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| --- |
| Use of Bioplastics in Food Safety |
| High School Chemistry  (Revised July 2018)  **Standards addressed in unit:**  **HS-PS1-3.** Cite evidence to relate physical properties of substances at the bulk scale to spatial arrangements, movement, and strength of electrostatic forces among ions, small molecules, or regions of large molecules in the substances. Make arguments to account for how compositional and structural differences in molecules result in different types of intermolecular or intramolecular interactions.  **HS-PS2-6.**  HS-PS2-6. Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.\*  **HS-ETS1-1.** Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.\*  *[See unit plan for clarification statements.]*  In this unit, students study the structure-property relationship of complex covalent molecules and apply some steps of the engineering design process. The chemical industry is used as a real-world example as students synthesize and test properties of new polymer materials that can be engineered to have specific properties by creating composites and by altering chemical structures at the nanoscale. Students learn about how the chemical industry researches and develops polymer and polymer composites (including polymer nanocomposites) that are designed to keep food safe for the food packaging industry. Students end the unit proposing designs for a synthetic bioplastic-based material that will be used for food packaging. |
| *This Model Curriculum Unit is designed to illustrate effective curriculum that lead to expectations outlined in the 2016 Science and Technology/Engineering Curriculum Frameworks (*[*www.doe.mass.edu/STEM/STE*](http://www.doe.mass.edu/STEM/STE)*) as well as the MA Curriculum Frameworks for English Language Arts/Literacy and Mathematics. This unit includes lesson plans, a Curriculum Embedded Performance Assessment (CEPA), and related resources. In using this unit it is important to consider the variability of learners in your class and make adaptations as necessary.*    This document was prepared by the Massachusetts Department of Elementary and Secondary Education. Mitchell D. Chester, Ed.D., Commissioner  The Massachusetts Department of Elementary and Secondary Education, an affirmative action employer, is committed to ensuring that all of its programs and facilities are accessible to all members of the public. We do not discriminate on the basis of age color, disability, national origin, race, religion, sex, or sexual orientation.  © 2015 Massachusetts Department of Elementary and Secondary Education (ESE).ESE grants permission to use the material it has created under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License. Additionally, the unit may also contain other third party material used with permission of the copyright holder. Please see Image and Text Credits for specific information regarding third copyrights.  Every effort has been made to acknowledge copyright. Any omissions brought to our attention will be corrected in subsequent editions.  The contents of this Model Curriculum Unit were developed under a grant from the U.S. Department of Education. However, those contents do not necessarily represent the policy of the U.S. Department of Education, and you should not assume endorsement by the Federal Government.  Massachusetts Department of Elementary and Secondary Education, 75 Pleasant St, Malden, MA 02148-4906. Phone 781-338-3300, TTY: N.E.T. Relay 800-439-2370, [www.doe.mass.edu](http://www.doe.mass.edu) |

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# Unit Assumptions and Comments on Sequence

The guiding question for this unit is “How can we keep our food safe?” Students learn about plastics and measure the density of different plastics. They describe the problems that an improved food packaging film must address and develop criteria and constraints. Students examine structure-property relationships in plastics by modeling polymers. Then use a jigsaw approach to synthesize three different bioplastics and measure properties of their bioplastic that relate to food packaging film criteria. Groups present their results and their hypothesis of aspects of the bioplastic structure to the class. The proposal includes a detailed rationale for the choice of starting bioplastic and any proposed changes to the structure and composition of that bioplastic in order to make the designed material more suited for meeting food safety and other criteria for an improved food packaging film. Students present their proposal along with a detailed explanation of themolecular-level structure of plastics and their specific properties to justify why that particular class of substances is useful for food packaging.

*It is assumed that students know or have experience doing the following:*

* Substances are made from some 100 different types of elements, which combine with one another in various ways. Substances are composed of molecules, compounds or atoms, and atoms form molecules that range in size from two to thousands of atoms.
* Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
* Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
* When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
* Criteria for a design selection may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
* Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
* Analyze complex real-world problems by specifying criteria and constraints for successful solutions.
* Use a model to predict the relationships between systems or between components of a system.
* Collect data to serve as the basis for evidence to test design solutions under a range of conditions
* Communicate technical information or ideas in multiple formats (including orally, graphically, textually, and mathematically).
* Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, and prioritized criteria.

*Notes about the Unit:*

* Throughout the unit there are notes to the teachers to suggest ideas and strategies.
* All handouts are located on pages 36-71at the end of the unit in the **Unit Resources section**. Integrate these resources as needed with your existing materials on polymers.
* The unit examines how intermolecular interactions are determined by atomic composition and molecular geometry for polymers but does not address this relationship in atom/ionic networks or molecular crystals.

See the strand map, next page, for an overview of the science standards that precede this unit and how the standards learned in this unit contribute to students learning in later grades.

Strand maps for standards HS-PS1-3, HS-PS2-6, HS-ETS1-1.

HS-PS1-3
 - Prior standards: 7.MS-PS2-5, 8.MS-PS1-1
 - Following standards: HS-PS1-1, HS-PS1-11(MA), HS-PS2-6

HS-PS2-6
 - Prior standards: 6.MS-ETS2-1(MA), 6.MS-ETS2-2(MA), HS-PS1-3
 - Following standards: None

HS-ETS1-1
 - Prior standards: 6.MS-ETS1-1
 - Following Standards: HS-ETS1-2, HS-ETS1-4

