Polymer Synthesis
ND EPSCoR Lesson Plan

Lesson Title: Polymer Synthesis

Lesson Overview: Many of the materials we use in our daily lives are polymers, chemicals made of short repeating units (monomers) linked to one another. In the 20th century we learned how to synthesize artificial polymers, or plastics, from fossil fuels, such as oil and natural gas. Today, increased awareness of the environmental effects of mining these fuels has led to the development of plastics that can be synthesized from natural feedstocks, these plastics are referred to as “bioplastics”. In today’s first activity, you will model common polymer building blocks, and predict the properties of polymeric materials based on your models. In the afternoon, you will synthesize these polymers, and see how well your predictions match with reality!

Lesson Objectives:

- You will be able to identify some different types of polymers.
- You will be able to define chemical bonds.
- You will be able to describe the molecular structures of polymers.
- You will be able to describe the chemical structure of some polymer monomers.
- You will be able to correlate the structure of polymer monomers with the physical properties of the polymers

NSF Subject Classification: Chemistry

National Next Gen Standards:

- MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.
- MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
- HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

North Dakota Standards:

- MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.
- MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
- HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Grade or Grade Band: 11-12

Time Needed (estimate): 3 50-minute class periods

Lesson Author: Jessi Kjemhus

Teaches 7-12 science at Northwood Public School since 2015 and 9-12 science at North Border Public School prior. She graduated in 2012 with a Composite Chemistry degree from Mayville State University and then with her Master's from Valley City State University in 2015. She can be contacted at jessi.kjemhus@northwoodk12.com

Scientist/K12 Collaborator & University: Alex Parent, NDSU

Scientist Bio/Research: I'm Alex Parent, an Assistant Professor of Chemistry and Biochemistry at NDSU. I grew up on the east coast and attended Clark University in Massachusetts for my Bachelor of Arts degree in chemistry and Yale University in Connecticut for my Doctor of Philosophy degree in chemistry. I then spent two years working in Fukuoka Japan researching sustainable energy. I am an avid hiker, and love walking the many parks in Fargo and occasionally getting out to the Badlands and upstate Minnesota to experience more vertical trails. (The things I miss most about New England and Japan are the easy access to hills and mountains!) I am also an avid board gamer, with Uwe Rosenberg games being some of my favorites. My research focuses on methods of generating materials from renewable resources, particularly on using air in chemical synthesis. My current projects include developing new catalysts for activating oxygen from the air and studying the process by which current catalysts utilize air to effect chemical transformations in paints.

Preparation/Materials

Background knowledge students must have to be successful
Students need to understand that atoms are the building blocks and molecules are atoms joined together to form bonds. Polymers are made up of many, many molecules all strung together to form really long chains. How polymers act depends on what kinds of molecules they're made up of and how they're put together. The *properties* of anything made out of polymers reflect what's going on at the ultra-tiny (molecular) level. Things that are made of polymers look, feel, and act depending on how their atoms and molecules are connected, as well as which ones we use to begin with.

Essential Terminology

- Chemical bond- A chemical bond is a lasting attraction between atoms, ions or molecules that enables the formation of chemical compounds.
- Covalent bonds- the bond formed by the sharing of a pair of electrons by two atoms
- Hydrogen bonds- a weak bond between two molecules resulting from an electrostatic attraction between a proton in one molecule and an electronegative atom in the other.
- Molecule- molecular, or covalent bond, is formed when atoms bond by sharing pairs of electrons
- Monomer- a molecule that can be bonded to other identical molecules to form a polymer
- Polymer- A chemical made from small, repeating units (monomers)
- Plastic- A polymer that can be molded or shaped using heat and/or pressure.

Resources:

- **This Is Plastics website**
- **PHET University of Colorado Boulder**
- **Making Molecules**
- **North Dakota Established Program to Stimulate Competitive Research STEM page**

Websites:

- https://www.thisisplastics.com/plastics-101/how-are-plastics-made/
- https://phet.colorado.edu/en/simulation/legacy/build-a-molecule
- https://elearning.cpp.edu/learning-objects/making-molecules
- https://www.ndepscor.ndus.edu/ndep/nature/sunday-academy/stem-module-topics/

Materials needed:

