

Polymeric Medical Sutures: An Exploration of Polymers and Green Chemistry

Student Handout

Part I: Drawing Threads Using Poly(ϵ -caprolactone)

Objective: To create imitation medical sutures using a polymer, poly(ϵ -caprolactone), with varying molecular masses.

Driving Question: Which molecular mass of poly(ϵ -caprolactone) draws the best imitation medical suture?

Introduction to Part I:

A **medical (surgical) suture** is a medical device used to hold body tissues together after an injury or surgery. We commonly refer to medical sutures as “stitches.” Most sutures are made of polymers. **Polymers** are large molecules made of small repeating units called **monomers**. The number of repeating units is designated by “ n ” and can vary in number from 50 to >100,000! Polymers made from repeating units of one monomer are called **homopolymers** (Figure 1a). Polymers made by combining two or more different monomers are called **copolymers** (Figure 1b). The properties of a polymer depend on the structure of the monomer(s) used, the size of the polymer chain (“ n ” value), and in the case of a copolymer, the composition and positioning of each repeating monomer chain.

Figure 1a. Homopolymer (repeating units of one type of monomer)

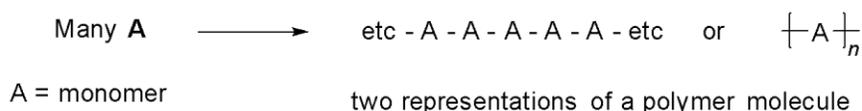


Figure 1b. Copolymer (repeating units of two different monomers)

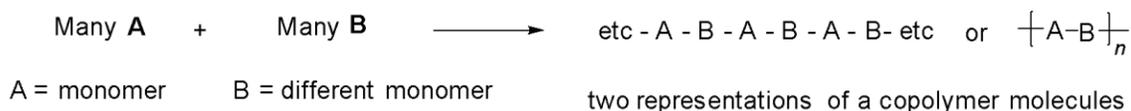


Figure 1: Representations of polymer and copolymer molecules.

Polymers are everywhere in our daily lives - from the plastic bags we use to carry groceries to the sneakers that we wear. As previously mentioned, sutures are made from polymers. Some sutures are meant to be strong and durable so that they must be manually removed, while others are meant to dissolve or degrade over time so that they don't need to be removed. The properties of the suture are determined by the molecular structure of the polymer and how the chains of polymers interact with each other. In part I of this experiment you will mimic how sutures might be made from a polymer of different molecular mass (or lengths or “ n ” values) and observe their properties.

The molecular mass of a linear polymer can influence how much entanglement occurs between the molecules in the polymer (Figure 2). Longer polymer chains (A) generally entangle easier than smaller polymer chains (B). The degree of entanglement can affect the physical and mechanical properties of a polymer. Intermolecular forces such as dipole-dipole interactions and hydrogen bonding can also affect their physical and mechanical properties. For example, flexible polymers tend to have chains that slide past each other easily. All of these

structural characteristics of a polymer can affect the quality, draw-ability, and strength when used to make a suture.



A = larger molecular mass

B = smaller molecular mass

Figure 2: A and B show the difference in entanglement between larger and smaller molecular mass polymers.

The polymer that will be used in part I of this experiment is called poly(ϵ -caprolactone) (Figure 3). Poly(ϵ -caprolactone) is degradable so methods to make it from a renewable monomer cost-effectively are under investigation by chemists. Suture like threads will be drawn using poly(ϵ -caprolactone) polymers with molecular masses of 14 kilograms/mole, 45 kilograms/mole, and 80 kilograms/mole. Note the significant difference in the molar mass of the caprolactone monomer and the caprolactone polymers.

