Lesson Title: Recycling Bioplastics

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 take one bioplastic, polylactic acid (PLA), and degrade it back into lactic acid using sodium hydroxide (lye), ethanol (drinking alcohol) and water. You will then neutralize (render harmless) the lactate/lye solution by adding vinegar to lower the pH of the solution. In our second activity, you will compare the hardness of biopolymers to traditional fossil fuel-based polymers.

Lesson Objectives:

- You will be able to identify some different types of polymers.
- You will be able to determine the most environmentally friendly way of disposing of certain polymers.
- You will be able to describe the chemical concept of "stoichiometry".
- You will be able to describe the chemical concept of "pH".

NSF Subject Classification: Physical Science

National Next Gen Standards:

- HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen may combine with other elements to form large carbon-based molecules.
- HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during chemical reaction.
- HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

North Dakota Standards:

- HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen may combine with other elements to form large carbon-based molecules.
- HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during chemical reaction.
- HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

Grade or Grade Band: 9-12

Time Needed (estimate) 3 50-minute class periods

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Scientist/K12 Collaborator & University: Alex Parent, NDSU

Scientist Bio/Research: Sustainable Chemistry through Catalysis

Research in our group is divided among three major goals, all tied together by the common theme of sustainability through catalysis. We synthesize our catalysts using standard organic and inorganic techniques, and characterize their activities through a variety of techniques, including electrochemistry, kinetic analysis via UV-Vis, NMR and MS. We also study their mechanisms through time resolved spectroscopy aided by DFT calculations. As members of the Center for Sustainable Materials Science (CSMS) we are particularly focused on reactions that improve the sustainability and efficiency of polymer precursor production.

Preparation/Materials

Background knowledge students must have to be successful

- Polymers are abundant in nature and consist of DNA, RNA, starch, cellulose, and rubber
- Polymers can be very resistant to chemicals
- Polymers are generally lightweight with significant degrees of strength
- Polymers are usually made of petroleum, but not always
- Polymers have countless uses

Essential Terminology

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.
Biodegradable- capable of being decomposed by bacteria or other living organisms
Biobased- products that are derived from plants and other renewable agricultural such marine, and forestry materials instead of created from petroleum.
Stoichiometry- whole number ratio relationship between compounds or elements in a reaction
Neutralize- transform an acid or base to have a neutral pH.

Resources:

- This Is Plastics website
- American Chemistry Council

Websites:

- https://www.thisisplastics.com/plastics-101/how-are-plastics-made/
- https://www.thisisplastics.com/topics/innovation/
- https://www.thisisplastics.com/topics/environment/
- https://www.biopreferred.gov/BioPreferred/faces/pages/BiobasedProducts.xhtml
- https://plastics.americanchemistry.com/plastics/The-Basics/
- https://www.ndepscor.ndus.edu/ndep/nature/sunday-academy/stem-module-topics/
- Extension: https://evavarga.net/plastics-lab-activity/

Materials needed:

Lesson 1

- 1 Set of pencils with varying hardness
    - https://www.amazon.com/Sketching-Different-Exquisite-Box-Lightwish-7001-12TN/dp/B073TW8QVR
- 1 Magnifying Glass
- 1 Set of Polymer Samples
    - https://scientificpolymer.com/shop/polymers-sample-kit/ this website sells it for $400
    - Mechanical engineering department at NDSU has some. If you don't need too many samples this may be an option for your class. If you are interested in this route you can try contacting Chad Ulven: chad.ulven@ndsu.edu. His group makes these types of samples in order to compare with their composite materials.

    - As an alternative, you could try using different types of common plastics, such as pieces of a soda bottle, milk jug and Tupperware.
    - There is also the possibility of buying samples from a chemical company. ACME sells samples for $5 each plus $10 in shipping, and they have Acrylic, Polycarbonate, PETG, PVC, and styrene samples available. https://www.acmeplastics.com/plastic-samples

Lesson 2

- 1 Hot plate
- Scissors
- 1 PLA cup
    - https://www.amazon.com/AmazonBasics-Compostable-Cold-Cups-000-Count/dp/B078S8RR88
- 1 Balance
- Safety glasses
- Gloves
- Lye (sodium hydroxide)
- 1 Spatula or Scoopula
- 1 Oven Mitt or 1 Pile of Paper Towels
- 30 mL ethanol
- 30 mL water
- 1 50 mL graduated cylinder
- 1 Clock or watch
- 1 100 mL Erlenmeyer flask
- 1 Stir bar