- Chemistry Model Set
  https://www.flinnsci.com/products/chemistry/models/flinn-molecular-model-sets/
  https://www.enasco.com/c/Education-Supplies/Science/Chemistry/Molecular-Models
- Safety Glasses
- Gloves
- 100 mL Guar Gum Solution
- 0.5 mL Borax Solution
- 100 mL of Skim Milk
- 50 mL of Vinegar

- 3 Large Beakers (~200 mL)
- 2 Graduated Cylinders
- 1 Metal Pan
- 1 Small Beaker (~10 mL)
- 1 Disposable Syringe
- 2 Stir Rods
- 1 Hot Plate
- 1 Stopwatch
- 1 Piece of PET
- 1 Piece of Foil
- 1 Wooden Stick per Person
- 1 Pair of Tweezers or Forceps

PowerPoint – found as separate attachment

Procedure/Activities

Lesson 1:

- PPT Slides 1 and 3
    - Description of Periodic Table. Number of electrons each atom has available for bonding given at top of table (ignore transition metals). Bonds are two electrons that are shared between two atoms. Atoms form bonds until each atom has eight electrons (except H). For this reason, carbon forms 4 bonds (8-4=4), and nitrogen forms 3 bonds (8-5=3). Bonds to H often not explicitly drawn in chemical structures. All C atoms assumed to have 4 bonds, bonds not drawn are to H.
        - Building molecule simulator download
            - https://phet.colorado.edu/en/simulation/legacy/build-a-molecule
        - Making Molecules simulator and lab
            - https://elearning.cpp.edu/learning-objects/making-molecules/
        - Covalent Bond Gizmo- if school has purchased Gizmo- this would add an extra to unit
- PPT Slide 4
    - Polymers are any molecule made from smaller, constituent molecules. Many natural polymers, DNA, proteins, etc. Plastics are polymers that can be molded or shaped w/ heat and/or pressure. Rubbers are natural plastics. Will model several natural polymers using model kits.
- PPT Slide 5
    - Amylose will be used to model Guar gum (polysaccharide from beans) that will be crosslinked in later activities. Polyalanine will be used to model the casein that will be concatenated in later activities as well.
- PPT Slide 6
    - Mission of the CSMS is developing more sustainable materials using chemistry and engineering. Multiple research topics including: 1) synthesis of polymers from bio-based monomers, 2) development of self-degrading polymers, and 3) incorporation of natural materials into materials to develop new properties.
- Hand out Activity 1 sheet and model kits
- Go over PPT Slide 7
    - After the students build the monomers, they should connect the glucose molecules to each other as shown on slide 5 to make amylose. The Terephthalic Acid and Ethene connect alternately to form PET (slide 10), and the alanine should be connected to make polyalanine. In the activities, the polyanaline/guar gum will be crosslinked with BO4 linkages to form a 3-D web/mesh (slide 11). The polyalanine (casein) will be heated and form concatenated structures like loose cables shaken up in a box.
- Go through and discuss discussion questions- PPT Slide 8
    - Note: Ethene should be much harder to bend. Only single bonds should rotate. The PET and polyamylose should be more rigid. All could potentially break. No limit to polymer length. Polymers are very large molecules.

Lesson 2:

- Reflect on previous lesson about building molecules and discuss which ones will be focused on in this lesson.
- Go through PPT Slide 9

    - The PET is made from individual PET strands that have cooled and are held together by intermolecular forces (H-bonding and dipolar interactions). Each individual PET strand is quite strong. This is why it can be reshaped when heated (unlike the guar gum and casein polymers). Once again reflect on the molecular models made from previous lesson when looking at strength
- PPT Slide 10
    - Note no chemical bonds will form between casein molecules, they will only be held together by H-bonds and sterics.
- PPT Slide 11
    - The polymerized guar gum actually ends up softer because it has more strength, the casein plastic crumbles when force is applied to it.
- Go through Slide 12, introduce any new instruments or equipment unfamiliar to students.
    - Hand out Activity Sheet and begin lab
        - Emphasize the borax needs to be added slowly while stirring, otherwise all of the crosslinks will form in the same region of the solution and you won't get the desired gooeyness.

