Lesson Title: Biobased Materials

Lesson Overview: Students explore the chemical identities of polymeric materials frequently used in their everyday lives. They learn how chemical composition affects the physical properties of the materials that they encounter and use frequently, as well as how cross-linking affects the properties of polymeric materials**.**

Lesson Objectives:
After this lesson, students should be able to:

- Identify common items in our everyday loves that are polymers
- Create polymer models of different types of polymers
- Understand the structure of polymers through the building models
- Understand condensation polymerization and how cross-linking effects flexibility
- Describe what is being done to decrease pollution and adverse effects of fossil fuels
- Produce a biodegradable plastic using common chemicals

NSF Subject Classification: Physical Science

National Next Gen Standards:
HS-PS2-6. Communicate scientific and technical information about why the molecular level structure is important in the functioning of designed materials. (Grades 9 - 12)

HS-PS1-5 Apply scientific principles and evidence to provide an explanation about the effects of the reacting particles on the rate at which a reaction occurs.

HS-LS4-6 Design and revise a solution to mitigate impacts of human activity on biodiversity.

North Dakota Standards:
RST.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific or technical context relevant to grade 9-10 or 11-12 texts and topics.

SL.1 Initiate and participate in a range of collaborative discussions with diverse partner on grapes 9-10 or 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

   a. Come to the discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate thoughtful, well-reasoned exchange of ideas.

Grade or Grade Band: 10-12

Time Needed (estimate) 4- 50 minute lessons

Lesson Author: Jeni Peterson is the Education and Innovation Center Coordinator at Mayville State University. She has a bachelor's degree in Elementary Education from Mayville State, a Master of Education degree with a concentration in Mathematics from Minot State and received her certification in English as a Second Language from Valley City State. Jeni has worked in education for 18 years.

Scientist Bio: Sivaguru Jayaraman, Department of Chemistry and Biochemistry, North Dakota State University. Research in the sivagroup involves the use of light to initiate chemical reactions and control photoreactivity in the excited state using molecular design and nanoconfinement. The cornerstone of the research program involves synthetic effort that allows a freedom of design to produce new structural motifs not only for studying stereoselective reactions but also for chemical and bio-molecular recognition of encapsulated guests within water-soluble nano-reaction vessels. The research program also investigates the molecular and supramolecular assembly characteristics of systems to gain a deeper understanding of the interplay between molecular structure, assembly, dynamics and the role of external interactions critical for molecular recognition events in light-initiated reactions. Sivagroup uses modern molecular tools and spectroscopic techniques to gain deeper understanding of molecular interactions in chemical and biological systems, using light as both a reagent that initiates the chemistry and as the product of excited state reactivity of organic molecules.

Summary of Research and/or Problem Being Studied: Plastic populates our world through everything from electronics to packaging and vehicles. Once discarded, it resides almost permanently in landfills and oceans. A new discovery holds scientific promise that could lead to a new type of plastic that can be broken down when exposed to a specific type of light and is reduced back to molecules, which could then be used to create new plastic. (North Dakota State University, 2014)

Preparation/Materials

Background knowledge students must have to be successful

Understand that atoms are the building blocks and molecules are atoms joined together to form bonds. Polymers are made up of many molecules all strung together to form 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 molecular level. Things that are made of polymers look, feel, and act depending on how their atoms and molecules are bonded, as well as their origin of source. Some are rubbery, like a bouncy ball, some are sticky and gooey, and some are hard and tough.

Essential Terminology

Copolymer - A polymer made from two or more types of monomer subunits.

cross-linker - A covalent bond linking two polymeric chains together, sometimes facilitated by a small molecule.

Graft polymer- A branched polymer having sidechains composed of different monomers to that of the main chain.

Homopolymer - A polymer made from only one type of monomer.

Monomer - The building block of polymers. Monomers can be combined in various repeating patterns to form different types of polymers.

natural polymer - A polymer that is synthesized naturally by a plant or organism.

Polymer – high molecular weight compounds made up of small repeating units (monomers)

Polymerization - The process of chemically linking monomers in various patterns to produce a polymeric material.

synthetic polymer – human-made polymers

Resources:

Ahluwalia, V. K. and Mishra, A. *Polymer Science: A Textbook*. Boca Raton, FL: CRC Press, 2008.

Bahadur, P. and Sastry, N. V. *Principles of Polymer Science*. Boca Raton, FL: CRC Press, 2002; p. 401.

Morgan, N. "Polymers and Plastics." in *Chemistry in Action: The Molecules of Everyday Life*. New York, NY: Oxford University Press, 1995, pp. 94-107.

Nicholson, J. W. *The Chemistry of Polymers*. Third Edition. London, UK: Royal Society of Chemistry, 2006.