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| Unit Plan **Stage 1 Desired Results** | | | |
| **ESTABLISHED UNIT GOALS G**  **HS-PS1-3.** Cite evidence to relate physical properties of substances at the bulk scale to spatial arrangements, movement, and strength of electrostatic forces among ions, small molecules, or regions of large molecules in the substances. Make arguments to account for how compositional and structural differences in molecules result in different types of intermolecular or intramolecular interactions. Clarification Statement: Substances include both pure substances in solid, liquid, gas and networked forms (such as graphite). Examples of bulk properties of substances to compare include melting point and boiling point, density, and vapor pressure. Types of intermolecular interactions include dipole-dipole (including hydrogen bonding), ion-dipole, and dispersion forces. State Assessment Boundary: Calculations of vapor pressure by Raoult’s law, properties of heterogeneous mixtures, and names and bonding angles in molecular geometries are not expected in state assessment.  **HS-PS2-6.**  HS-PS2-6. Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.\* Clarification Statement: Examples could include comparing molecules with simple molecular geometries; analyzing how pharmaceuticals are designed to interact with specific receptors; and considering why electrically conductive materials are often made of metal, household cleaning products often contain ionic compounds to make materials soluble in water, or materials that need to be flexible but durable are made up of polymers. State Assessment Boundary: State assessment will be limited to comparing substances of the same type with one compositional or structural feature different.  **HS-ETS1-1.** Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.\* Clarification Statement: Examples of societal requirements can include risk mitigation, aesthetics, ethical considerations, and long-term maintenance costs.  **CCSS.ELA-LITERACY.SL.9-10.4** Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. | | ***Transfer*** | |
| ***Students will be able to independently use their learning to…* T**   * use principles of the physical world to assess designed products and systems based on social needs and wants * engage in public discourse of scientific and technical issues in the news and community * analyze structure-property relationships in natural and designed materials based on physical and chemical principles | |
| ***Meaning*** | |
| **UNDERSTANDINGS U**  ***Students will understand that…***   * properties of covalent substances are related to the spatial arrangements of the molecules and the electrostatic forces among the molecules * an essential step in the design process is the development of design criteria and constraints * scientific discourse requires presentation, explanation, and evaluation of evidence-based claims * materials can be engineered to meet high-performance specifications by combining substances in specific configurations and by altering geometry of the chemical structure | **ESSENTIAL QUESTION EQ**  How can we keep our food safe?  **GUIDING QUESTIONS GQ**   1. How is it possible to create so many different kinds of polymers? 2. What are examples of structure-property relationships? 3. What are the advantages of using a designed material? |
| ***Acquisition*** | |
| ***Students will know…* K**   * atomic composition and molecular geometry of substances relate to their chemical and physical properties * a polymer’s specific properties at the bulk scale depends on these aspects of polymer structure: atomic composition of monomers, polymer chain length, degree of crystallinity, and polymer chain shape—which can be linear, branched, or cross-linked * there are a variety of natural and synthetic polymers, including synthetic plastics and bioplastics * a composite is made from two or more different materials which remain distinct * a nanocomposite incorporates very small nanoscale particles 0 to 100 nm in size * criteria should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them | ***Students will be skilled at…* S**   * comprehending, evaluating, and communicating technical information about materials * building and analyzing models * integrating multiple sources of information * cooperating and collaborating in group work * engaging in whole-class discussion * analyzing design criteria and constraints for a real-world design problem |
| **Stage 2 - Evidence** | | | |
| **CEPA Performance Task** | **Evaluative Criteria** | | |
| Understanding of plastics and its application to the design proposal | 0) Included no aspects of structure & properties of plastics to support their use in food packaging; 1) Included few aspects of structure & properties of plastics to support their use in food packaging; 2) Included some aspects of structure & properties of plastics to support their use in food packaging; 3) Included many aspects of structure & properties of plastics to support their use in food packaging; 4) Included & connected many aspects of structure & properties of plastics to support their use in food packaging | | |
| Design proposal content | 0) Nano and molecular scale of design not presented & not connected to criteria & constraints. Rationale for choice of starting material & proposed changes unclear or missing; 1) Nano and molecular scale of design poorly presented & minimally connected to criteria & constraints. Rationale for choice of starting material & proposed changes mostly unclear; 2) Nano and molecular scale of design adequately presented & partially connected to criteria & constraints. Rationale for the choice of starting material & proposed changes somewhat clear; 3) Nano and molecular scale of design well presented & mainly connected to criteria & constraints; 4) Rationale for the choice of starting material & the proposed changes clear. Nano and molecular scale of design well presented & fully connected to criteria & constraints. Rationale for the choice of starting material & the proposed changes very clear & concise. | | |
| Presentation organization | 0) Presentation of chemistry & proposal was incomplete & not clear. Listeners could not follow the line of reasoning. 1) Presentation of chemistry & proposal was unorganized & mostly unclear. Listeners had difficulty in following the line of reasoning. 2) Presentation of chemistry & proposal was somewhat organized & partially clear. Listeners were mostly able to follow the line of reasoning. 3) Presentation of chemistry & proposal was organized and clear. Listeners were able to follow the line of reasoning. 4) Presentation of chemistry & proposal was organized, clear, & concise. Listeners were able to follow the line of reasoning easily. | | |
| Appropriateness of presentation for purpose, audience, and task | 0) Organization, development, substance, & style were inappropriate; 1) Organization, development, substance, & style were mostly inappropriate; 2) Organization, development, substance, & style were somewhat appropriate; 3) Organization, development, substance, & style were mostly appropriate; 4) Organization, development, substance, & style were fully appropriate | | |
| **Other evidence** | **Evaluative Criteria** | | |
| Entrance tickets: Prior knowledge about an aspect of the lesson | 0) Not answered; 4) Answered | | |
| Exit tickets: Reasonable & justified opinions or reasonable & accurate explanations of an aspect of the lesson | OPINION: 0) Not answered; 1) Opinion & unreasonable or no justification provided; 2) Opinion & somewhat reasonable justification provided; 3) Opinion & mostly reasonable justification provided; 4) Opinion & completely reasonable justification provided  EXPLANATION: 0) Not answered; 1) Explanation is unreasonable & inaccurate; 2) Explanation is somewhat reasonable & accurate; 3) Explanation is mostly reasonable & accurate; 4) Explanation is completely reasonable & accurate | | |
| Labs and polymer modeling activity | Follow safety rules & procedure: 0) No; 4) Yes; Cooperate & collaborate: 0) No; 4) Yes; Record notes, observations, & conclusions: 0) No; 4) Yes | | |
| Apply understanding of density, polarity, & intermolecular bonding (prior knowledge) to predict which polymer configurations are more or less dense | 0) Not answered; 1) Explanation for prediction unreasonable or missing; 2) Explanation for prediction is somewhat reasonable; 3) explanation for prediction is mostly reasonable; 4) Explanation for prediction is completely reasonable  (See answers in **Lesson 4** Instructional Tips/Strategies/Suggestions for Teacher) | | |
| Describe problems that food packaging films must address | 0) Not answered or descriptions are inaccurate; 1) Accurately described one problem; 2) Accurately described two problems; 3) Accurately described three problems; 4) Accurately described four or more problems | | |
| Develop criteria & constraints for an improved food packaging film | 0) Not answered; 1) Proposed less than three criteria & two constraints; 2) Proposed three criteria & two constraints but did not give reasons for each choice; 3) Proposed three criteria & two constraints & gave reasons for each choice, but did not quantify criteria or explain how constraints limited possible solutions; 4) Proposed three criteria & two constraints & gave reasons for each choice, quantified the criteria if applicable, & explained how constraints limited possible solutions | | |
| Contribute to discussion by sharing, combining, categorizing, critiquing, & prioritizing criteria & constraints | (Students self-assess their contributions): 0) No contribution; 1) Contributed to discussion once; 2) Contributed to discussion twice; 3) Contributed to discussion three times; 4) Contributed to discussion once four or more times | | |
| Identify polymer chain arrangements, shapes, & bonds using models & determine how aspects of polymer structure relate to properties | Percentage correct (See answers in Lesson 4 Instructional Tips/Strategies/Suggestions for Teacher) | | |
| Verbally present a claim, evidence, & explanation on how an aspect of polymer structure relates to a specific property | 0) Not presented; 1) Claim, evidence, & explanation are unclear or missing; 2) Claim, evidence, & explanation are somewhat clear & reasonable; 3) Claim, evidence, & explanation are mostly clear & reasonable; 4) Claim, evidence, & explanation are completely clear & reasonable | | |
| Contribute to class discussion by matching tests and criteria and comparing properties and structures of plastics and bioplastics. | (Students self-assess their contributions): 0) No contribution; 1) Contributed to discussion once; 2) Contributed to discussion twice; 3) Contributed to discussion three times; 4) Contributed to discussion once four or more times | | |
| **Stage 3 – Learning Plan** | | | |
| ***Summary of Key Learning Events and Instruction***  **Lesson 1:** **Relate Density of Plastics to their Structure (50 minutes):** Students share what they know about the uses, manufacture, chemical makeup, and recycling of plastics. Students identify plastics by measuring their density and then consider the relationship between polymer structure and density. For homework, they examine and describe plastic items noting their SPI number and consider the reasons for food packaging.  **Lesson 2: Develop Criteria and Constraints for a Food Packaging Film (50 minutes):** Students share what they know about how food decomposes and how packaging prevents decomposition. Students learn that new food packaging is being developed in order to must meet longer shelf-life requirements and adhere to international food safety/quality standards. Student pairs describe the problems that food packaging films must address and develop criteria and constraints for the films. The teacher facilitates a discussion that results in a compiled list of criteria and constraints.  **Lesson 3: Model Structure-Property Relationships in Polymers (50 minutes):** Students learn that so many polymers can be made because of the complexity and size of polymer structures. Students learn that key aspects of polymer structure are atomic composition of monomers, polymer chain length, degree of crystallinity, and polymer chain shape—which can be linear, branched, or cross-linked. Student groups build and explore models of polymers and answer questions about how polymer structure is related to the properties of density, hardness, melting point, and flexibility.  **Lesson 4:** **Synthesize, Test, and Hypothesize the Structure of a Bioplastic: (150 minutes):** Using a jigsaw format, students make one of three bioplastics and determine the bioplastic’s and plastics’ properties of density, hardness, flexibility, reactivity with acids and bases, and transparency. Students report results and the teacher facilitates a discussion in which students compare properties and structures of bioplastics and plastics.  **CEPA:** **Propose a Criteria-based Design for a Bioplastic-Based Food Packaging Film (150 minutes):** Students choose two of the criteria developed in **Lesson 2** to guide their design of a bioplastic-based food packaging film. Students identify which of the three bioplastics synthesized in **Lesson 4** they will use in their film and propose changes to their polymeric structure and their composition in order to meet the criteria. Students prepare and give presentations that have two parts: a summary of themolecular structure and general properties of plastics that explains why that particular class of substances should be used for food packaging, and a detailed description of their proposed design for a bioplastic-based food packaging film. | | | |
| Adapted from Understanding by Design 2.0 © 2011 Grant Wiggins and Jay McTighe Used with Permission  July 2012 | | | |

# Lesson 1: Relate Density of Plastics to their Structure

**Brief Overview of Lesson:** Students share what they know about the uses, manufacture, chemical makeup, and recycling of plastics. Students identify plastics by measuring their density and then consider the relationship between polymer structure and density. For homework, they examine and describe plastic items noting their SPI number and consider the reasons for food packaging.