Lesson 3

- pH test strips
- 20 mL vinegar
- 100 mL beaker
- 1 Sheet of Graphing Paper
- 1 5 mL Graduated Cylinder
- Safety glasses
- Gloves
- Lactate Solution from Lesson 2

PowerPoint – found as separate attachment

Procedure/Activities

Lesson 1:

- Most students are probably unaware that North Dakota has a center for sustainable materials. If time allows, have students visit the site and learn about the research they do: https://csms-ndsu.org/
- PPT Slides 1-3
- Follow up questions such as: what do we use plastic for in our lives and list some things around you that are not plastic
- PPT Slides 4-7
- Follow up question: why is it so important to create plastic that can be recycled
- Watch the following video: https://www.thisisplastics.com/plastics-101/how-are-plastics-made/
- Review vocabulary for monomer, polymer, plastic, biobased, and biodegradable
- Hand out Activity 1 sheet and go through the directions
- Discuss what students found out PPT Slide 9

Lesson 2:

*Recommend having lab stations set up with materials that is needed to ensure activity can be done in a 50-minute period

- Go over PPT Slide 10
- Optional activity- Have students assemble smores out of graham crackers, marshmallows, and Hershey's bars to see how many they would get out of what is given. An extension could be going over which item would be the excess reactant and which one would be the limiting reactant.
- Review vocabulary for stoichiometry
- Go over PPT Slide 11 and work through amount of lye needed
- PPT Slide 12 and talk about next activity, showing what they need and the go over chemical safety
- Hand out Activity 2 sheet and go over the steps with students and then let them carry out the activity
    - Have students record their observations every 5 minutes on the Activity 2 handout
- Go around to groups checking in and talking about what is happening with where they are at
- Ask questions 1-4 found on PPT Slide 13
    - Let students know to keep their products for tomorrow as they will use it again
- Have students research what are PET plastics and compare them with PLA plastics
- Asking final question found on PPT Slide 13

Lesson 3:

- Go over PPT Slide 14
- Review vocabulary for neutralize
- Go over PPT Slide 15 with what to do in the activity and materials needed
- Hand out Activity 3 sheet and carry out activity
- Go around to groups checking in and talking about what is happening with where they are at
- PPT Slide 16 question discussion
- Optional extension: test various commons solutions and with pH strips and change the pH by adding either vinegar or baking soda and recording how much is needed to make the solution neutral

Extensions for above average students:

- Research items that are created from recycled plastics
- Research future developments scientists hope to achieve with creating or recycling plastics
- Plastic and Polymer Lab extension- categorizing types of plastics

Mediation/Support for students that need it:

- 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):

- HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen may combine with other elements to form large carbon-based molecules.
- HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during chemical reaction.
- HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

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

ND Math DPI Standards:

HS.NQ.1* Use units as a way to understand problems and to guide the solution of multi-step problems (e.g., unit analysis). Choose and interpret units consistently in formulas. Choose and interpret the scale and the origin in graphs and data displays.

HS.NQ.2* Define appropriate quantities for the purpose of descriptive modeling

HS.FIF.4* Use tables, graphs, verbal descriptions, and equations to interpret and sketch the key features of a function modeling the relationship between two quantities.

Next Gen Standards:

- HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen may combine with other elements to form large carbon-based molecules.
- HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during chemical reaction.
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Science and Engineering Practices

- Developing and Using Models

Cross Cutting Concepts

- Stability and Change

- Energy and Matter
- Patterns

Unit Objectives

- Students will be able to carry out a chemical reaction to transform one form of plastic into another usable substance thus replicating the idea behind recycling.

Assessment

- Students provide an explanation with examples on how plastics are generated and recycled. They can create a defense with support to why it is necessary to recycle plastics for our environment.

Daily Plans and Assessments

Learning Target for each day/activity

- Lesson 1/Day 1- Students will be able to understand polymers and how they can be categorized.
- Lesson 2/Day 2- Students will be able to carry out stoichiometry to create a PLA and analyze its ability to be broken down.
- Lesson 3/ Day 3- With a background in pH, students will be able to neutralize solution.

Criteria for Success/Assessment for each activity

- Lesson 1- Students will be assessed on their ability to classify their polymer using different pencils with varying hardness. They will share numerous uses for plastics.
- Lesson 2- Students will successfully carry out degrading PLA or reflect on what went wrong.
- Lesson 3- Students will successfully neutralize their lactate solution.