Materials needed:

Lesson 1

- 2 different colors of paperclips

Lesson 2

- Bouncy Ball Activity:
    - Chemicals
        - Solid borax
        - Elmer’s glue
        - Water
        - Food color
        - Corn starch
    - Materials
        - Beakers
        - Graduated cylinder
        - Stir rods
        - Weighing balance
        - Gloves
        - Scoopula
- Silly Putty Activity
    - Chemicals
        - 2% borax solution or Solid borax
        - Elmer’s glue
        - Water
        - Food color
    - Materials
        - Beakers
        - Graduated cylinder
        - Stir rods
        - Gloves

Lesson 3

- Chemicals required:
    - Styrene
    - Biobased photoinitiator
    - Acetonitrile
    - Methanol
- Materials:
    - Light source
    - Pipette
    - plastic bottle cap

Lesson 4

- Chemicals
    - Corn Starch
    - Liquid Glycerin
    - Water

- White vinegar
- Food color

- Materials
    - Glass rod (stirring rod)
    - 2 Beakers (200 or 400 ml)
    - Graduated cylinder
    - Hot plate

PowerPoint – found as separate attachment

Procedure/Activities

Lesson 1:

1. Present PowerPoint presentation Slides 3-6

   Slide 3

   Polymers can be found almost everywhere is our day to day lives. The examples on this slide are just a few of the polymers you might encounter. Notice that some polymers can be hard and rigid like the toothbrush while others can be flexible and gooey such as the paint or adhesives. Think about your day so far. What polymers have you encountered polymers today?

   Slide 4

   What are polymers?

   A polymer is a high molecular weight compound made up of small repeating units called monomers. An energy sources is needed to convert a monomer to a polymer. This process is known as polymerization. Electricity is the most common source of energy used for polymerization.

   Slide 5

   Polymers can be classified in a number of ways including: Origin of Source, Structure, Intermolecular forces. Review the chart for each classification. Keep in mind there are many other ways to classify polymers

   Slide 6

   Introduce each polymer model one at a time and have students create the following models using paperclips. Each paperclip is considered an induvial monomer.

   1. Make a homopolymer: Take 10 paper clips of one color and attach to one another, which results in the formation of homopolymer (A-A-A-A-A-A-A)
   2. Make an alternating polymer: Take 5 paper clips of one color (A) and 5 paper clips of a different color (B). Attach paper clip (A) on both ends to 1 paper clip (B). Attach another paper clip (A) to the previous paper clip (B). Continue attaching paper clips in alternating order until you have no more paper clips. This forms an alternating polymer. (A-B-A-B-A-B-A-B-A-B-A-B-A-B-A)
   3. Make a Block Copolymer: Take 5 clips of one color and attach them into a chain (Chain 1). Next, choose 5 units of another color and make them into a chain (Chain 2). Attach Chain 1 and Chain 2. This forms a block copolymer. (A-A-AA-A-B-B-B-B-B)
   4. Make a Random polymer-monomers are located randomly in the polymer molecule
   5. Challenge: Given the following definition, can you make a graft polymer?
      a. Graft polymer- A branched polymer having sidechains composed of different monomers to that of the main chain.
   6. Lesson 1 wrap-up- Discuss:
      a. What is the name of the polymer with only one type of monomer arranged linearly?
      b. What is the difference between a graft polymer and a homopolymer?

Lesson 2:

1. Present PowerPoint slides 7- 11

   Slide 7

   Review the classification of polymers. Yesterday we created models based on the structure of the polymers. Today we will form a polymer classified by the mode of polymerization.

   Slide 8

Condensation polymerization- molecules join together losing small molecules as byproducts such as water. A polypeptide is a linear organic polymer with amino acids bonded together forming a protein molecule. Carboxylic acid and Amine are bonded to create Amide and the byproduct of water. Polyesters is a polymer where units are bonded together by ester linkages. Carboxylic acid and alcohol bond to create ester and the byproduct of water.

Slide 9

Chemicals required: • Solid borax • Elmer's glue • Water • Food color • Corn Starch

Materials required: • Beakers (2) • Graduated cylinder • Stir rods • Weighing balance • Gloves • Scoopula

1. Acquire two beakers and label the two beakers A and B.
2. Weigh 2 g of Borax in beaker A. Add 20 mL of water to beaker A. Add three (3) drops of food coloring to beaker A and stir contents.
3. Take 2 mL of the solution in beaker A and add to beaker B.
4. add 1 plastic spoon full of glue to beaker B. Add 6 g of cornstarch to beaker B. Stir mixture. Continue stirring the mixture for five (5) minutes or until it becomes solid. Take solid mixture into hands and form into a ball.
5. Allow to dry for 5 minutes. Enjoy!

Write down as many observations as you can about your bouncy ball:

Does your ball bounce?