**Prior Knowledge Required**

* Substances are made from some 100 different types of elements, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
* Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.

**Estimated Time:** 50 minutes (1 class period)

**Resources**

* *Text****:*** Entrance and Exit Ticket questions, Introduction to Plastics, Identifying Polymers, Polymer Structures**,** Examine Plastics
* *Materials for class*: Solutions 1-6: Six solutions of known densities, made from ethanol, deionized/distilled water, and potassium carbonate. Make solutions as follows:

1. Ethanol (HIGHLY FLAMMABLE, HARMFUL)
2. 471 g (596 mL) ethanol in 439 mL deionized/distilled water (FLAMMABLE, HARMFUL)
3. 354 g (448 mL) ethanol in 586 mL deionized/distilled water (FLAMMABLE, HARMFUL)
4. Distilled/deionized water
5. 184 g potassium carbonate in 965 mL deionized/distilled water
6. 513 g potassium carbonate in 866 mL deionized/distilled water (IRRITANT)

* *Materials for each group of four students:* Fifteen mL each of Solutions 1-6, Six 150 x 25 mm test tubes, Test tube rack, Method for labeling test tubes, 25-mL graduated cylinder, Three samples of different plastics large enough to be cut into six 4-mm squares, Scissors capable of cutting plastic samples, Glass stirring rod, Paper towels

**Standard(s)/Unit Goal(s) to be addressed in this lesson:**

* **HS-PS2-6.** Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.\* Clarification Statement: Examples could include comparing molecules with simple molecular geometries; analyzing how pharmaceuticals are designed to interact with specific receptors; and considering why electrically conductive materials are often made of metal, household cleaning products often contain ionic compounds to make materials soluble in water, or materials that need to be flexible but durable are made up of polymers. State Assessment Boundary: State assessment will be limited to comparing substances of the same type with one compositional or structural feature different.

**Essential Question(s) addressed in this lesson:** What are examples of structure-property relationships?

**Objectives:**

**Students will be able to…**

1. Investigate the density of plastics
2. Use evidence from investigations to predict how the density of a plastic is related to its chemical makeup and structure

**Language Objectives****:**

**Students will be able to…**

1. Verbally describe or explain; record notes, observations, and conclusions,

**Targeted Academic Language:** structure, property**,** plastics, properties, molecules, polymer, monomer

**What students should know and be able to do before starting this lesson:**

* Interpret chemical formulas and depictions of substances at the atomic level
* Work in groups with limited supervision
* Follow lab procedures
* Use of lab equipment
* Know and follow lab safety rules

**Anticipated Student Preconceptions/Misconceptions:**

Students may think that:

* the macroscopic, submicroscopic, and representational aspects of substances are not connected

**Instructional Tips/Strategies/Suggestions for Teacher:**

*Identifying Polymers:* Seven plastics will be tested in all, with each group testing three plastics. Each group will need six 4-mm square samples of the three plastics they are testing, one sample to be added to each of the six solutions. Each plastic can be provided as a larger flat, thin sheet with scissors to cut the samples, or as ready cut samples. Different types of plastics, if not identifiable by color, will need to be labeled with a code letter or number, or even cut into different shapes for identification. They should NOTbear the SPI code or the name of the plastic/polymer, as students need to identify the plastics. Note that product containers and their lids are not always the same material. See <http://www.interplas.com/help/glossary-resin-identifiacation> for list of different products for each SPI code.

IMPORTANT: Retain extra samples of each plastic for use in **Lesson 4**; those samples DO need to be labeled with their SPI code.

The densities of the seven polymers (shown in Identifying Polymers) are somewhat variable. Test plastic samples ahead of time to check they float and sink as expected. Solutions should be labeled with their densities (shown in the header of table below). Temperature affects densities of solutions, so store solutions at room temperature immediately prior to use. If carefully controlled, the solutions should be recoverable afterwards to be stored for re-use. Expected float and sink results follow (EPS = expanded polystyrene):

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SPI | Solution 1,  0.79 g/cm3 | Solution 2,  0.91 g/cm3 | Solution 3,  0.94 g/cm3 | Solution 4,  1.00 g/cm3 | Solution 5,  1.15 g/cm3 | Solution 6,  1.38 g/cm3 |
| 1 (PET) | S | S | S | S | S | S |
| 2 (HDPE) | S | S | S | F | F | F |
| 3 (PVC) | S | S | S | S | S | F |
| 4 (LDPE) | S | S | F | F | F | F |
| 5 (PP) | S | F | F | F | F | F |
| 6 (PS) | S | S | S | S | F | F |
| EPS | F | F | F | F | F | F |

*Polymer Structures:*  Use students’ answers to the two questions in this handout to assess students’ understanding of density, polarity, and intermolecular forces, and ability to interpret molecular structures, and visualize molecules in three-dimensional space.

*Extension:* You can extend the lesson by facilitating more activities or labs on measuring properties and by showing the video: *Introduction to plastics* (2:36), <http://www.pbslearningmedia.org/resource/ate10.sci.phys.matter.plasticsintro/introduction-to-plastics/>. See Unit Resources.

**Formative Assessment**

|  |  |  |
| --- | --- | --- |
| **Item** | **Students ability to:** | **Rubric** |
| *Entrance ticket* | Describe what they already know about the uses, manufacture, chemical makeup, & recycling of plastics | 0) Not answered; 4) Answered |
| *Identifying Polymers* lab (group of 4) | Follow safety rules & procedure | 0) No; 4) Yes |
| Cooperate & collaborate | 0) No; 4) Yes |
| Record notes, observations, & conclusions | 0) No; 4) Yes |
| *Polymer Structures* questions | Apply understanding of density, polarity, & intermolecular bonding (prior knowledge) to predict which polymer configurations are more or less dense (Answers in **Lesson 4** Instructional Tips/Strategies/Suggestions for Teacher) | 0) Not answered; 1) Explanation for prediction unreasonable or missing; 2) Explanation for prediction is somewhat reasonable; 3) explanation for prediction is mostly reasonable; 4) Explanation for prediction is completely reasonable |

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| **Item** | **Students ability to:** | **Rubric** |
| *Exit ticket* | Justify their opinion about whether plastic is the best material for food packaging | 0) Not answered; 1) Opinion and unreasonable or no justification provided; 2) Opinion and somewhat reasonable justification provided; 3) Opinion and mostly reasonable justification provided; 4) Opinion and completely reasonable justification provided |
| *Examine Plastics* | Describe plastic items in terms of use, texture, gloss or shine, transparency, color, flexibility, relative strength, & SPI code | 0) Blank; 2) Partial completion—less than 5 items; 4) Full completion—5 or more items described |

**Lesson Details**

**Opening:** *Entrance Ticket***:** Each student describes what he or she knows about plastics’ uses, manufacture, chemical makeup, and recycling. Students report out. [5 mins]

**During the Lesson:** *Identifying Polymers* *lab:* Students work in groups of four to measure density of three kinds of plastics. [30 mins]

**During the Lesson:** *Polymer Structures:*  Students work in groups of four to review polymer structures and answer three questions that relate density to polymer structure. [10 mins]

**Closing:** *Exit ticket***:** Each student evaluates if plastic is the best material for food packaging [5 mins]

**Homework:** *Examine Plastics***:** Due at beginning of **Lesson 2.** Examine and describes plastics in the home.

**Homework:** *Safety, Convenience and Quality Drive Barrier Packaging Trends*: Due at beginning of **Lesson 2.** Read and underline at least 4 problems that food packaging must address.

# Lesson 2: Develop Criteria and Constraints for a Food Packaging Film

**Brief Overview of Lesson:** Students share what they know about how food decomposes and how packaging prevents decomposition. Students learn that new food packaging is being developed in order to must meet longer shelf-life requirements and adhere to international food safety/quality standards. Student pairs describe the problems that food packaging films must address and develop criteria and constraints for the films. The teacher facilitates a discussion that results in a compiled list of criteria and constraints.

**Prior Knowledge Required:**

* When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
* Criteria for a design selection may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
* Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
* Analyze complex real-world problems by specifying criteria and constraints for successful solutions.

