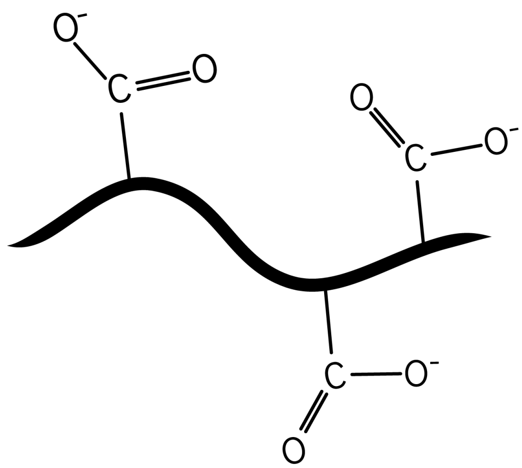
2. Thinking about what you just read, and the diagram of the crosslinked sodium polyacrylate (**Figure 2**), draw a model of a polymer that has been crosslinked. Use circles to represent the monomers in the polymer and squares to represent the crosslinks. Include at least three polymer chains.

3. The first sample of sodium polyacrylate you investigated had some crosslinks, while the second sample had many more crosslinks between polymer threads.

   a. Based on your observations, how did increasing the amount of crosslinking affect the properties of the sodium polyacrylate?

   b. Sodium polyacrylate absorbs water by forming hydrogen bonds between the negatively charged oxygens on each monomer and water molecules. On the simplified diagram of the polymer below, draw how the water molecules will interact with the polymer.
   Be specific! Be sure you:

   - show the partial charges on the atoms in the water molecule,
   - clearly identify which part of the water molecule forms a hydrogen bond with the oxygens on the polymer, and
   - show the hydrogen bonds as dotted lines. Explain why you drew the water molecules in that position.



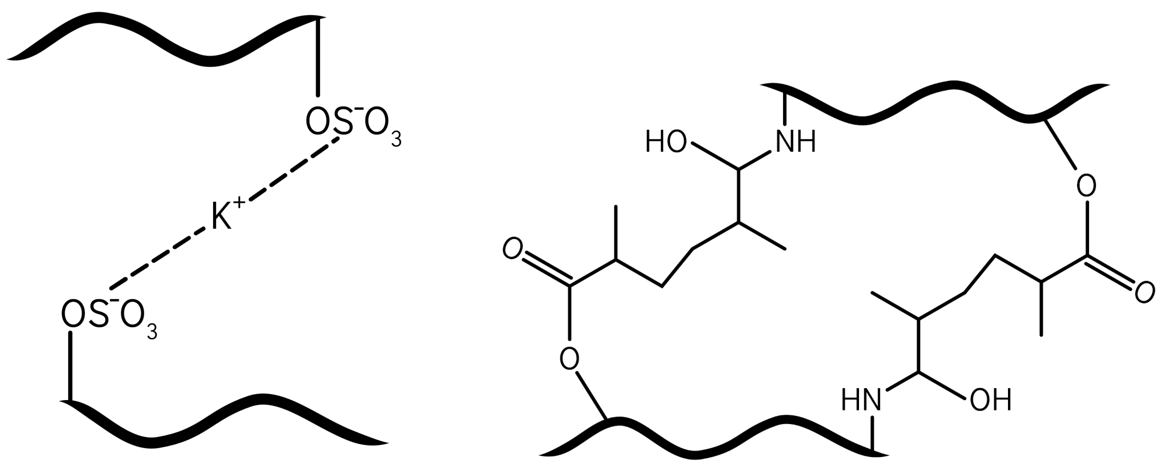
   c. Recall that when sodium polyacrylate is crosslinked, bonds form between the crosslinking molecule and the negatively charged oxygens shown above. Once the bonds form, the oxygens are no longer negatively charged. As the amount of crosslinking increases, what do you think happens to the amount of water the polymer can absorb?

d. Explain how your answer to part c makes sense based on the observations you made in the activity. Develop a hypothesis as to *why* the crosslinking affected the properties of the sodium polyacrylate. Base your hypothesis on your observations, your knowledge of what happens to sodium polyacrylate when it is crosslinked, and your answer to part b.

STOP & read Science Bite:

A NICE Way to Save Lives

Figure 3 shows the structures of the two polymers that make up the NICE bioink.



Kappa-Carrageenan (kCA) Gelatin Methacrylate (GelMA)

Figure 3. Chemical Structures of Polymers Used in NICE Bioink. These simplified structures show the backbone of each polymer as a bold wavy line and emphasize the crosslinks between polymer chains. Please note that for simplicity, not all carbons and hydrogens are shown in the GelMA structure.

4. Circle a crosslink in kCA and put a square around a crosslink in GelMA in **Figure 3**.

5. What is different about the structures between the crosslinks in kCA and GelMA? Include a discussion of bonds and intermolecular forces in your response.

In the Science Bite, the scientists used these two different polymers to change the strength and flexibility of the NICE bioink. **Figure 4** shows the relative strengths of the polymers and the NICE Bioink by measuring the amount of strain (how far in mm the polymer is squished per mm of polymer) when a particular amount of stress (pressure) is applied.

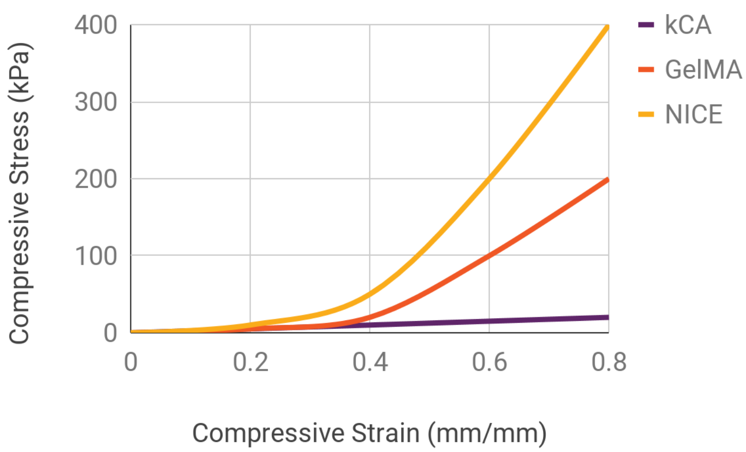


Figure 4. Polymer Strengths. The relative strengths of the individual polymers used compared to the combined NICE bioink when undergoing stress.

6. Use the graph to complete the table below, reporting the amount of stress it takes to compress 1 mm of the polymer 0.6 mm.

Polymer	Amount of stress needed to compress 1 mm of the polymer 0.6 mm
kCA	kPa
GelMA	kPa
NICE	kPa

7. The Bite states that the NICE polymer is the strongest. How does the data from **Figure 4** support that conclusion?

8. Remembering your observations when water was added to the sodium polyacrylate, what do you think happens when live cells are incorporated into the NICE bioink scaffold?

9. **Connect to the Big Question**. Projects like the one described here have great potential to save many lives, but they also bring up some ethical questions regarding growing human tissues. Do you think human organs on their own are alive? Would you consider a 3D printed organ as alive?