Polymeric Medical Sutures:
An Exploration of Polymer and Green Chemistry

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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.

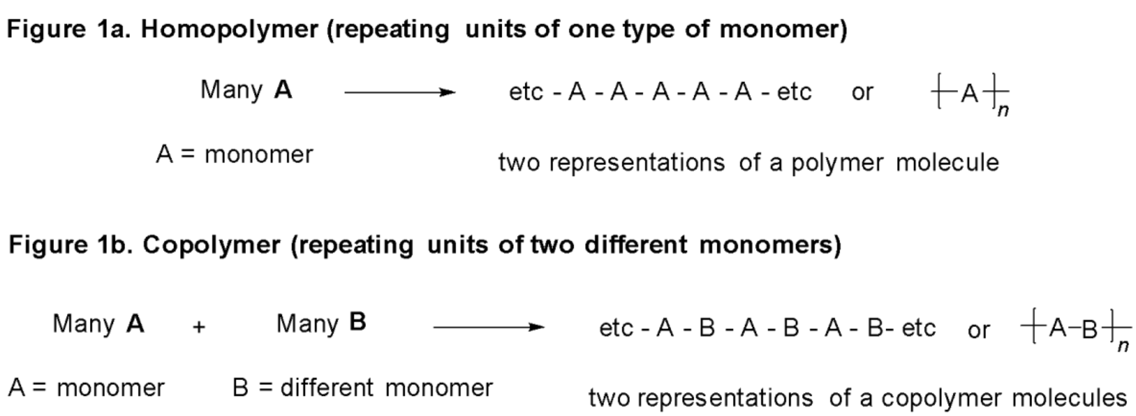


Figure 1: Representations of polymer and copolymer molecules.

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

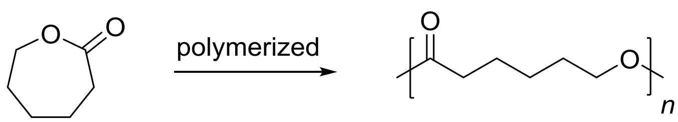
(B).The degree of entanglement can affect the physical and mechanical properties of a polymer. Intermolecular forces such as dipole-dipole interactions and hydrogen bonding can also affect their physical and mechanical properties. For example, flexible polymers tend to have chains that slide past each 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 molecuar mass

B = smaller molecuar 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.



ε-caprolactone monomer
MW 114.14 g/mol

poly(ε–caprolactone)
MWs of 14,000 to 80,000 g/mol

For 14 Kg/mol, n = 122

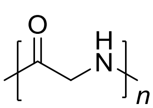
For 45 Kg/mol, n = 395

For 80 Kg/mol, n = 697

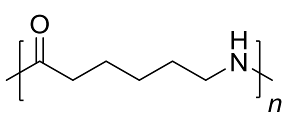
Figure 3: The ε-caprolactone monomer can be polymerized to form poly(ε-caprolactone) polymer with varying molecular masses.

Pre-Lab Questions:

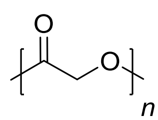
1. Examine the structures of the four polymers below:



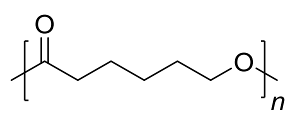
polyglycine
melting point 290 ^{o}C



nylon 66
melting point 265 ^{o}C



polyglycolide, PGA
melting point 220 ^{o}C



polycaprolactone
melting point 60 ^{o}C

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

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

c. 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 suture? 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:		
Actual Suture:		
Actual Suture:		
Actual Suture:		
Actual Suture:		
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 ^oC.
    a. Adjust the hot plate setting as needed to maintain a temperature of 50 ^oC.

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:		
Actual Suture:		
Actual Suture:		
Actual Suture:		
Actual Suture:		
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 <u>and</u> 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.