**Estimated Time:** 50 minutes (1 class period)

**Resources**

* *Text:*Entrance and Exit Ticket questions; Safety, Convenience and Quality Drive Barrier Packaging Trends; Criteria and Constraints for an Improved Food Packaging Film, Compiling Criteria and Constraints
* *Class materials:* Physical or computer method to collect student ideas about criteria and constraints and compile into two prioritized lists

**Standard(s)/Unit Goal(s) to be addressed in this lesson:**

* **HS-ETS1-1**. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society. Clarification Statement: Examples of societal requirements can include risk mitigation, aesthetics, ethical considerations, and long-term maintenance costs.
* **CCSS.ELA-LITERACY.SL.9-10.4** Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.

**Essential Question(s) addressed in this lesson:** How can we keep our food safe?

**Objectives:**

**Students will be able to…**

1. Identify relevant criteria and constraints for a social problem (need for improved food packaging film)
2. Combine, categorize, critique, and prioritize criteria and constraints through class discussion

**Language Objectives:**

**Students will be able to…**

1. Verbally describe or explain; read and analyze text and visuals; record notes and conclusions

**Targeted Academic Language:** problem, criteria, constraints

**What students should know and be able to do before starting this lesson:**

* Work in groups with limited supervision
* Contribute to class discussions

**Anticipated Student Preconceptions/Misconceptions:**

Students may think that:

* engineering is the solving of well-defined, straightforward problems,
* no research or planning is needed before building a prototype, or
* there is only one right solution to an engineering problem.

**Instructional Tips/Strategies/Suggestions for Teacher**

*Extension:* You can extend the lesson by including more information about the engineering design cycle and by playing the audio *Packaging You Can Eat* (5:50),<http://www.pbslearningmedia.org/resource/arct14.sci.nvpackeat/packaging-you-can-eat/>. (Note, the audio has a brief mention of alcohol in the context of dining. Please review to make sure it is appropriate for your class.) See Unit Resources.

**Formative Assessment**

|  |  |  |
| --- | --- | --- |
| **Item** | **Students ability to:** | **Rubric** |
| *Entrance ticket* | Describe prior knowledge of how food decomposes and how packaging prevents decomposition | 0) Not answered; 4) Answered |
| *Convenience and Quality Drive Barrier Packaging Trends* (pair) | Apply information presented in the reading to describe problems that food packaging films must address | 0) Not answered or descriptions are inaccurate; 1) Accurately described one problem; 2) Accurately described two problems;  3) Accurately described three problems; 4) Accurately described four or more problems |
| *Criteria & Constraints for an Improved Food Packaging Film* (pair) | Apply their own knowledge & information presented in reading “Convenience and Quality Drive Barrier Packaging Trends” to develop criteria & constraints for an improved food packaging film | 0) Not answered; 1) Proposed less than three criteria & two constraints; 2) Proposed three criteria & two constraints but did not give reasons for each choice; 3) Proposed three criteria & two constraints & gave reasons for each choice, but did not quantify criteria or explain how constraints limited possible solutions;  4) Proposed three criteria & two constraints & gave reasons for each choice, quantified the criteria if applicable, & explained how constraints limited possible solutions |
| *Compiling Criteria & Constraints* | Contribute to class discussion by sharing, combining, categorizing, critiquing, & prioritizing criteria & constraints | (Students self-assess their contributions): 0) No contribution;  1) Contributed to discussion once; 2) Contributed to discussion twice; 3) Contributed to discussion three times; 4) Contributed to discussion once four or more times |

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| **Item** | **Students ability to:** | **Rubric** |
| *Exit ticket* | State and justify their opinion about the most important criterion for a food packaging film | 0) Not answered; 1) Opinion and unreasonable or no justification provided; 2) Opinion and somewhat reasonable justification provided; 3) Opinion and mostly reasonable justification provided; 4) Opinion and completely reasonable justification provided |

**Lesson Details**

**Opening:** *Entrance ticket:* When students share prior knowledge of food preservation, prompt students to use previous biology and chemistry learning to support their thinking. Students report out. [5 mins]

**During the Lesson:** *Safety, Convenience and Quality Drive Barrier Packaging Trends:*Student pairs describe the problems that are solved by an improved food packaging film and report out to the class. [10 mins]

**During the Lesson:** *Criteria and Constraints for an Improved Food Packaging Film:* Student pairs describe and explain 3 criteria and 2 constraints. Circulate to pairs during this activity to provide support. Criteria can include no reaction with food, protection from microbes, protection from air, strength, flexibility, transparency, printable, ability to see if tampering occurred, and inclusion of sensors that detect spoilage. Constraints can include cost of materials, cost to make, use of existing materials, use of renewable materials, biodegradability and/or ability to be recycled. [10 mins]

**During the Lesson:** *Compiling Criteria and Constraints:* Student pairs report out their criteria. Facilitate a discussion in which students collectively combine, categorize, critique, and prioritize all criteria, which results in a broad list of at least five testable criteria. The same process is repeated with constraints, which results in a broad list of at least three constraints. Post the final lists for later use. [20 mins]

**Closing:** *Exit ticket:* Each student states and justifies the most important criterion for a food packaging film [5 mins]

**Homework:** *Structure-Property Relationships in Polymers*. Due at beginning of **Lesson 3.** Each student readsand identifies five examples of structure-property relationships.

# Lesson 3: Model Structure-Property Relationships in Polymers

**Brief Overview of Lesson:** Students learn that so many polymers can be made because of the complexity and size of polymer structures. Students learn that key aspects of polymer structure are atomic composition of monomers, polymer chain length, degree of crystallinity, and polymer chain shape—which can be linear, branched, or cross-linked. Student groups build and explore models of polymers and answer questions about how polymer structure is related to the properties of density, hardness, melting point, and flexibility.

**Prior Knowledge Required:**

* Substances are made from some 100 different types of elements, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
* Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
* Substances are composed of molecules, compounds or atoms, and atoms form molecules that range in size from two to thousands of atoms.
* Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
* Use a model to predict the relationships between systems or between components of a system.

**Estimated Time:** 50 minutes (1 class period)

**Resources**

* *Text:*Entrance/Exit Questions, Structure-Property Relationships in Polymers, Modeling Polymers
* *Internet:* Science 101: What are Polymers? video (1:56), <https://www.youtube.com/watch?v=bJi8x7bKHqQ>
* *Materials for each group of four students:* 64 silver paper clips, 12 colored paper clips, small resealable plastic bag, double-sided tape

**Standard(s)/Unit Goal(s) to be addressed in this lesson:**

* **HS-PS1-3.** Cite evidence to relate physical properties of substances at the bulk scale to spatial arrangements, movement, and strength of electrostatic forces among ions, small molecules, or regions of large molecules in the substances. Make arguments to account for how compositional and structural differences in molecules result in different types of intermolecular or intramolecular interactions. Clarification Statement: Substances include both pure substances in solid, liquid, gas and networked forms (such as graphite). Examples of bulk properties of substances to compare include melting point and boiling point, density, and vapor pressure. Types of intermolecular interactions include dipole-dipole (including hydrogen bonding), ion-dipole, and dispersion forces. State Assessment Boundary: Calculations of vapor pressure by Raoult’s law, properties of heterogeneous mixtures, and names and bonding angles in molecular geometries are not expected in state assessment.
* **HS-PS2-6.** Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.\* Clarification Statement: Examples could include comparing molecules with simple molecular geometries; analyzing how pharmaceuticals are designed to interact with specific receptors; and considering why electrically conductive materials are often made of metal, household cleaning products often contain ionic compounds to make materials soluble in water, or materials that need to be flexible but durable are made up of polymers. State Assessment Boundary: State assessment will be limited to comparing substances of the same type with one compositional or structural feature different.
* **CCSS.ELA-LITERACY.SL.9-10.4** Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.

**Essential Question(s) addressed in this lesson:** How is it possible to create so many different kinds of polymers? What are examples of structure-property relationships?

**Objectives:**

**Students will be able to…**

1. Identify polymers and monomers; describe crystalline and amorphous polymer chain arrangements; and describe linear, branched, and cross-linked, chain shapes.
2. Use polymer models to explain how aspects of polymer structure relate to the properties of density, hardness, flexibility, and melting point.
3. Construct a claim supported by evidence to explain how an aspect of polymer structure relates to a specific property.