Compare your ball with those of the other members of the class. How many properties can you compare? (Size, height of bounce, etc)

Slide 10/11

Chemicals required: • 2% borax solution or solid borax • Elmer's glue, water • Food color

Materials required: • Goggles • Gloves • Beaker • Stirring rod

Procedure:

- Acquire two beakers and label the two beakers A and B. Weigh 2g of Borax in beaker A. Add 20ml of water to beaker A. Add three (3) drops of food coloring to beaker B. Then add 1 plastic spoon full of glue to beaker B. Combine beaker A into beaker B. Stir mixture. Continue stirring the mixture for five (5) minutes or until it becomes solid.
- Wearing gloves, take the polymer formed in hands and enjoy.

Principle: Elmers Glue is made up of polyvinyl acetate, which reacts with water to some extent to replace some of the acetate groups with OH (alcohol) groups. The B-OH groups on the borax molecules react with the acetate groups on the glue molecules (relatively long polymer chains) to eliminate acetic acid and form new bonds between the borax and two glue molecules. The linking of two glue molecules via one borax molecule is called polymer cross-linking and it makes a bigger polymer molecule, which is now less liquid-like and more solid.

Observe and write down the physical properties of the silly putty

What are the differences in the silly putty and the bouncy ball?

What compound/chemical did we add in the bouncy ball that we did not add in the silly putty?

Lesson 3: *Note- the experiment will require 3 hours to synthesize

Present slides 12-21

Slide 12

Why Polymers?

Based on methods of synthesis, type of monomer, and organization of monomers, polymer properties can be modified

Polymers can be: Elastic, Hard, or Soft

But most important polymers are CHEAP!

Slide 13

The Issue

Lot of polymers are made from fossil fuels (petrochemicals)

Ask students if they can think of why this might be an issue.

The negative aspects of making polymers out of fossil fuels include:

- Fossil fuels are a non-renewable source
- Commercialization of petrochemical products causes pollution
- Petrochemical products take a long time to degrade

Slide 14

How to resolve the issues

Ask students to come up with ideas on how to solve the issues discussed on slide 13

Some ideas include:

- Synthesize polymers from naturally available (abundant) sources
- Synthesize polymers with cheaper, abundant, benign light
- Make these polymers easily degradable
- Decrease pollution and adverse effects of fossil fuels

Slide 15

Polymer synthesis with light

Polymerization of styrene/methylmethacrylate with biomass derived photoinitiator

Chemicals required: • Styrene • Biobased Photoinitiator • Acetonitrile • Methanol

Materials required: • Light source • Pipette • Plastic bottle and cap

Procedure:

• Acquire vial with cap. Measure into the vial 1 mL of biobased Photoinitiator, 0.5 mL of thiophenol (coinitiator) and 1 mL of inhibitor free styrene/methyl methacrylate into test tube into the vial.

• Place the samples under suitable light source.

• After 3 hours remove the vial from the light source. add 2 mL of methanol, stir the mixture. Observe the change in the solution.

Slide 16

Principle: Initiators react with monomers and initiates the polymerization.

Questions:

1. How do you know the polymer was formed?
2. based on the paper clip models we made in lesson 1 what type of polymer did you synthesize?

Slide 17

Direct students to go to **https://csms-ndsu.org/**

North Dakota seeks to advance new Discoveries of bio-based, sustainable materials that give more consideration to the environment and contribute to its economy through their sourcing (low cost, renewable), durable lifetimes (long, high durability), and recyclability (efficient, high value).

Allow students to explore the site to learn more about who is involved in this project and all of the research that has been conducted.

Slide 18

This slide shows how biomass can be converted into a photodegradable polymer with endless opportunities to be recycled. Furanicarboxylic acid (FDCA) is a potential alternated for Terephthalic acid (used to make clothing and plastic bottles)

Slide 19, 20, 21

In a photocleavage reaction of FDCA approximately 85% of the monomer is recovered. The pictures show the polymer prior to irradiation and the progress over 1 hour, 3 hours and 6 hours of irradiation back to the monomer

Lesson 4:

Slide 22

- Biodegradable plastics: plastic that decomposes naturally in the environment.
- Made from all-natural plant materials. These can include corn oil, orange peels, starch, and plants
- Can be broken down by microorganisms (bacteria or fungi) into water, carbon dioxide (CO2) and some bio-material.
- Biodegradable plastics are better for the environment than traditional plastic.

Slide 23

Chemicals Required

- Corn starch
- Liquid Glycerin
- Water
- White Vinegar
- Food Color

Notice all of the everyday items at the bottom of the slide that can be made with biodegradable plastics

Slide 24

• Measure out 15 mL of cold water and half tablespoon of cornstarch into the beaker
• Add (5 mL) of vinegar and 5 mL of glycerin into the mixture.
• Add five (5) drops of food coloring to make it colored
• Place beaker on hot plate and keep on slow heating, constantly stirring. The mixture will start to thicken and become a gooey, opaque substance. Mix until it boils and becomes clear - should be bouncy and should stick to itself rather than the beaker.
• Pour some onto a piece of aluminum foil and let it dry, so students can take it home with them at the end of the day
• In this experiment, students will have the opportunity to make plastic out of household materials. They will learn about the importance of environmental friendliness while they make the plastic.