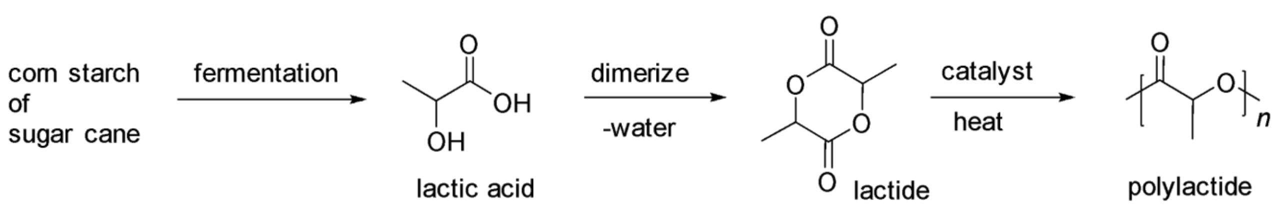


Figure 4. Steps to convert corn starch or sugar cane to polylactide, a commercially available renewable and compostable polymer.

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… *What are your independent and dependent variables?*	

↓

What data will you collect? *What masses will you need to measure?* *What observations will you need to make?* *What tests will you need to conduct?*	

↓

How will you collect your data? *Which substances will you use?* *How much of each substance will you use?* *Which parts will you need to keep constant?* *How many times will you repeat the experiment?* *How will you reduce error?* ***What safety precautions will you follow?***	**Your Procedure (diagram and description)**

↓

How will you analyze your data? *What type of calculations will you need to conduct?* *How will you determine if a significant change occurred?*	

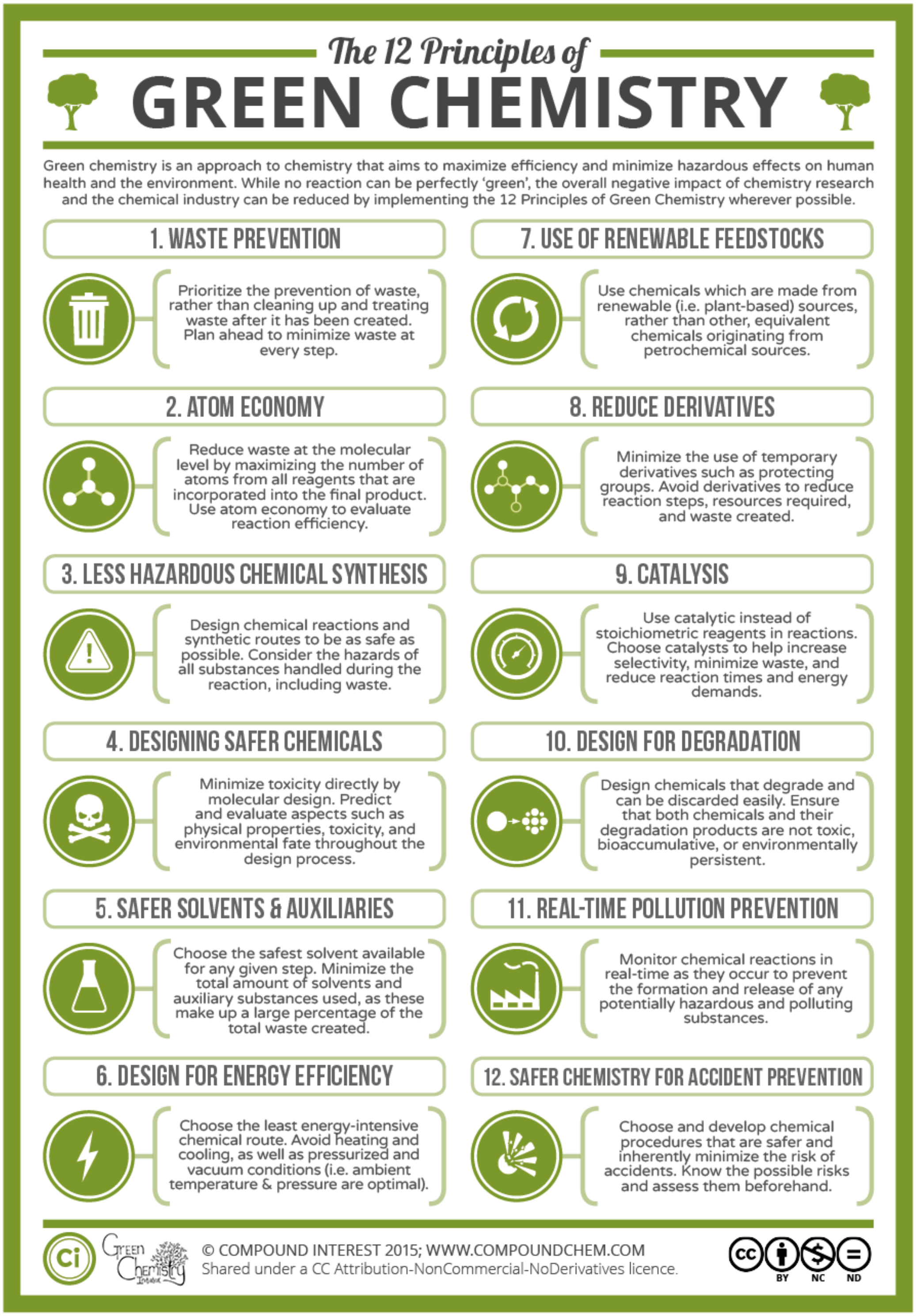
Data and Observations: Design a table to collect and present your experimental data below.