Lesson 3:

- Discuss about the observation from the previous day
- Go through PPT Slide 13
    - Hand out Activity 3 Sheet
- Slide 14 group discussion
    - The guar gum plastic will be stronger, some reasons students might give include molecular linkages in the guar gum, or more connections in the guar gum. The plastics are similar to PET in that they can change shape when heat is applied. Unlike the PET, they cannot be reshaped if reheated (thermoset), while the PET can be reshaped if heat is applied (thermoplastic). At higher T the individual strands of PET in the bottle begin to separate from one another, allowing it to be reformed

Extensions for above average students:

- For activity one, add different organic compounds for students to work on modeling as others catch up.
- Research about items coming from recycled plastics and try and identify items in the room that could be made from recyclable plastics

Mediation/Support for students that need it:

- This is a challenging lesson; modifications for concept wise. Recommend for upper classman. May need to give background information on Lewis structure and go through how to make molecular models first. Work together on basic Lewis structures and models, then release them to activity one
- Present only one step at a time
- Have solutions measured out and ready to go
- Reword or break up questions if not understanding

Lesson Outline (for research-based lessons)

1) Observe Phenomena
2) What questions should we be able to answer?
3) Write a Hypothesis
4) Come up with a Research Plan
5) Carry out investigation
6) Revisit the Background Research
7) Construct Explanations. (TASKS-Publish/Communicate Findings)

Standards Alignment

ND Science Standard(s):

- MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.
- MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
- HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Disciplinary Core Idea: e.g. Chemistry – using chemical reactions to recycle plastics

Chemical reactions take one substance and transform it into another without any matter being destroyed

North Dakota DPI Standards:

ND ELA

W.7 Conduct short as well as more sustained research projects to answer questions (including self-generated questions) or solve problems.

a. Develop a research question.

b. Narrow or broaden the inquiry when appropriate.

c. Synthesize multiple source

Next Gen Standards:

- MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.
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Science and Engineering Practices

- Developing and Using Models

Cross Cutting Concepts

- Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

Unit Objectives

- Students will be able to analyze characteristics of polymers from plastics

Assessment

- Students will be able to create various polymers to understand its properties and how it relates to the plastic itself.

Daily Plans and Assessments

Learning Target for each day/activity

- Lesson 1/Day 1- Students will be able to look at a Lewis Structure to make a model to understand characteristics those molecules have

- Lesson 2/Day 2- Students will be able to create guar gum and casein plastic and analyze its properties

- Lesson 3/ Day 3- Students will be able to extract PET polymer strands and compare its properties to other plastics

Criteria for Success/Assessment for each activity

- Lesson 1- Students successfully create molecular model and can relate to molecular properties

- Lesson 2- Students analyze properties of plastics

- Lesson 3- Students analyze properties of plastics and can compare two types of plastics to each other

Additional Lesson Resources / Materials

References:

Based on "Polymers & Molecular Models: Petretec Industry Example" Beyond Benign 2017 Web. 2 May 2018. https://www.beyondbenign.org/lessons/polymers-molecular-models-petretec-industry-example/

Parent, A. “Polymer Synthesis from Common Materials”. Web. 23 June 2020. https://www.ndepscor.ndus.edu/ fileadmin/ndus/ndepscor/SundayAcademy/2018-19SAPolymerSynthesisLessonPlan_2018-11-16.pdf

Websites for purchasing materials

Molecular Model kits:
https://www.flinnsci.com/products/chemistry/models/flinn-molecular-model-sets/
https://www.enasco.com/c/Education-Supplies/Science/Chemistry/Molecular-Models

General Lab supplies:

Nasco
    https://www.enasco.com/c/Education-Supplies/Science

Flinn
    https://www.flinnsci.com/

Carolina
    https://www.carolina.com/lab-supplies-and-equipment/science-lab-supplies/science-lab-classroom-supplies/10300.ct

School Specialty
    https://www.schoolspecialty.com/science-supplies-and-products

Amazon
    www.amazon.com

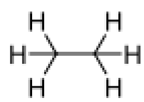
Retailers such as Target or Walmart

Activity 1 – Modeling Molecular Structures

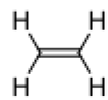
Materials:

- 1 Model Set

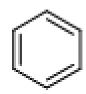
Instructions: Construct each of the following molecules based on their Lewis structure, then try to bend and rotate each bond. Record your observations in the table below. Save your ethane, terephthalic acid, glucose and alanine molecular models. Note that some of the molecules contain common structural motifs.