Principle: Vinegar ferments cornstarch and help to produce polylactic acid, which is a polymer.

Extensions for above average students:
Have student(s) research and present to classmates on what is being done to decrease the use of plastics in our world or research the biodegradable alternatives to plastics.

Mediation/Support for students that need it:

- Partner struggling students with more advanced students.
- Provide highlighted notes of the essential terminology.
- Provide word banks when writing rationales.
- Print slide show with room to take notes on the side.

Lesson Outline (for research-based lessons)

Lesson 1:
– Intro to polymers
  - Overview of types of polymers
  - Modeling polymers with paperclips

Lesson 2:
  - Classification of polymers
  - Bouncy ball activity
  - Silly

Lesson 3:
  - Resolving the issues of using fossil fuel polymers
  - Polymer synthesis with light activity
  - Explore the Center for Sustainable Materials Science

Lesson 4:
  - Biodegradable polymers
  - Create a biodegradable plastic

Standards Alignment

ND Science Standard(s):

HS-PS2-6. Communicate scientific and technical information about why the molecular level structure is important in the functioning of designed materials. (Grades 9 - 12)

HS-PS1-5 Apply scientific principles and evidence to provide an explanation about the effects of the reacting particles on the rate at which a reaction occurs.

HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Disciplinary Core Idea: e.g.

- Chemical Reactions • Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

North Dakota DPI Standards:

HS-PS2-6. Communicate scientific and technical information about why the molecular level structure is important in the functioning of designed materials. (Grades 9 - 12)

RST.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific or technical context relevant to grade 9-10 or 11-12 texts and topics.

SL.1 Initiate and participate in a range of collaborative discussions with diverse partner on grapes 9-10 or 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

a. Come to the discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate thoughtful, well-reasoned exchange of ideas.

Next Gen Standards:

HS-PS2-6. Communicate scientific and technical information about why the molecular level structure is important in the functioning of designed materials. (Grades 9 - 12)

Science and Engineering Practices

- Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Cross Cutting Concepts

- Patterns -Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.
- Cause and Effect- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
- Stability and Change - Much of science deals with constructing explanations of how things change and how they remain stable.

Unit Objectives

- Describe how polymers are synthesized by combining two types of monomers with heat for a sufficient period of time.
- Predict how a cross-linker will cause a change in the physical properties of a polymer system and how molecular arrangements influence these materials properties.
- Describe examples how polymers are used in everyday life.
- Learn and become familiar with methods of synthesizing polymers

Assessment

Discussion Questions from slides and lesson plan: Have students complete the questions from the activities. Review their answers to gauge their comprehension.

Daily Plans and Assessments

Learning Target for each day/activity

Lesson 1

- Understand the structure of polymers through the building models

Lesson 2

- Understand condensation polymerization and how cross-linking effects flexibility

Lesson 3

- Describe what is being done to decrease pollution and adverse effects of fossil fuels

Lesson 4

- Produce a biodegradable plastic using common chemicals

Criteria for Success/Assessment for each activity

Completion of questions that correlate with each activity.

Additional Lesson Resources / Materials

References:
North Dakota State University. (2014, November 25). New plastic that disappears when you want it to. ***ScienceDaily***. Retrieved September 3, 2020 from
www.sciencedaily.com/releases/2014/11/141125101741.htm

Chemistry and Biochemistry - Basic Organic Chemistry. (n.d.). Retrieved September 06, 2020, from https://nptel.ac.in/courses/104/103/104103071/

Websites for purchasing materials:

Solid Borax
https://www.sigmaaldrich.com/catalog/search?term=borax&interface=All&N=0&mode=match%20partialmax&lang=en&region=US&focus=product

Liquid Glycerin
https://www.sigmaaldrich.com/catalog/product/sial/g9012?lang=en&region=US&gclid=Cj0KCQjw7sz6BRDYARIsAPHzrNILv1JQrcNVNo_pnZYlcx5k4kuZSoW4RU25xMYg5txSqPIRDVGKOkcaAoziEALw_wcB

Styrene
https://www.sigmaaldrich.com/catalog/product/sial/s4972?lang=en&region=US

Acetonitrile
https://www.sigmaaldrich.com/chemistry/solvents/products.html?TablePage=17292084&gclid=Cj0KCQjw7sz6BRDYARIsAPHzrNKBqN3L3U5usJetswcrmWaKPpt-4p4OQpaFLcukVSfUGp5dd4H4YTAaArXOEALw_wcB