Conclusion? *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.*	

References

1. Anastas, P. T.; Warner, J.C. Green Chemistry: Theory and Practice, Oxford University Press,1998.
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.

The 12 Principles of Green Chemistry



Polymeric Medical Sutures: An Exploration of Polymers and Green Chemistry

Instructor Notes

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

General Notes:

- Part I should take 45 minutes, depending on the depth of the introduction to the lab. The introduction takes about 15 minutes, the melting of the poly(ε-caprolactone) takes about 15 minutes, and the drawing of the threads takes about 15 minutes.
- Consider including a demonstration during the introduction that mimics the entanglement of polymers of varying molecular mass with strings cut to varying lengths.
    - **Prep:** Have 6-10 small (3-5 inches) pieces of yarn cut up and 6-10 large (24 inches) pieces of yarn cut up. Arrange all the small pieces in a pile and the large pieces in a separate pile.
    - **Demonstration:** Attempt to pull a piece of yarn out of each of the piles to show how larger polymers can entangle easier than small polymers. Discuss what might happen when 14K, 45K, and 80K polymers are pulled into a suture and how their entanglement will affect the quality of the suture.
- Part I includes showing students an example of real sutures. There are many possible options for sutures, including those suggested below. A minimum of one type is necessary for the purpose of this experiment.
- Plastic bags can be used for ease of collecting and storing the sutures. Have students label the plastic bags using labeling tape and a permanent marker so the bags can be reused each year.
- The 80K poly(ε-caprolactone) can be drawn into lengthy sutures. You may consider having a drawing contest to see which students can draw the longest sutures. Carefully drawn sutures may even extend the length of the classroom.

Expected (Typical) Results:

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...)
Nylon	4-0	Black, smooth, thicker than nylon 5-0, feels like fishing line, strong, not very stretchy
Nylon	5-0	Black, smooth, thinner than nylon 4-0, feels like fishing line, strong, not very stretchy
Polygalactic Acid (PGA)	4-0	Blue, smooth, thicker than PGA 5-0, feels like thread, strong, not very stretchy
Polygalactic Acid (PGA)	5-0	Blue, smooth, thinner than PGA 4-0, feels like thread, strong, not very stretchy

Natural/Chromic Gut (PCM)	4-0	Brown, smooth, thicker than PCM 5.0, feels like hair, strong, not very stretchy
Natural/Chromic Gut (PCM)	5-0	Brown, smooth, thinner than PCM 4.0, feels like hair, strong, not very stretchy

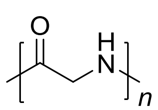
Table II. Observations of Drawn Poly(ε-caprolactone) (PCL) Suture Threads

