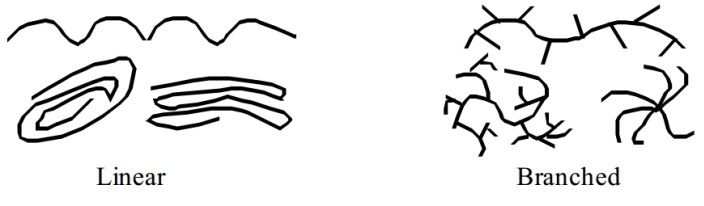
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**Lab: From Monomers to Polymer by Polymerization (Answer Key)**

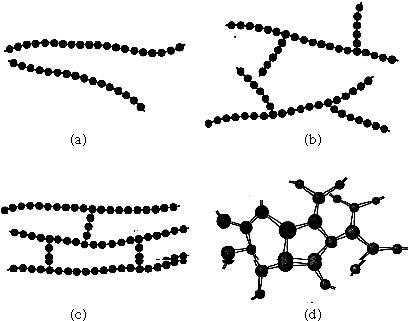
**Introduction:**

Polymers are in 90% of all products and devices in our world extend from adhesives, coatings, packaging materials, textile, industrial fibers, electronic, to biomedical devices. We have been using ***natural polymers*** obtain from the environment such as cellulose, wool, silk and cotton fibers for thousands of years. Bakelite was the first ***synthetic or man-made polymers*** was discovered in 1907 and has grown to be the largest materials-science related industry. Unlike natural polymers, we engineered synthetic polymers and create them chemically. Many polymers, especially synthetic polymers, are very strong materials, for example a simple plastic grocery bag is extremely thin but can support lot of weight! Polyester used in clothing will not shrink compared to cotton fibers. Polyethylene, nylon, polystyrene and polyvinyl chloride (PVC) are some examples of synthetic polymers that are widely used for many applications. However, all synthetic polymers are made from oil (petroleum) and they are not biodegradable (decay in the environment) in landfills.

Monomers are the basic repeating unit that made up polymers. Monomers connect to each other through **polymerization reactions** to form long chain polymers. The chemical reactions of polymerization occur in a variety of ways and therefore the polymers can be arranged in a number of different ways. **Linear** polymers are made up of one long continuous chain. **Branched** polymers have a chain structure that consists of one main chain of molecules with smaller chains branching from it (see figure 1). Branched polymers take up more space than linear when they are stacked on top of each other. The smaller chains branching from the main ones forms pocket of air and lower its density. Branched polymers lighter than linear polymers (see figure 2). **Homopolymers** are composed of only one type of monomer. **Copolymer** have two or more different type monomers, it can have several arrangements of the monomers along the chain. Alternating copolymer is the most orderly arranged (most crystalline) and has a sharp melting point. Other copolymers structures with random patterns are referred to as amorphous and do not have an exact melting point. The four main copolymer arrangements are depicted below:



**Figure 2:** Linear polymers can fold into itself and stack with little air in between the layers



**Figure 1:** Linear vs. branched polymers

Random Copolymers

Alternating Copolymers

Block Copolymers

Graft Copolymers

**Figure 3:** Copolymer configurations

Polymers can be separated into two different groups depending on their behavior when heated. Polymers with linear molecules are likely to be **thermoplastic**. They have primary covalent bonds and weaker secondary **Van der Waals** bonds between the chains. These secondary forces can be overcome by thermal energy, making thermoplastics moldable at high temperatures. These are substances that soften upon heating and can be reshaped and recycled. Common things made with thermoplastic are plastic bags, CD/DVD cases, disposable utensils, and stationery supplies.

The other group of polymers is known as **thermosets**. These are substances that do not soften under heat and pressure and cannot be remolded or recycled. Strong covalent bonds chemically hold different polymer chains together in a thermoset material. The chains may be directly bonded to each other or be bonded through other molecules. This "cross-linking" between the chains allows the material to resist softening upon heating and harder to recycle. Common things made with thermoset plastic are gardening tools, epoxy fiberglass, automotive tires and parts.

**Objectives:**

* Introduce the concepts and vocabulary of polymers with simple models
* Understand the difference between thermoplastic and thermoset polymers
* Observe a polymerization reaction and understand characteristics of polymer chains

**Materials:**

Part 1 Part 2  
10ml glass graduated cylinder 30g of polycaprolactone thermoplastic 4% wt. polyvinyl alcohol solution 6 neodymium magnets  
Acetone thermometer  
Paper clip 400ml beaker glass stirrer   
 hot plate

**Safety Precautions:**1) Wear goggles when working with acetone in part 1  
2) Hot water is used in part 2, be careful to avoid burns  
 **Pre-lab:**a) What is the difference between natural and synthetic polymer?  
\_Natural polymers are obtained from the environment such as cellulose, wool, silk and cotton. Synthetic polymers are man-made and human engineered them with chemistry\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
b) Explain polymerization reaction (draw a picture to represent this concept)  
Polymerization is when monomers attached/connect through each other and form a long chain of repeated unit. See figure 1 or 3 for example picture\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

c) How is a linear polymer different from branched polymer?  
**Linear** polymers are made up of one long continuous chain. **Branched** polymers have a chain structure that consists of one main chain of molecules with smaller chains branching from it\_\_

d) What is a copolymer?  
**Copolymer** have two or more different type monomers, it can have several arrangements of the monomers along the chain. Alternating copolymer is the most orderly arranged (most crystalline) and has a sharp melting point.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

e) Name the types of copolymer  
Random, alternating, block, and graft copolymer\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
  
f) Explain the difference between thermoplastic and thermoset polymer  
**Thermoplastic** are moldable and melt under high heat. **Thermosets** are substances that do not soften under heat and pressure and cannot be remolded or recycled\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