Additional Lesson Resources
Materials

References:

"Recycling Polylactic Acid" Beyond Benign 2010 Web. 25 May 2017
http://www.beyondbenign.org/K12education/hsgc/recycling%20polylactic%20acid.doc

“Hydrolysis of Post-Consumer Polylactic Acid Waste” Greener Education Materials for Chemists University of Oregon 2008 Web. 25 May 2017 http://greenchem.uoregon.edu/PDFs/GEMsID102.pdf

Parent, A. “Recycling Bioplastics”. Web. 14 June 2020. https://www.ndepscor.ndus.edu/fileadmin/ndus/ndepscor/SundayAcademy/2017-18SARecycling_Bioplastics_Lesson_Plan.pdf

Websites for purchasing materials

Pencils with varying hardness

https://www.amazon.com/Sketching-Different-Exquisite-Box-Lightwish-7001-12TN/dp/B073TW8QVR

Polymer Sample Kit

- https://scientificpolymer.com/shop/polymers-sample-kit/ this website sells it for $400
- Mechanical engineering department at NDSU has some. If you don’t need too many samples this may be an option for your class. If you are interested in this route you can try contacting Chad Ulven: chad.ulven@ndsu.edu. His group makes these types of samples in order to compare with their composite materials.
- As an alternative, you could try using different types of common plastics, such as pieces of a soda bottle, milk jug and Tupperware.
- There is also the possibility of buying samples from a chemical company. ACME sells samples for $5 each plus $10 in shipping, and they have Acrylic, Polycarbonate, PETG, PVC, and styrene samples available. https://www.acmeplastics.com/plastic-samples

If need general 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

Activity 1 – Measuring the Hardness of Plastics

Materials:

- 1 Set of Pencils
- 1 Magnifying Glass
- 1 Set of Polymer Samples

Instructions: Try to bend each of the polymer samples, then rank the samples in order of easiest to bend to hardest to bend:

Easiest: _____

_____

_____

Hardest: _____

Predict which sample will be easiest to scratch, and which sample will be hardest to scratch:

Easiest: _____ Hardest: _____

Starting with the softest pencil, try to scratch each polymer sample. Record the softest pencil that will scratch each sample.

Polymer Sample	Pencil Hardness

Which polymer sample was the hardest to scratch? Which was the easiest?

Activity 2 – Depolymerizing Polylactic Acid (PLA)

Based on the "Recycling Polylactic Acid" high school chemistry experiment developed by Beyond Benign1 , and the "Cups to Cleaners, Trash to Treasure: Converting a PLA cup to LA soap an Introductory Organic Chemistry Laboratory" experiment developed by Prof. Rich Gurney, Simmons College.[2]

Materials:

- 1 Hot plate
- Scissors
- 1 PLA cup
- 1 Balance
- Safety glasses
- Gloves
- Lye
- 1 Spatula or Scoopula
- 1 Oven Mitt or 1 Pile of Paper Towels
- 30 mL ethanol
- 30 mL water
- 1 50 mL graduated cylinder
- 1 Clock or watch
- 1 100 mL Erlenmeyer flask
- 1 Stir bar

Instructions: Predict how much lye you would need to decompose one gram of PLA:

_____ g lye / g PLA (predicted) _____ g lye / g PLA (actual)

Cut a PLA cup into strips of varying size, then measure out the total mass of PLA you will be depolymerizing (aim for 0.5 g). Leave any extra PLA pieces, we will clean them up later.
_____ g PLA used

Predict which part of the PLA will depolymerize the fastest: _____
Use the stoichiometric ratio between lye and PLA to determine how much lye you will need.
_____ g lye needed.

Add 30 mL of water and 30 mL of ethanol to an Erlenmeyer flask, then add a magnetic stir bar to the solution. Measure out the amount of lye you need onto a weigh boat, then slowly add the lye to the flask while stirring. (Note the lye will absorb water while on the weigh boat, so measure with due haste). We used _____ g lye.

Add your PLA strips to the lye solution, then heat the solution at max power until it boils. Reduce the heat until your solution is at a simmer.

Time	Observations

Our solution started boiling at _____ (AM/PM).

Watch your solution, making sure that it does not start to boil. Record your observations every 5 minutes. Time Observations 0 min 5 min

Record the time at which no solid PLA is visible: _____ (AM/PM).

Turn off your hot plate, and allow your solution to cool to room temperature (about 3 minutes).

Activity 3 – Neutralizing a Lactate Solution

Materials:

- pH test strips
- 20 mL vinegar
- 100 mL beaker
- 1 Sheet of Graphing Paper
- 1 5 mL Graduated Cylinder
- Safety glasses
- Gloves
- Lactate Solution from Activity 2

Instructions:

Measure the pH of your solution using pH paper: pH ___

Slowly add 2 mL of vinegar to the solution, then measure the pH of your solution again: pH ___

Keep adding 2 mL of vinegar to your solution and recording the pH until the pH is below 7:

Amount of Vinegar Added	pH
0 mL	
2 mL	

On your sheet of graphing paper, plot the pH of your solution as a function of how much vinegar you added.