Molecular Mass of PCL	Time Required for Melting	Qualitative Observations	Draw-Ability (easy, medium, difficult, impossible)	Quality of Sutures (low, medium, high)
80K	Most Time (typically 5-10 minutes)	Melted slowly, turned from white to clear upon melting, very thick, draws into very long sutures	Easy	High/Medium
45K	Medium Time (typically 3-5 minutes)	Turned from white to clear upon melting, draws into shorter sutures	Easy/Medium	High/Medium
14K	Least Time (typically 1-3 minutes)	Melted quickly, turned from white to clear upon melting, very thin, unable to draw a suture from	Difficult/Impossible*	N/A

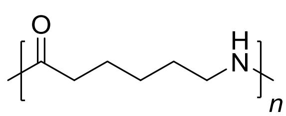
*Students will not be able to draw the 14K poly(ε-caprolactone) into a suture. Do not allow them to waste too much time attempting to do this.

Answers to Pre-Lab Questions:

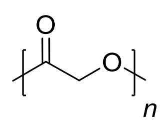
1. Examine the structures of the four polymers below:


polyglycine

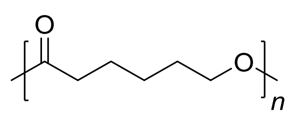
melting point 290 °C


nylon 66

melting point 265 °C


polyglycolide, PGA

melting point 220 °C


polycaprolactone

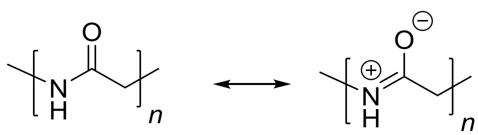
melting point 60 °C

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

Polyglycine and nylon 66 have oxygen and nitrogen heteroatoms along with C & H, whereas polyglycolide and poly(ε-caprolactone) have C, H, and O. only. Also the chain lengths differ.

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

The polyglycine and nylon 66 have an N-H bond which can be used for hydrogen bonding. The bond is actually an amide bond so very polar. The ester polymers can have dipole-dipole interactions but no H-bonding except on the end groups.



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

Stronger bonds (H-bonds) lead to higher melting points and intermolecular interactions.

Answers to Post-Lab Questions:

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

   Answers will vary depending on the sutures used for comparison, but likely students will notice that the poly(ε-caprolactone) threads are stretchy and not as strong as the actual sutures.

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

   As the molecular mass of the poly(ε-caprolactone) increases, the draw-ability of the suture increases. Larger polymer chains are generally able to entangle with other molecules easier than smaller polymer chains, and therefore are easier to pull into sutures.

Materials:

Item	Suggested Supplier	Estimated Cost*	Number of Class Periods the Materials Cover
Aluminum dish (100 pk)	Flinn Scientific (AP6390) VWR (25433-016)	\$10.30 \$25.78	3
poly(ε-caprolactone) 80K (250 g)	Sigma Aldrich (440744)	\$110.50	16
poly(ε-caprolactone) 45K (250 g)	Sigma Aldrich (704105)	\$99.90	16
poly(ε-caprolactone) 14K (250 g)	Sigma Aldrich (440752)	\$120.50	16
Some Options for Actual Sutures			
4-0 PGA (12 sutures)	AD Surgical (#M-G418R19)	\$31.50	24**
5-0 PGA (12 sutures)	AD Surgical (#M-G518R19)	\$31.50	24**
4-0 Nylon (12 sutures)	AD Surgical (#M-N418R19)	\$17.50	24**
5-0 Nylon (12 sutures)	AD Surgical (#M-N518R19)	\$17.50	24**
4-0 PMC (12 natural sutures)	AD Surgical (PMC-418R19)	\$31.60	24**
5-0 PMC	AD Surgical	\$31.60	24**

(12 natural sutures)	(PMC-518R19)		

*The estimated cost does not include shipping costs and costs were obtained July 2016.
**If the suture portion of the experiment is done as a demonstration, less than half of a suture should be consumed per class period meaning the sutures will last for 24 class periods.

Part II: Tie-Ability and Tensile Strength Testing

General Notes:

- Part II takes about 25-30 minutes.
- Only one type of real suture is required, but more can be purchased for deeper exploration. If the tie-ability and tensile strength test of the experiment is done as a demonstration, less than half of a suture should be consumed per class period meaning the sutures will last for 24 class periods.
- Vernier Dual-Force Probe with interface is recommended as the tensile strength tester, but if probe equipment is not available, a simple trigger pull scale or spring scale could work but will give less quantitative data.
- If students are going to collect and compare data as a class, a consistent procedure must be used across the entire class.