-Teacher’s approval \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (cannot start without signature)

**Procedure Part 1: Observing a polymerization reaction**1. Turn on your hot plate to 150 Celsius  
2. Obtain a 400ml beaker and add 200ml tap water to it  
3. Place your beaker on top of the hot plate   
4. Monitor your water temperature; turn the hot plate down to 100 Celsius once the water reaches  
 60 Celsius  
5. While you’re waiting for your water, get the following materials: graduated cyclinder, PVA solution and acetone solution  
6. Use a pipet to get 5ml of polyvinyl alcohol solution and transfer to your graduated cylinder  
7. Use a different pipet to get 3ml of acetone  
8. Slowly add the acetone to the polyvinyl alcohol solution, make sure your pipet tip touches the side of the graduated cylinder when you’re adding acetone  
9. Do not mix, shake or stir the two solutions  
10. You should be able to see two layers  
11. The top layer is where the polymerization reaction occur  
12. Use a paper clip and slowly fish (lift) out the fibers, place it on your data table below it will stick to your paper

**Part 1: Data and Analysis**

1. Sample of polyvinyl alcohol polymer fibers 2. Describe what the fibers look like (color, shape, texture) when first lifted out of solution. What happens to the fibers they have been exposed to air for 5 minutes?  
Clear can be thin or tangled together into a bundle. Fibers dried and harden after exposed to air.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
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3. What will happen if you mix the two solutions polyvinyl alcohol and acetone solutions? Why do you think this is? (Explain your answer) \_Polyninyl alcohol is soluble in water but doesn’t in acetone. Therefore a small amount crashed out when exposed to acetone and polymerize into a chain of fibers.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Procedure Part 2: Making models using polycaprolactone (Hot water involve use caution)**1. Make sure your water is at 60 Celsius when doing this portion of the lab  
2. Obtain 30 grams of polycaprolactone from your teacher  
3. When your water reaches 60 Celsius turned your hot plate down to 100 degrees  
4. Drop 30 grams of polycaprolactone (1/4 cup) in your warm water once it’s at 60 Celsius  
5. Wait till all the polycaprolactone turn clear (transparent), use a stirrer to fish them out  
6. Be careful it might be hot, start molding and dipping it in water to soften them up if necessary  
7. Using your polycaprolactone, create models for copolymer structures: block pattern vs. alternate pattern  
8. Must have at least 4 monomers for each copolymer structure  
9. Must incorporate magnets to connect the monomers together, representing a polymerization reaction  
10. Combine your monomers with another group and create a branched polymer   
11. Show me when you have your models and draw your models

**Part 2: Data and Analysis**

1. Drawing of a alternate copolymer Drawing of a block copolymer

2. Drawing of a branched polymer

3. Describe at least 3 physical characteristics of the polycaprolactone and explain why this is a physical change.

Moldable and clear when heated, hardens and cloudy when cooled. This is a physical change because we’re changing the shape and not the underline chemical structure of this polymer\_\_\_

4. Is polycaprolactone a thermoplastic or thermoset? Why?  
Polycaprolactone is a thermoplastic because it softens and can be molded under high temperature\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

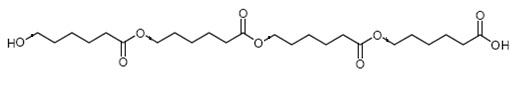
**Conclusion Questions:**

1. Define a polymer in your own words.  
Polymers are made up of repeated monomers unit, can be arranged as branched or linear.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2. In part 2, if you have more polyvinyl alcohol solution with the same amount of acetone, will you produce more fibers or fewer fibers? Why?  
More fibers will form because you have more polymer (polyvinyl alcohol) that will crash out as it touches acetone solution.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

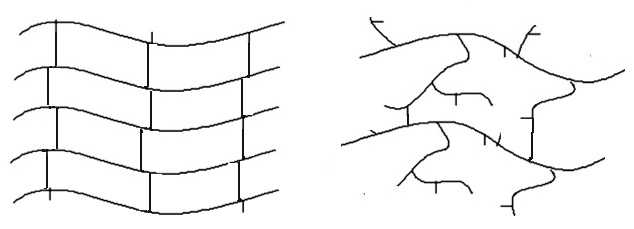
3. What are some possible commercial applications of polycaprolactone?  
Making molds for manufacturing purposes, create decoration materials, make do-it-yourself gadgets or parts.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

4. Below is the structure of polycaprolactone. Circle the repeated monomer unit of this polymer.



5. Look at polymer A vs. B picture below. Which structure will be harder to break? Why?   
Which structure is denser (heavier)? Why?

Polymer A Polymer B



Polymer A structure will be harder to break because the linear chains have a high degree of cross linking with one another generating a rigid structure that are harder to pull apart. On the other hand, polymer B structure will be easier to break because it has less cross linking between the linear polymers.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Polymer A will be denser because it is organized and linear chain polymers are stack one on top of another. Polymer B will be less dense because the branching takes up space but there are not as much polymers in between the space.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_