**Language Objectives:**

**Students will be able to…**

1. Verbally describe or explain; read and analyze text and visual depictions; follow written procedures; record notes, observations, and conclusions; write an explanation supported with evidence

**Targeted Academic Language:** plastics,properties, structure, molecules, polymer, monomer, chain, linear, branched, cross-linked, crystalline, amorphous, intermolecular bonding, polarity, density, hardness, flexibility, melting point

**What students should know and be able to do before starting this lesson:**

* Interpret chemical formulas and depictions of substances at the atomic level
* Understand that intermolecular bonding is an attractive force among molecules based on electrostatic attractions
* Understand the concept of polarity in covalent bonds
* Work in groups with limited supervision
* Build and analyze models

**Anticipated Student Preconceptions/Misconceptions:** Students may think that:

* the macroscopic, submicroscopic, and representational aspects of chemical knowledge are not connected
* matter is continuous
* atoms are large enough to be seen by sight or by a light microscope
* each unit (atom, molecule, or ion) of a substance has all the properties that a measurable sample has
* atoms and molecules are the same
* matter does not contain empty space
* covalent bond polarity depends on quantity of valence electrons
* in a covalent bond all electrons are shared equally
* confuse intramolecular and intermolecular bonds.
* models are a depiction of reality rather than ideas or theories that serve the development and testing of ideas
* natural substances are fundamentally different from designed substances
* confuse monomer and polymer
* stretching of polymer (e.g. rubber) occurs because of stretching of the polymer bonds

**Instructional Tips/Strategies/Suggestions for Teacher**

*Extension:* You can extend the lesson by having student answer more questions on structure-properties relationships and by including more information about plastics and polymers and/or recycling. See Unit Resources.

**Formative Assessment**

|  |  |  |
| --- | --- | --- |
| **Item** | **Students ability to:** | **Rubric** |
| Entrance ticket | Explain possible reasons that there are so many kinds of plastics | 0) Not answered; 4) Answered |
| Watch video | Students use information from the video to emend their entrance ticket | 0) Not emended; 4) Emended |
| *Modeling Polymers* | Follow procedure | 0) No; 4) Yes |
| Cooperate & collaborate | 0) No; 4) Yes |
| Record notes, observations, & conclusions | 0) No; 4) Yes |
| *Modeling Polymers* questions | Identify polymer chain arrangements, shapes, and bonds between chains using models and determine how aspects of polymer structure relate to properties | Percentage correct (Answers in **Lesson 4** Instructional Tips/Strategies/Suggestions) |
| *Modeling Polymers* claim | Verbally present a claim, evidence, & explanation on how an aspect of polymer structure relates to a specific property. | 0) Not presented; 1) Claim, evidence, & explanation are unclear or missing; 2) Claim, evidence, & explanation are somewhat clear & reasonable; 3) Claim, evidence, & explanation are mostly clear & reasonable; 4) Claim, evidence, & explanation are completely clear & reasonable |

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| --- | --- | --- |
| **Item** | **Students ability to:** | **Rubric** |
| Exit ticket | Explain what they learned about polymer structure | 0) Not answered; 1) Explanation is unreasonable & inaccurate; 2) Explanation is somewhat reasonable & accurate; 3) Explanation is mostly reasonable & accurate; 4) Explanation is completely reasonable & accurate |

**Lesson Details**

**Opening:** *Entrance ticket:* Each student proposes explanation(s) for why there are so many kinds of plastics. Select a few students to share responses. Have students keep tickets and emend them after watching the video. [5 mins]

**During the Lesson:** *Science 101: What are Polymers? (1:56):* Students watch the video and emend their entrance tickets by adding something they learned from the video that helps explain why there are so many kinds of plastics. The video reviews the following: definitions of polymer and monomer; polymers can be synthetic or natural and include plastics, DNA, proteins, and cellulose; polymers have different shapes; properties of polymers will depend on which atoms and molecules they contain and how they are connected; scientists are constantly looking for new ways to create even better polymers with useful properties; some examples of research are study of natural polymers like spider silk and learning how to control polymer assembly; understanding how to build polymers from different types of monomers will provide new materials in the future. [5 mins]

**During the Lesson:** *Modeling Polymers:*Students work in groups of four to build polymer models that are amorphous and crystalline, have linear, branched, and cross-linked chain shapes, and have covalent and intermolecular bonds between the chains. Students explore these structures and answer questions about how structure is related to properties of density, hardness, melting point, and flexibility. Students then present a claim on how an aspect of polymer structure relates to a specific property. You may want to present an example claim with evidence and an explanation that links the clam and evidence. [35 mins]

**Closing:** *Exit ticket:* Each student describes what he or she learned about polymer structure in this lesson. [5 mins]

**Homework:**  *Introduction to Bioplastics*: Due at beginning of **Lesson 4.** Read and underline ways to modify bioplastics to improve their properties.

# Lesson 4: Synthesize, Test, and Hypothesize the Structure of a Bioplastic

**Brief Overview of Lesson:** Using a jigsaw format, students make one of three bioplastics and determine the bioplastic’s and plastics’ properties of density, hardness, flexibility, reactivity with acids and bases, and transparency. Students report results and the teacher facilitates a discussion in which students compare properties and structures of bioplastics and plastics.

**Prior Knowledge Required:**

* Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
* Substances are composed of molecules, compounds or atoms, and atoms form molecules that range in size from two to thousands of atoms.
* Criteria for a design selection may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
* Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

**Estimated Time:** 150 minutes (3 class periods)

**Resources**

* *Text:* Entrance/Exit Questions, Introduction to Bioplastics, Making and Testing Bioplastics Films, Compare Bioplastics and Plastics
* *Materials for each group of four students:* (Part A) Starch, Agar, Gelatin, 100 mL of 1% glycerol solution, 400-mL or 600-mL beaker, 100-mL graduated cylinder, Digital balance, Plastic weighing dish, Stir bar or small paper clip, Glass stirring rod, Hot plate with magnetic stirrer, Thermometer, Stand and clamp to hold the thermometer, Hot-hands or oven mitts, Teflon nonstick pan (~38cm x 25cm), (Part B) Digital balance, Plastic weighing dish, 100-mL graduated cylinder, Scissors, Penny, Iron nail or other iron piece, Steel file, Tongs, Three 200-mL beakers, 0°C water, 80°C water, Watch glass, Two plastic pipettes, 2.0 M HCl, 2.0 M NaOH, Wooden stir stick, Two samples of plastics
* *Internet:* Sustainable Polymers: The Invention of Greener Plastic video (3:11), <https://www.youtube.com/watch?v=u9lr_vonGN4>
* *Class materials:* Physical or computer method to record student ideas about the results of their tests, matches between the tests and the criteria, and how bioplastics should be improved to be suitable for food packaging.

**Standard(s)/Unit Goal(s) to be addressed in this lesson:**

* **HS-PS1-3.** Cite evidence to relate physical properties of substances at the bulk scale to spatial arrangements, movement, and strength of electrostatic forces among ions, small molecules, or regions of large molecules in the substances. Make arguments to account for how compositional and structural differences in molecules result in different types of intermolecular or intramolecular interactions. Clarification Statement: Substances include both pure substances in solid, liquid, gas and networked forms (such as graphite). Examples of bulk properties of substances to compare include melting point and boiling point, density, and vapor pressure. Types of intermolecular interactions include dipole-dipole (including hydrogen bonding), ion-dipole, and dispersion forces. State Assessment Boundary: Calculations of vapor pressure by Raoult’s law, properties of heterogeneous mixtures, and names and bonding angles in molecular geometries are not expected in state assessment.
* **HS-PS2-6.** Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.\* Clarification Statement: Examples could include comparing molecules with simple molecular geometries; analyzing how pharmaceuticals are designed to interact with specific receptors; and considering why electrically conductive materials are often made of metal, household cleaning products often contain ionic compounds to make materials soluble in water, or materials that need to be flexible but durable are made up of polymers. State Assessment Boundary: State assessment will be limited to comparing substances of the same type with one compositional or structural feature different.
* **HS-ETS1-1.** Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society. Clarification Statement: Examples of societal requirements can include risk mitigation, aesthetics, ethical considerations, and long-term maintenance costs.

**Essential Question(s) addressed in this lesson:** How can we keep our food safe? How is it possible to create so many different kinds of polymers? What are the advantages of using a designed material?

**Objectives:**

**Students will be able to…**

1. Synthesize and test the properties of a bioplastic using **Lesson 2** criteria.
2. Compare properties and structures of bioplastics and plastics.
3. Make a claim based on evidence arguing which property of a bioplastic should be changed to make it more suitable for food packaging.