Expected (Typical) Results:

Data and Observations Part II:

Table III. Tensile Strength and Tie-Ability

Thread/Suture	Force (Newtons)	Qualitative Observations
45K PCL	Low (typically <1 N)	Hard to tie, breaks when tied
80K PCL	Low (typically 1-5 N)	Hard to tie, stretchy
Actual Suture: Nylon 4-0	High (typically ~12-15 N)	Easy to tie, hard to break
Actual Suture: Nylon 5-0	High (typically 10-12 N)	Easy to tie, hard to break
Actual Suture: PGA 4-0	High (typically ~12-15 N)	Easy to tie, hard to break
Actual Suture: PGA 5-0	High (typically 10-12 N)	Easy to tie, hard to break
Actual Suture: Natural 4-0	High (typically ~12-15 N)	Easy to tie, hard to break
Actual Suture: Natural 5-0	High (typically 10-12 N)	Easy to tie, hard to break

Answers to 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.

   The type of material impacts the tie-ability. The poly(ε-caprolactone) threads were less tie-able than the other sutures indicating the type of material matters. The type and thickness of material both impact the tensile strength. The thicker the material the greater the tensile strength. The poly(ε-caprolactone) had less tensile strength than the other sutures indicating the type of material matters.

2. How did the poly(ε-caprolactone) threads compare in thickness and in strength to the actual sutures? Would they make good commercial products? How might they be improved?

   The poly(ε-caprolactone) threads are not as strong as actual sutures and would not make good commercial products as a result. The threads could be improved by increasing their strength. This could be done by drawing thicker sutures or braiding sutures together. Students might speculate that a PCL of even higher molecular mass than 80K might have better properties.

Materials:

Item	Suggested Supplier	Estimated Cost*
Dual Range Force Sensor	Vernier (DFS-BTA)	$109
LabQuest 2 (or another Vernier interface)	Vernier (LabQ2)	$329

*The estimated cost does not include shipping costs and costs were obtained July 2016.

Part III: Degradability Testing

General Notes:

- Part III takes about 25-30 minutes.
- Only one type of real suture is required, but more can be purchased for deeper exploration. If the degradation test is done as a demonstration, less than half of a suture should be consumed per class period meaning the sutures will last for 24 class periods.

Expected (Typical) Results:

Data and Observations:

Table IV: Degradability of Sutures

Suture	Time to Dissolve (min)	Qualitative Observations
45K PCL	Low (typically <1 min)	Dissolves quickly
80K PCL	Low (typically 1-3 min)	Turns clear and then dissolves
Actual Suture: Nylon 4-0	Never	Does not change

Actual Suture: Nylon 5-0	Never	Does not change
Actual Suture: PGA 4-0	Low (typically 1-3 min)	Turns clear and then dissolves
Actual Suture: PGA 5-0	Low (typically 1-3 min)	Turns clear and then dissolves
Actual Suture: Natural 4-0	High (typically 5-7 min)	Slowly curls, turns clear, and then dissolves
Actual Suture: Natural 5-0	High (typically 5-7 min)	Slowly curls, turns clear, and then dissolves

Answers to Post-Lab Questions:

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

   Answers will vary depending on the sutures tested. The type of material impacts the degradability of a suture. Some materials are degradable and others are not. The thickness of the material impacts the time required to degrade the suture. Thicker sutures generally take longer to degrade.

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

   It would be important for sutures to dissolve when they are used inside the body so that the body wouldn't have to be opened to remove the stitches.

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?

   Answers will vary depending on sutures tested, but sutures that degrade can be used as sutures designed to dissolve and sutures that do not degrade can be used a sutures designed to not dissolve in the body.