Congratulations, you have just turned your PLA cup into a vinegar and lactic acid based cleaning solution! This solution is safe to use for cleaning counters, windows, or tiling in the kitchen or bathroom.

Extension: Plastics & Polymers: A
Plastics Lab Activity

Posted by Eva Varga

Plastics are everywhere – from airplanes to drinking bottles to sports equipment. They are most commonly derived from petrochemicals but many are partially natural. Typically, plastics are organic polymers (or chains of carbon atoms with hydrogens hanging off), but they often contain other substances.

Each plastic is chemically unique and has distinct properties that make it suitable for certain products. These different characteristics (weight, durability, stacking, and even consumer appeal) are taken into consideration when packaging is considered for new products.

Plastics Lab Activity

Plastics can provide hands-on, inquiry based lab activities with which students can investigate materials that are common to your everyday lives. To begin our initial plastics lab activity, I asked the kids to name as many things as they could that are made of plastic. Are all plastics the same? How are they different?

I then displayed a number of plastic materials I had collected and we talked about the characteristics of each. [Alternatively, you could do this lesson in two parts and ask the students to bring in samples themselves.]

I explained that plastics are classified #1 through #7 and I showed them how to check the bottom of the object to locate the number inside the recycle symbol. Even though some recycling centers only accept certain numbers, all plastics with this symbol are recyclable. Markets just don't exist for all recycled products.

After our discussion, students were asked to sort the plastic bottles and containers according to their numbers. Then, students were asked to brainstorm different physical properties that are characteristic of each type of plastic and test them. The students were encouraged to make a table in their science notebook and record the physical properties of each type of plastic. This data table would then be used to help them classify a set of unknown plastic pieces.

Density – Does the plastic float or sink in water? (Cut plastics into pieces before dunking in water. #2, #4, and #5 float while #1 and #6 sink.)

Transparency – Is the plastic clear or opaque?

Luster – Is the plastic dull or shiny?

Brittleness – Does the plastic break when bent?

Rigidness – Is the plastic flexible or tough?

Color – Is the color the same for every sample number?

Mystery Plastics

In advance, samples of #1, #2, #3, #4, #5, and #6 plastics were cut into small pieces (about 1 to 2 in.). As many were not distinguishable by sight, I cut each number into a different shape. For example, I cut #1 plastic into squares, #2 into triangles, and so on. I made a key that identified each plastic by its number. A mixture of all types of plastics were then placed into a bag for each group.

When the students' data tables were complete, I gave a bag of mystery plastics to each group and challenged the kids to identify the different plastics by their physical properties. Could they assign a number to each sample? Once a group was finished, they could check their predictions with the key.

Take it Further

During the testing process, one of the students made an interesting discovery in class – he had pulled on a

strip of plastic cut from a bread bag and discovered it stretched quite a distance before breaking. Another plastic (a sandwich zip baggie) took significantly more force before breaking. This lead us to talk a little about tensile strength.

I encouraged the kids to pursue this further by cutting strips (approximately 2.5cm by 12cm) from a variety of different plastics (freezer bags, food wrap, microwave wrap, trash bags, grocery bags, or any other type of similar plastic) and developing a test to determine the weight needed to break each of the plastic strips. As you slowly pull the ends apart (stress), you can feel the resistance of the material as you pull it (strain).

Note: If you choose to pursue this, be certain to cut out plastic strips that are consistent in size and either parallel or perpendicular to the grain of the material. [By holding the bag to the light, the lines you see indicate the general direction of the polymer chains. The direction in which these chains are lined up is also known as the anisotropic nature of the material, or the direction of extrusion.]

Extension to Activity 3
Neutralizing Mystery Solution

Materials:

- pH test strips
- 30 mL vinegar
- 100 mL beaker
- 50 g of baking soda
- 1 5 mL Graduated Cylinder
- Safety glasses
- Gloves
- Various solutions (borax, milk of magnesia, lemon juice, pop, etc)

Instructions:

Choose a mystery substance and test the pH

Measure the pH of your solution using pH paper: pH ___

If your solution is a base adding 2 mL of vinegar to your solution and recording the pH until the pH is below 7:
If your solution is an acid add 5 grams of baking soda to your solution and recording the pH until the pH is above 7:

Substance	Amount of Baking Soda Added (by 5 g increments)	Amount of Vinegar Added (by 2 mL increments)	pH