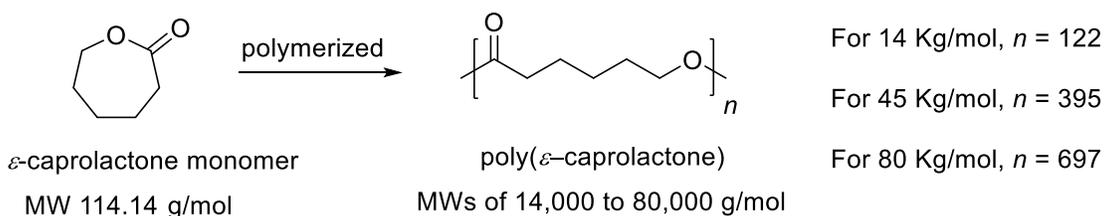
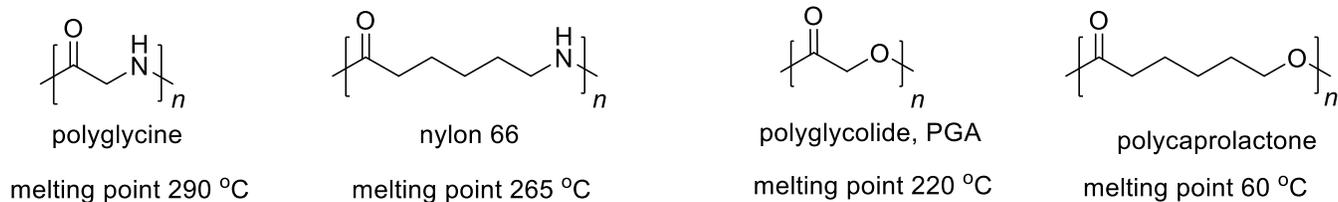


Figure 3: The ϵ -caprolactone monomer can be polymerized to form poly(ϵ -caprolactone) polymer with varying molecular masses.

Pre-Lab Questions:

1. Examine the structures of the four polymers below:



a. What similarities and differences exist in the molecular structures?

b. Draw the entire polymer that would be represented by polyglycine where n is equal to 3. Assume one terminus group of the “trimer” is a carboxylic acid (CO_2H) and the other an amine (NH_2).

c. Draw the entire polymer that would be represented by polycaprolactone where n is equal to 3. Assume one terminus group of the “trimer” is a carboxylic acid (CO_2H) and the other an alcohol (OH).

d. What types of intermolecular forces are possible for each molecule?

e. How might the intermolecular forces identified above affect the properties of the polymer?

Materials (per group):

- poly(ϵ -caprolactone) 80K (~1.5 g)
- poly(ϵ -caprolactone) 45K (~1.5 g)
- poly(ϵ -caprolactone) 14K (~1.5 g)
- 3 aluminum dishes
- Spoon or scoopula
- Scale
- Permanent marker
- Hot plate
- Glass stir rod
- Forceps or tongs
- Scissors
- Labeling tape
- Plastic sealable sandwich bags

Safety:

- Goggles, long pants, and closed toe shoes should be worn.
- Caution should be used with the hot plate.
- Caution should be used when handling the hot aluminum dishes and hot poly(ϵ -caprolactone).

Procedure:

Observations of Actual Medical Sutures

1. Record your observations of actual medical sutures in Table I. Be sure to write down the type of suture for which you are recording observations.

Melting Poly(ϵ -caprolactone)

1. Measure approximately 1.5 g of 14K, 45K, and 80K poly(ϵ -caprolactone) into 3 separate aluminum dishes and label each dish respectively using a permanent marker.
2. Place all three aluminum dishes on a hot plate at a medium setting.
3. Record the time at which each sample of poly(ϵ -caprolactone) melts completely and qualitative observations of the melted polymers in Table II.

- a. If the samples do not melt after 5 minutes, turn up the temperature setting until all of the polymer is melted.

Drawing Poly(ϵ -caprolactone)Threads to Mimic Actual Medicals Sutures:

1. Draw the threads starting with the melted 80K poly(ϵ -caprolactone).
 - a. Hold the aluminum dish down with a pair of tongs or forceps.
 - b. Dip the end of the glass stir rod into the melted poly(ϵ -caprolactone).
 - c. Gently twist the stir rod two to three times then slowly lift the stir rod vertically away from the dish.
 - d. Keep lifting until the thread is approximately 2 feet in length. You may need to practice drawing samples a few times before you are comfortable with the technique.
 - e. Cut off the region of the thread that is most uniform in thickness.
 - f. Store the threads in a plastic bag.
 - g. Label the bag with the type of threads using labeling tape and a permanent marker.
2. Repeat the process until you have 2 or more threads of similar thickness and quality for each sample of poly(ϵ -caprolactone).
 - a. Make sure to keep a consistent temperature throughout the drawing process - the poly(ϵ -caprolactone) should stay clear and melted in the aluminum dish.
 - b. Time permitting and for fun, see how long of a thread you can pull.
 - c. Also, take a cool thread which has a relatively thick section. Slowly pull the thread in this area and you should be able to observe something called "cold draw" where it looks like a small thread is coming out of the larger one. See how far you can cold draw the thread.
3. Record observations about the draw-ability and quality of the sutures in the Table II below.

Data and Observations Part I:

Table I. Observations of Actual Medical Sutures

Name/Type	Gauge (Thickness)	Observations (How it feels, thickness, stretch, color, weave, etc...)

Table II. Observations of Drawn Poly(ϵ -caprolactone) (PCL) “Suture” Threads

Molecular Mass of PCL	Time Required for Melting	Qualitative Observations	Draw-Ability (easy, medium, difficult, impossible)	Quality of threads (low, medium, high)
80K				
45K				
14K				

Post-Lab Questions:

1. Compare the thickness, texture, strength, stretchiness, etc. of the poly(ϵ -caprolactone) threads to an actual suture. Describe any similarities or differences observed.

2. What is the relationship between the molecular mass of poly(ϵ -caprolactone) and the draw-ability and quality of the thread? Propose a reason for this observation.

Part II: Tie-Ability and Tensile Strength Testing

Objective: To test the tie-ability and tensile strength of the poly(ϵ -caprolactone) threads and actual sutures.

Driving Question: Does the type and thickness of material impact the tie-ability and tensile strength of a suture?

Introduction to Part II:

Sutures need to be strong enough to hold an incision together yet flexible enough to tie. In this part of the experiment you will investigate the tie-ability and tensile strength of sutures. **Tensile strength** is the resistance of a material to breaking under tension. A **tensile test** is a fundamental materials science test in which a sample is subjected to a controlled force until failure. The test shows how a material reacts under certain forces. You will use an improvised tensile strength tester (such as a force probe) to measure the force required to break the suture upon pulling.

In addition to testing the threads made in part one you will also test actual sutures. Actual sutures vary in **gauge** (thickness). It is important to note that the number listed and the thickness of the thread is inversely proportional. For example, 4.0 nylon sutures are actually thicker than 5.0 nylon sutures.

Materials:

- poly(ϵ -caprolactone) 80K threads (from part I)
- poly(ϵ -caprolactone) 45K threads (from part I)
- Actual suture(s)
- Tensile strength tester

Safety:

- Goggles should be worn.

Procedure:

Tie-Ability Test

1. Select a portion of each of your poly(ϵ -caprolactone) threads - make sure they are similar in thickness and quality - or an actual medical suture.
2. Tie a knot with one of the threads to the tensile strength tester.
3. Record your observations of how easy or difficult it was to tie the thread/suture in Table III below. Note if the thread/suture breaks or stretches upon tying.
4. With the thread/suture tied continue to the tensile strength test.

Tensile Strength Test

1. Set up the tensile strength tester to collect data.
2. Either use the tied knot from above or hold a looped thread/suture on both ends and pull with consistent force. What is most important is to perform each test precisely the same.
3. Pull the thread/suture away from the tensile strength tester until it breaks.
4. Record the maximum force needed to break the thread upon pulling in Table III below.
5. Time permitting, repeat each test to check for consistency.

Data and Observations Part II:

Table III. Tensile Strength and Tie-Ability

Thread/Suture	Force (Newtons)	Qualitative Observations
45K PCL		
80K PCL		
Actual Suture:		

Post-Lab Questions:

1. Does the type and thickness of material impact the tie-ability and tensile strength of a suture? Explain why or why not.

2. How did the PCL threads compare in thickness and in strength to the actual sutures? Would they make good commercial products? If they are not commercial quality, how might they be improved?