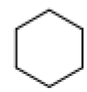
Ethane



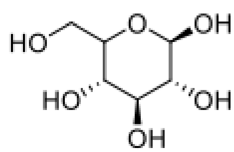
Ethene



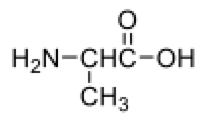
Benzene



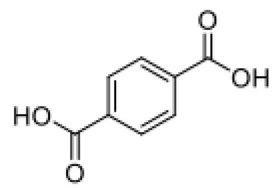
Cyclohexane



Glucose



Alanine



Terephthalic Acid

Molecule	Observation

Activity 2 – Crosslinking: Polymers to Plastics

Based on "Polymers & Molecular Models: Petretec Industry Example" Beyond Benign 2017 Web. 2 May 2018. https://www.beyondbenign.org/lessons/polymers-molecular-models-petretec-industry-example/

Materials:

- Safety Glasses
- Gloves
- 100 mL Guar Gum Solution
- 0.5 mL Borax Solution
- 100 mL of Skim Milk
- 50 mL of Vinegar
- 3 Large Beakers (~200 mL)
- 2 Graduated Cylinders
- 1 Metal Pan
- 1 Small Beaker (~10 mL)
- 1 Disposable Syringe
- 2 Stir Rods
- 1 Hot Plate
- 1 Stopwatch

Instructions:

Predict whether casein or guar gum will make the stronger (harder to deform) plastic when crosslinked:

____

Why do you predict this will be the case?

____

____

Predict whether the casein or guar gum will make a more durable (harder to break) plastic when crosslinked: ____

Why do you predict this will be the case?

____

____

Casein-based plastic:

- When you get into the lab, take a pair of gloves and safety glasses and put them on. Do not remove them until you leave the lab area.
- Form groups of 3-4, then have one person from your group collect the materials listed above.
- Add 100 mL of skim milk to a 200 mL beaker.
- Cover your hot plate with aluminum foil.
- Place your metal pan on your hot plate, then place the beaker on the pan.
- Fill the pan with water to just below the level of the milk.
- Begin heating your milk at high heat with constant stirring.
- Record your observations of the milk.
- When the milk begins to simmer, record the time, lower the heat to medium-high and slowly add 10 mL

of vinegar to the milk.

• Record your observations of the milk/vinegar solution.
• After 1 minute, add an additional 10 mL of vinegar to the solution and record your observations.
• Continue adding 10 mL of vinegar and making observations until no further changes occur.
• Turn off the heat, remove the beaker and allow your casein product to cool.
• When cool, pour the liquid portion of the product down the drain, and measure and record the properties of your solid casein plastic.

Vinegar Added	Observation
0 mL	
10 mL	
20 mL	

Properties of the casein plastic: ____

<u>Guar gum-based plastic:</u>

• Add 100 mL of the guar gum solution to a 200 mL beaker.
• Place the beaker into your pan of warm water, and set the heat to medium.
• While constantly stirring, slowly add 0.5 mL of the borax solution to the guar gum solution using a syringe.
• Record your observations of the changes that occur as you add the borax.
• Pour out the liquid portion of your product and examine the properties of your guar gum-based plastic.

Observations when adding borax to guar gum: ____

____

Properties of the guar gum plastic: ____

____

Activity 3 – Extracting Polymer Strands from Soda Bottles

Materials:

- Safety glasses
- Gloves
- 1 Hot Plate
- 1 Piece of PET
- 1 Piece of Foil
- 1 Wooden Stick per Person
- 1 Pair of Tweezers or Forceps

Instructions:

- Cut a small piece of plastic out of the soda bottle and place it on the foil on your hotplate (make sure the hotplate has cooled down!). (Ensure the plastic is fully on the foil).
- Set your hotplate to medium high and wait until the plastic begins to melt.
- Remove the plastic from the foil using your tweezers.
- Use your wooden sticks to try to draw out polymer strands from the molten plastic, see how long a strand you can make! • Allow the plastic to cool on a piece of foil.
- Try to pull and bend the polymer strands after it has cooled.

Activity 2 & 3 Discussion

- Is the casein or guar gum plastic stronger?
- Why do you think this is the case?
- Is the casein or guar gum plastic more durable?
- Based on their structures, why might this be the case?
- In what ways are the plastics you made similar to PET?
- When the PET was hot, could you change its shape?
- After the PET cooled were you able to change its shape?
- Why do you think the PET might have different properties at different temperatures?