**Language Objectives:**

**Students will be able to…**

1. Verbally describe or explain, read and analyze text and visual depictions, record notes and observations, follow written procedures

**Targeted Academic Language:** bioplastic, biodegradable, properties, density, hardness, flexibility, reactivity with acids and bases, transparency, criteria

**What students should know and be able to do before starting this lesson:**

* Interpret chemical formulas and depictions of substances at the atomic level
* Work in groups with limited supervision
* Follow lab procedures
* Use of lab equipment
* Know and follow lab safety rules
* Contribute to class discussions

**Anticipated Student Preconceptions/Misconceptions:** Students may think that:

* the macroscopic, submicroscopic, and representational aspects of chemical knowledge are not connected
* natural substances are fundamentally different from designed substances
* confuse monomer and polymer
* stretching of polymer (e.g. rubber) occurs because of stretching of the polymer bonds
* engineering is the solving of well-defined, straightforward problems

**Instructional Tips/Strategies/Suggestions for Teacher**

*Making and Testing Bioplastics Films:* Synthesize the three bioplastic films in advance so that students will have a sample to test in case their synthesis is not successful. Assign each student group to make one of the three bioplastic films. If time is short or lab use is restricted, have students test the films you made. With this modification, the lesson can be completed in 100 minutes (2 class periods). When you or the students make the bioplastic films, allow at least one day for drying.

*Review:* Review the questions and answers in *Identifying Plastics* (**Lesson 1)** and *Modeling Polymers* (**Lesson 3)**. You may choose to hand out the answers and have students self-review or peer-review.

***Polymer Structures* questions and answers:**

1. Two polymers have the same chemical composition; one polymer was cooled quickly and has tangled chains (amorphous) and the other was cooled slowly and has chains ordered in rows (crystalline). Which polymer is more dense? Explain your choice. *When ordered the chains will take up less space*
2. Two polymers have the same chemical composition; one polymer has linear chains and the other has chains with lots of branches. Which polymer is more dense? Explain your choice. *Linear chains pack more tightly than chains with branches*
3. Two polymers have linear chains of the same length; one polymer has polar chain molecules and the other has non-polar chain molecules. Which polymer is more dense? Explain your choice. *Polar molecules are attracted to each more than non-polar molecules so the chains will be closer and take up less space*

***Modeling Polymers* questions and answers:**

1. Describe polymer arrangement, polymer shape, and types of bonds, if any, between chains in each model.

Model 1: *Amorphous arrangement and linear shape*

Model 2: *Amorphous arrangement, linear shape, and intermolecular bonding between chains*

Model 3: *Mixed amorphous and crystalline arrangement, linear shape, and, more intermolecular bonding between chains than Model 2*

Model 4: *Amorphous arrangement and branched shape*

Model 5: *Amorphous arrangement, lightly cross-linked shape, and covalent bonding between chains*

Model 6: *Amorphous arrangement, strongly cross-linked shape and, more covalent bonding between chains than Model 5*

1. Density is higher when polymer chains pack together more tightly and take up less space. Divide the models into two lists, models that are more dense and models that are less dense. *More dense: Model 1, Model 2, Model 3; Less dense: Model 4, Model 5, Model 6 (answer may vary slightly according to perceptions of the models)*
2. Properties of melting point and hardness are related to the strength of bonds among polymer chains and the ability of the chains to move around. Which models had bonds among the chains? *Models 2, 3, 5, and 6 had bonds among the chains.*
3. How did arrangements, shapes, and bonds between chains affect the ability of chains to move around and to be pulled out of the bag? *Crystalline arrangement impeded motion, branching and cross-linking impeded motion, and bonding between chains impeded motion. Intermolecular bonds can break easily, however.*
4. Flexibility is represented in the model by bending the bag back and forth. Divide the models into two lists, models that are more flexible and models that are less flexible. *More flexible: Model 1, Model 2, Model 3, Model 4, Model 5; Less Flexible: Model 6 (answer may vary slightly according to perceptions of the models)*

**Formative Assessment**

|  |  |  |
| --- | --- | --- |
| **Item** | **Students ability to:** | **Rubric** |
| *Entrance ticket* | Explain possible reasons that there are so many kinds of plastics | 0) Not answered; 4) Answered |
| *Making & Testing Bioplastics Films* (group of 4) | Follow safety rules & procedure | 0) No; 4) Yes |
| Cooperate & collaborate | 0) No; 4) Yes |
| Record notes, observations, & conclusions | 0) No; 4) Yes |
| Report out results in an organized way | 0) No; 4) Yes |
| *Compare Bioplastics and Plastics* | Contribute to class discussion by matching tests and criteria and comparing properties and structures of plastics and bioplastics. | (Students self-assess their contributions): 0) No contribution;  1) Contributed to discussion once; 2) Contributed to discussion twice; 3) Contributed to discussion three times; 4) Contributed to discussion once four or more times |
| *Exit ticket* | Explain which property of a bioplastic should be changed to make it more suitable for food packaging. | ) Not answered; 1) Explanation is unreasonable and inaccurate; 2) Explanation is somewhat reasonable and accurate; 3) Explanation is mostly reasonable and accurate; 4) Explanation is completely reasonable and accurate |

**Lesson Details**

**Opening:** *Entrance Ticket***:** Each student describes one advantage and one drawback for making polymers out of plants rather than oil. Select a few students to share responses. [5 mins]

**During the Lesson:** *Sustainable Polymers: The Invention of Greener Plastic video (3:11)*: Students watch the video and report out on what they learned. The video reviews the following: plastics are critically important but also are thrown away in large amounts; polymers are long chain molecules made up of thousands of repeating units and are the giants of the molecular world; scientists are looking to make plastics from bio-based resources rather than petrochemical resources; to help in this effort scientists use computer modeling to custom design polymers; goal of some scientists are to make more environmentally friendly plastics; one way to design new polymers is using microbes; important to test each new material; one of the biggest hurdles of environmentally friendly plastics is cost to make; there is a need for environmentally friendly plastics because the US produces billions of pounds of plastics each year. [10 mins]

**During the Lesson:** *Making and Testing Properties of Bio-Plastics Films lab:* Students work in groups of four to synthesize a bioplastic. There are three recipes for biofilms and each group will make one of them. The synthesized biofilms need to dry overnight. In the second 50-minute class period, students test their biofilm and two samples of plastics that you retained from Lesson 1, which should be labeled with their SPI code. At the end of the testing, create a class table that includes all the work by groups and make it available to students. [85 minutes]

**During the Lesson:** *Compare Bioplastics and Plastics:* Students work in pairs to match the tests they did in the lab to criteria developed in **Lesson 2,** compare the properties of bioplastics and plastics and identify differences, and hypothesize how the structures of bioplastics and plastics differ in amount of crystallinity, amount of branching, and strength of intermolecular bonds. Have students answer each question and then ask them to share their ideas. Encourage students to reply to each other and to critique the ideas put forward. [30 minutes]

**During the Lesson:** *Identifying Plastics* and *Modeling Polymers:* Have students peer- or self-review their work using an answer key. (Answers are provided in Instructional Tips/Strategies/Suggestions for Teacher in this lesson.) Based on reporting by students, go over questions that were most problematic. [15 mins]

**Closing:** *Exit Ticket***:** Each student describes which property of the bioplastic he or she synthesized should be changed to make it more suitable for food packaging. [5 mins]

# Curriculum Embedded Performance Assessment (CEPA)

Propose a Criteria-Based Design for a Bioplastic-Based Food Packaging Film

**Explanation of CEPA:** Students choose two of the criteria developed in **Lesson 2** to guide their design of a bioplastic-based food packaging film. Students identify which of the three bioplastics synthesized in **Lesson 4** they will use in their film and propose changes to their polymeric structure and their composition in order to meet the criteria. Students prepare and give presentations that have two parts: a summary of themolecular structure and general properties of plastics and bioplastics that explains why that particular class of substances should be used for food packaging, and a detailed description of their proposed design for a bioplastic-based food packaging film.

**Prior Knowledge Required:**

* Use a model to predict the relationships between systems or between components of a system.
* When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
* Criteria for a design selection may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
* Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
* Communicate technical information or ideas in multiple formats (including orally, graphically, textually, and mathematically).