Part III: Degradability Testing

Objective: To test the degradability of the poly(ϵ -caprolactone) threads and actual sutures in an ethanol/sodium hydroxide solution.

Driving Question: Does the type and thickness of material impact the degradability of a suture?

Introduction:

The polymers that have been used in this experiment are plastics. **Plastics** are traditionally manmade, composed of organic compounds containing the elements carbon, hydrogen, oxygen, and nitrogen, and synthesized from fossil fuels. Plastics have widespread application because they can be made in many forms: flexible, sticky, soft, etc. They are stable to temperature changes and durable, being resistant to corrosion and degradation. Unfortunately, it is these very characteristics that are responsible for their continued accumulation and harmful effects to our health and the environment. A plastic (PET) soda bottle can last from 450-1000 years in nature or a landfill. Additionally, these polymers are made from petroleum-based starting materials which are non-renewable and will be depleted in the not so distant future.

Paul Anastas and John Warner developed 12 green chemistry principles (see References) that focus on sustainability and provide a framework for scientists to use when designing new products or processes.

Principle ten states “not only do we want materials and products to come from renewable resources, but we would also like them to not persist in the environment” (Anastas, 1998). Therefore, the ability of a product to degrade and prevent buildup of materials in the environment is important. Scientists are currently researching new alternatives for today’s polymers which address the needs of consumers without damaging the environment, human health, and economy. Part III of this experiment will investigate the degradability of the sutures that were used in parts I and II.

Materials:

- poly(ϵ -caprolactone) 80K threads (from part I)
- poly(ϵ -caprolactone)45K threads (from part I)
- Actual suture(s)
- 25 mL 1.8 M sodium hydroxide solution
- 25 mL ethanol
- Graduated cylinder
- 100 mL beaker
- Hot/stir plate
- Stir rod or stir bar
- Ruler
- Scissors
- Thermometer

Safety:

- Goggles, long pants, and closed toe shoes should be worn.
- Caution should be used with the hot plate.
- Ethanol is a highly flammable liquid and its vapors may cause respiratory irritation. Do not breathe fumes. Use in a well-ventilated area.
- Sodium hydroxide is corrosive and is a skin and eye irritant. Do not breathe fumes. Wash hands and any exposed skin thoroughly after handling.

Procedure:

1. Measure 25 mL of 1.8 M sodium hydroxide solution using a graduated cylinder and place in a 100 mL beaker
2. Measure 25 mL of ethanol solution using a graduated cylinder and add to the 100 mL beaker.
3. Heat the solution on a hot plate until the temperature of the solution is approximately 50 °C.
 - a. Adjust the hot plate setting as needed to maintain a temperature of 50 °C.
4. Cut off a 5 cm portion of one of the sutures and place into the solution.

- a. Make sure to carefully observe the suture the entire time.
 - b. Record the time required to dissolve the piece of suture and any qualitative observations in the Table IV below.
 - c. If the suture does not dissolve after 5 minutes carefully remove it from the ethanol/sodium hydroxide solution.
5. Repeat this process for the rest of the sutures.

Data and Observations:

Table IV: Degradability of Sutures/Threads

Sample	Time to Dissolve (min)	Qualitative Observations
45K PCL		
80K PCL		
Actual Suture:		

Post-Lab Questions:

1. Does the type, strength, or thickness of material impact the degradability of a suture? Explain why or why not.

2. When would it be important or not important for sutures to dissolve in the human body? Explain.

3. Which of the sutures that you tested would be appropriate for use as stitches that were designed to dissolve or not dissolve in the human body?

Part IV: Guided Inquiry with Polylactic Acid (PLA)

Objective: Design an experiment that systematically incorporates PLA into a poly(ϵ -caprolactone) (PCL) suture with the goal of modifying and improving upon the quality of suture prepared. Properties to consider are the draw-ability, tie-ability, tensile strength, and degradability.

Introduction:

Medical sutures made of nylon are representative of the vast number of non-degradable synthetic plastics that are found in society today. The buildup of these materials is evident on our land (check out a parking lot after the snow melts in the spring) and in our water ways. Of particular concern is the large amount of plastics that are accumulating in the oceans. Current predictions are that by 2050, there will be more plastic by mass than fish in our oceans (World Economic Forum).