Part IV: Guided Inquiry with Polylactic Acid (PLA)

General Notes:

- Part IV takes 50-60 minutes, but more time can be provided to allow students to investigate their questions more thoroughly.
- PLA cups for this experiment can be found at Greenware, WorldCentric, or another source.
  - Greenware website: http://www.fabri-kal.com/product/greenware-cold-drink-cups/
  - Worldcentric website: http://worldcentric.org/biocompostables/cups
- To incorporate PLA into the poly(ε-caprolactone), cut the PLA cups (or other source) into small pieces (~1 cm^2) and add them to aluminum dish with the poly(ε-caprolactone)
  - Note that the aluminum dishes will not be able to be reused once the PLA has melted.
  - To improve the melt blending of PLA and poly(ε-caprolactone), make sure to stir the mixture with a glass stir rod

- The level of inquiry can be adjusted based on time and level of students. For example, for open inquiry students can develop their own testable question regarding PLA and sutures. Or for more guided inquiry student groups can be assigned a question to test. Here is a list of possible questions:
    - Does the incorporation of PLA with 14K poly(ε-caprolactone) create a quality, drawable suture?
    - Does the incorporation of PLA into a suture (14K, 45K, or 80K) increase the degradability?
    - Does the incorporation of PLA into a suture (14K, 45K, or 80K) increase the tensile strength?
    - What effect does the incorporation of PLA with 45K poly(ε-caprolactone) have on the sutures?
    - What effect does the incorporation of PLA with 80K poly(ε-caprolactone) have on the sutures?
    - Does the source (blueberry container, plastic cup, etc.) of PLA have an effect on suture quality?
    - What would happen to the quality of the suture if you braided the sutures together?

Materials:

Item	Suggested Supplier	Estimated Cost*
6 oz. PLA Cups (pack of 50)	World Centric	$3.14

*The estimated cost does not include shipping costs and costs were obtained July 2016.

Pre- and Post- Survey Data from White Bear Lake AP Chemistry Students to Assess Learning Outcomes

Table I. Pre- and Post- Survey Questions and Results to Assess Learning Outcomes

Questions	Pre-Test	Post-Test
Polymers are: a. made of small repeating units called monomers b. made of one large complex molecule c. made of many types of atoms in random order d. made from plastics	13 answered A 1 answered D	14 answered A
Large linear polymer chains, compared to small ones, generally: a. have more entanglement b. are more highly colored c. are easier to make d. melt faster	7 answered A 1 answered B 4 answered C 2 answered D	12 answered A 2 answered D
Green Chemistry seeks to: a. focus on cleaning up the environment b. eliminate the use of chemicals c. design materials from renewable resources that are degradable d. design chemicals that are cheaper to save consumers money	5 answered A 1 answered B 8 answered C	3 answered A 11 answered C
Modern medical sutures, "stitches," are made from: a. recycled plastics b. wool threads c. both degradable and non-degradable materials d. non-degradable materials	1 answered A 1 answered B 11 answered C 1 answered D	1 answered A 1 answered B 12 answered C
Polylactide (PLA) is: a. a plastic made from petroleum b. a plastic used to make compostable cups and dinnerware c. is a recyclable plastic with a recycle code of 1 d. a plastic used for soda pop bottles	4 answered A 2 answered B 6 answered C 2 answered D	2 answered A 9 answered B 3 answered C

Continued on next page.

Table II. Individual Student Pre- and Post- Survey Results

Pre-Test			Post-Test		Change from Pre- to Post-Test
Student	Number Correct (out of 5)	Percent Correct	Number Correct (out of 5)	Percent Correct	
1	3	60.00%	5	100.00%	+40%
2	4	80.00%	5	100.00%	+20%
3	2	40.00%	4	80.00%	+40%
4	5	100.00%	5	100.00%	-
5	3	60.00%	5	100.00%	+40%
6	2	40.00%	2	40.00%	-
7	3	60.00%	3	60.00%	-
8	2	40.00%	4	80.00%	+40%
9	3	60.00%	5	100.00%	+40%
10	1	20.00%	4	80.00%	+60%
11	4	80.00%	5	100.00%	+20%
12	3	60.00%	3	60.00%	-
13	2	40.00%	4	80.00%	+40%
14	3	60.00%	4	80.00%	+20%