**Estimated Time:** 150 minutes (3 class periods)

**Resources**

* *Text:*Design Proposal, Design Proposal Presentation (includes rubric)
* *Materials for each group of four students:* Copies of all readings and lab notes from the unit, access to computers with PowerPoint or posters for presentation
* *Class materials:* Projection equipment if students are using PowerPoint for their presentations

**Standard(s)/Unit Goal(s) to be addressed in CEPA:**

* **HS-PS2-6.** Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.\* Clarification Statement: Examples could include comparing molecules with simple molecular geometries; analyzing how pharmaceuticals are designed to interact with specific receptors; and considering why electrically conductive materials are often made of metal, household cleaning products often contain ionic compounds to make materials soluble in water, or materials that need to be flexible but durable are made up of polymers. State Assessment Boundary: State assessment will be limited to comparing substances of the same type with one compositional or structural feature different.
* **HS-PS1-3.** Cite evidence to relate physical properties of substances at the bulk scale to spatial arrangements, movement, and strength of electrostatic forces among ions, small molecules, or regions of large molecules in the substances. Make arguments to account for how compositional and structural differences in molecules result in different types of intermolecular or intramolecular interactions. Clarification Statement: Substances include both pure substances in solid, liquid, gas and networked forms (such as graphite). Examples of bulk properties of substances to compare include melting point and boiling point, density, and vapor pressure. Types of intermolecular interactions include dipole-dipole (including hydrogen bonding), ion-dipole, and dispersion forces. State Assessment Boundary: Calculations of vapor pressure by Raoult’s law, properties of heterogeneous mixtures, and names and bonding angles in molecular geometries are not expected in state assessment.
* **HS-ETS1-1.** Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.Clarification Statement: Examples of societal requirements can include risk mitigation, aesthetics, ethical considerations, and long-term maintenance costs.
* **CCSS.ELA-LITERACY.SL.9-10.4** Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.

**Essential Question(s) addressed in this lesson:** How can we keep our food safe? What are the advantages of using a designed material?

**Objectives:**

**Students will be able to…**

1. Propose a design for a bioplastic-based food packaging film that that meets selected criteria; the design may include engineering of the bioplastic structure at the nanoscale and addition of other polymers and nanoparticles.
2. Argue the rationale for all aspects of the designed material.
3. Prepare and deliver a presentation that communicates the proposed design, its rationale, and explains why plastics are the material of choice for food packaging.

**Language Objectives:**

**Students will be able to…**

1. Prepare a written and visual presentation, and orally deliver the prepared presentation

**Targeted Academic Language:** nanotechnology,composites, criteria, properties, constraints, structure, design

**What students should know and be able to do before starting this lesson:**

* Work in groups with limited supervision
* How to prepare and give presentations

**Anticipated Student Preconceptions/Misconceptions:** Students may think that:

* natural substances are fundamentally different from designed substances
* engineering is the solving of well-defined, straightforward problems
* no research or planning is needed before building a prototype
* testing of a prototype is a simple process
* engineering is a linear rather than an iterative process
* there is only one right solution to an engineering problem
* haphazard trial-and-error approaches will result in a good solution to an engineering design problem

**Instructional Tips/Strategies/Suggestions for Teacher**

*Design Proposal and Design Proposal Presentation:* You may want to add another 50 minutes to the lesson and have students carry out additional research on the Internet. If students choose a starting bioplastic they did not synthesize and test in the lab, they must find out equivalent information about its properties.

**Summative Assessment: Rubric for the Design Proposal and Presentation**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Criteria** | **0** | **1** | **2** | **3** | **4** |
| Chemistry | Included no aspects of structure & properties of plastics to support their use in food packaging | Included few aspects of structure & properties of plastics to support their use in food packaging | Included some aspects of structure & properties of plastics to support their use in food packaging | Included many aspects of structure & properties of plastics to support their use in food packaging | Included & connected many aspects of structure & properties of plastics to support their use in food packaging |
| Design Proposal | Nano and molecular scale of design not presented & not connected to criteria & constraints. Rationale for choice of starting material & proposed changes unclear or missing. | Nano and molecular scale of design poorly presented & minimally connected to criteria & constraints. Rationale for choice of starting material & proposed changes mostly unclear. | Nano and molecular scale of design adequately presented & partially connected to criteria & constraints. Rationale for the choice of starting material & proposed changes somewhat clear. | Nano and molecular scale of design well presented & mainly connected to criteria & constraints.  Rationale for the choice of starting material & the proposed changes clear. | Nano and molecular scale of design well presented & fully connected to criteria & constraints.  Rationale for the choice of starting material & the proposed changes very clear & concise. |
| Appropriate for Purpose, Audience, & Task | Organization, development, substance, & style were inappropriate | Organization, development, substance, & style were mostly inappropriate | Organization, development, substance, & style were somewhat appropriate | T Organization, development, substance, & style were mostly appropriate | Organization,, development, substance, & style were fully appropriate |
| Organization | Presentation of chemistry & proposal was incomplete & not clear. Listeners could not follow the line of reasoning. | Presentation of chemistry & proposal was unorganized & mostly unclear. Listeners had difficulty in following the line of reasoning. | Presentation of chemistry & proposal was somewhat organized & partially clear. Listeners were mostly able to follow the line of reasoning. | Presentation of chemistry & proposal was organized and clear. Listeners were able to follow the line of reasoning. | Presentation of chemistry & proposal was organized, clear, & concise. Listeners were able to follow the line of reasoning easily. |

**Lesson Details**

Student groups have 100 minutes of in-class time to develop their design proposal and complete their presentation. Set up structured milestones for the work and check in with students on their progress. Have students complete work at home as necessary. Remind students to be efficient by splitting up the work. In the final 50 minutes of the lesson, student groups give their presentations. Encourage students to evaluate the designs.

# Unit Resources

## General

*Expert guest speaker:* An optional event that can be integrated with the unit is a presentation on polymers from a graduate student at the Materials Research Science and Engineering Center (MRSEC) at the University of Massachusetts Amherst. See <http://www.pse.umass.edu/mrsec/Education-Outreach/PolymersAllAroundUS.html>

## Lesson 1

*Lesson text resources:* Entrance/Exit Questions, Introduction to Plastics, Identifying Polymers, Polymer Structures, Examine Plastics

*Lesson Internet resources*

* Source for Identifying Polymers: <http://www.nuffieldfoundation.org/practical-chemistry/identifying-polymers>
* Plastics SPI categories: <http://www.interplas.com/help/glossary-resin-identifiacation>

*Extension Internet resources*

* Video: Introduction to plastics (2:36), <http://www.pbslearningmedia.org/resource/ate10.sci.phys.matter.plasticsintro/introduction-to-plastics/>
* Labs on measuring properties: #22 Chemical Resistance and Synthetic Polymers, available as a link from <http://www.terrificscience.org/lessonpdfs/PolymerLab22.pdf> , Recyclable Plastics (Polymers) and Fiber Formation, <http://www.ccmr.cornell.edu/wp-content/uploads/sites/2/2015/11/PolymerInvestigations.pdf>

## Lesson 2

*Lesson text resources:* Entrance/Exit Questions; Safety, Convenience and Quality Drive Barrier Packaging Trends; Criteria and Constraints for an Improved Food Packaging Film, Compiling Criteria and Constraints

*Lesson Internet resources*

* Source for Safety, Convenience and Quality Drive Barrier Packaging Trends, <http://www.multibriefs.com/briefs/exclusive/barrier_packaging_1.html#.VOJf3bDF8Zs>

*Extension Internet resources*

* Engineering design cycle: <https://www.teachengineering.org/engrdesignprocess.php>
* Audio:Packaging You Can Eat (5:50),<http://www.pbslearningmedia.org/resource/arct14.sci.nvpackeat/packaging-you-can-eat/> (Note, mention of alcohol in dining context, review to make sure it is appropriate for your class)
* Food packaging films: <http://plastics.americanchemistry.com/Understanding-Plastic-Film>

## Lesson 3

*Lesson text resources:* Entrance/Exit Questions, Structure-Property Relationships in Polymers, Modeling Polymers, Propose a Method to Separate Plastics

*Extension text resource*

* You can extend the lesson by having students solve the following problems on structure-property relationships:

1. Use understanding of covalent bonding and molecular structure to explain why diamond is much harder than carbon graphite
2. Use understanding of ionic bonding, ionic structure, and intermolecular bonding to explain why salt (NaCl) has a melting point of 801 °C while sugar (sucrose, C12H22O11) has a melting point of 186 °C
3. Use understanding of metallic bonding to explain why iron is a better electrical conductor than carbon steel, which is iron mixed with 1% carbon