To address these environmental issues, scientists are researching ways to design new polymeric materials which will still meet the needs of consumers, but take into account their effect on the environment, human health, and the economy. As stated in **Green chemistry principle seven**, "A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical" (Anastas, 1998). Sutures that are absorbable represent the types of materials scientists are exploring because of their ability to degrade under natural physiological conditions; that is, are biodegradable. Also, those derived from renewable resources offer an alternative to those synthesized from fossil fuels; thus sustainable.

One notable success story in the efforts to develop more sustainable polymers is polylactide (PLA). PLA is a renewable and degradable polymer that has been made into commercial products. Cargill, a local company in Wayzata, MN, was one of the first to develop and market products made from this material. The starting material is derived from corn starch or sugarcane and its products degrade under compostable conditions over several months (see Figure 4). You can find containers made from PLA in the produce aisle of your grocery store or at food service businesses that use them for cups and utensils. Your objective today will be to examine the properties of a PLA commercial product and use it to design an experiment which incorporates PLA into the PCL polymer to create a suture like thread that more closely replicates the properties of an actual suture. One proposed method for incorporating PLA into the PCL polymer is through melt blending of the two polymers. **Melt blending** is where two or more polymer chains are mixed during melting, creating new interactions, but the individual chemical structure of each polymer remains intact. This differs from co-polymerization which involves two monomers combining together to form one new copolymer.

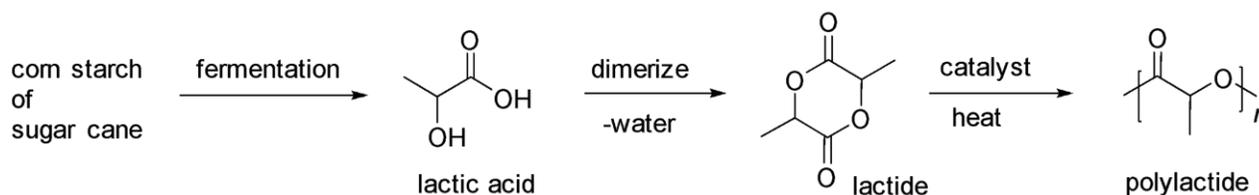


Figure 4. Steps to convert corn starch or sugar cane to polylactide, a commercially available renewable and compostable polymer.

Pre-Lab Question:

1. How might the information regarding plastics and PLA influence your choices as a consumer?

Procedure:

1. Work with your lab group to develop a testable, specific research question about the incorporation of PLA into PCL to create a suture.
2. Once your question has been approved by the instructor, complete the experimental plan below.
3. Once your experimental plan has been approved by the instructor, carry out the experiment, recording observations and data and making note of any changes in procedure.

Experimental Plan

The Driving Question... <i>What are your independent and dependent variables?</i>	
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What data will you collect? <i>What masses will you need to measure?</i> <i>What observations will you need to make?</i> <i>What tests will you need to conduct?</i>	
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How will you collect your data? <i>Which substances will you use?</i> <i>How much of each substance will you use?</i> <i>Which parts will you need to keep constant?</i> <i>How many times will you repeat the experiment?</i> <i>How will you reduce error?</i> <i>What safety precautions will you follow?</i>	Your Procedure (diagram and description)
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<p>How will you analyze your data?</p> <p><i>What type of calculations will you need to conduct?</i></p> <p><i>How will you determine if a significant change occurred?</i></p>	
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Data and Observations: Design a table to collect and present your experimental data below.

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<p>Conclusion?</p> <p><i>Write a paragraph that summarizes the question you were addressing, analysis of your experimental data, and the conclusions that could be drawn from your results.</i></p>	
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References

1. Anastas, P. T.; Warner, J.C. Green Chemistry: Theory and Practice, Oxford University Press, 1998 and <https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/12-principles-of-green-chemistry.html>
2. Wearden, G. (2016, January). Retrieved from <https://www.theguardian.com/business/2016/jan/19/more-plastic-than-fish-in-the-sea-by-2050-warns-ellen-macarthur>.