*Extension Internet resources*

* Video: Polymers | Crash Course Chemistry #45 video (10:14), <http://www.pbslearningmedia.org/resource/ce972499-d67f-4eee-af0e-fe1dddfc03af/polymers-crash-course-chemistry-45/>
* Plastics and polymers: <http://www.rsc.org/Education/Teachers/Resources/Inspirational/resources/3.1.5.pdf>, <http://www.encyclopedia.com/topic/Plastics.aspx>, <http://www.nobelprize.org/educational/chemistry/plastics/readmore.html>, and <http://www.scientificamerican.com/article/how-are-polymers-made/>
* Recycling: <http://rstb.royalsocietypublishing.org/content/364/1526/2115> and <http://plastics.americanchemistry.com/Sustainability-Recycling>

## Lesson 4

*Lesson text resources:* Entrance/Exit Questions, Introduction to Bioplastics, Making and Testing Bioplastics Films, Compare Bioplastics and Plastics

*Lesson Internet resources:*

* Video: Sustainable Polymers: The Invention of Greener Plastic (3:11), <https://www.youtube.com/watch?v=u9lr_vonGN4>
* Source for Making and Testing Properties of Bio-Plastics Films:

<http://www.ccmr.cornell.edu/wp-content/uploads/sites/2/2015/11/PolymerInvestigations.pdf>

*Extension Internet resources*

* Video: The Business of Bioplastics (2:00), <http://www.pbslearningmedia.org/resource/nvms.sci.materials.cleanerdemo/the-business-of-bioplastics/>, and Properties of Plastic (2:15, Spanish and English), http://www.pbslearningmedia.org/resource/619f39de-7691-4efa-956e-ad07386c3517/properties-of-plastic/
* Audio: Bioplastic Boom (4:39), <http://www.pbslearningmedia.org/resource/47841697-7be8-4878-87ab-0fbdff556288/bioplastic-boom/>
* Nanotechnology: <http://www.nano.gov/nanotech-101/what>

### CEPA

*Lesson text* *resources:* Design Proposal, Design Proposal Presentation (includes rubric)

Lesson 1 Entrance and Exit Tickets

Entrance ticket: What do you know about plastics? Describe uses, manufacture, chemical makeup, and recycling of plastics.

Exit ticket: What type of plastic do you think is the best material for food packaging? Justify your opinion.

Lesson 2 Entrance and Exit Tickets

Entrance ticket: What causes food to decompose? How can packaging delay decomposition?

Exit ticket: What is the most important criterion for a food packaging film, and why?

Lesson 3 Entrance and Exit Tickets

Entrance ticket: What are possible reasons that there are so many kinds of plastics?

Exit ticket: What did you learn about polymer structure in this lesson?

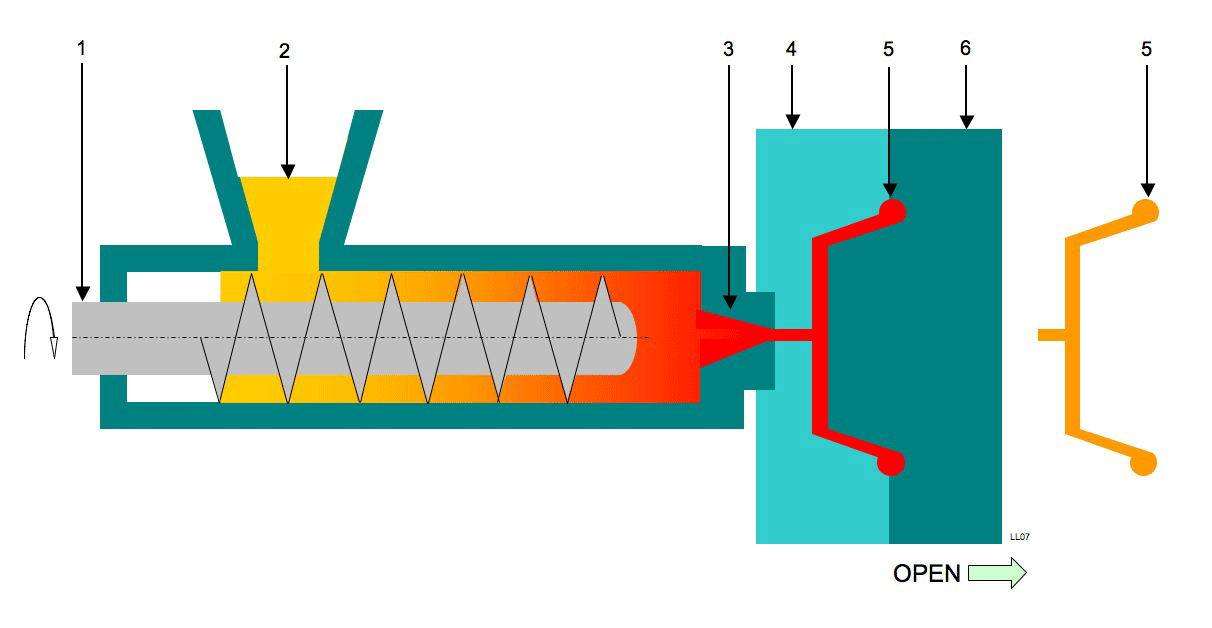
Lesson 4 Entrance and Exit Tickets

Entrance ticket: What are one advantage and one drawback of making a polymer from plants?

Exit ticket: Which property of the bioplastic you synthesized would you change to make it more suitable for food packaging? Explain.

# Introduction to Plastics

Plastics are materials that can be shaped into almost any form. Synthetic plastics are lightweight, strong, durable, moisture resistant, and can be engineered to have many different properties. Most synthetic plastics are made in the form of small pellets, which are then melted and extruded into sheets or injected into molds to make parts. See **Figure 1**.



**Figure 1:** Making plastic parts. A screw (1) pushes plastic pellets (2) through a heated barrel and a nozzle (3) into a mold (4 and 6). The plastic melts during this process and takes on the shape of the space in the mold (5). The mold is then cooled and opened to retrieve the part (5).

Public domain via Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Injection\_moulding\_process.png

The precursors of most synthetic plastics are small organiccompounds distilled from oil. Chemists carry out reactions that covalently bond these small organic compounds together into very long molecules. These long molecules are called *polymers* or “chains.” The small organic compounds are called *monomers*. Plastics can have different properties based on the chemical makeup of the monomer(s) and the size, arrangement shape of the polymer chains.

More than three hundred billion pounds of plastics are made each year. To lessen the amount of plastics in the waste stream, many kinds of plastics are recycled and used to make new plastics. To facilitate recycling, in 1988 the Society of the Plastics Industry (SPI) introduced a coding system with seven categories of plastics that can be recycled. The SPI code is shown on plastic items as triangles with the numbers 1 through 7 inside. The SPI coding system is primarily based on the atomic composition of the monomer. An exception is LDPE and HDPE, two categories of plastics made from the same monomer.

The monomers of synthetic recyclable plastics categories 1 through 6 are shown in **Table 1**. A single polymer molecule or chain may consist of hundreds to a million monomers and may have a linear, branched, or cross-linked shape.

**Table 1:** Monomers of Recyclable Plastics

|  |  |  |
| --- | --- | --- |
| SPI Code | Name | Monomer Unit |
| 1 | PET or PETE—polyethylene terephthalate | PET or PETE—polyethylene terephthalate |
| 2 | HDPE—high density polyethylene | HDPE—high density polyethylene |
| 3 | PVC—polyvinyl chloride | PVC—polyvinyl chloride |
| 4 | LDPE—low density polyethylene | LDPE—low density polyethylene |
| 5 | PP—polypropylene | PP—polypropylene |
| 6 | PS—polystyrene | PS—polystyrene |

Source: <https://www.sciencehistory.org/science-of-plastics>

# Identifying Polymers

Source: <http://www.nuffieldfoundation.org/practical-chemistry/identifying-polymers>

Samples of several polymers found as everyday plastics are placed into a range of liquids of known density and observed, to see whether they float or sink. From a table of known polymer densities, it is possible to identify each polymer. The known polymer densities are shown in **Table 2**. Discuss the meaning of density with your group.

**Table 2:** Polymer Densities

|  |  |
| --- | --- |
| **Polymer** | **Density range, g/cm3** |
| EPS—expanded polystyrene | 0.02 - 0.06 |
| PP—polypropylene | 0.89 - 0.91 |
| LDPE—low density polyethylene | 0.91 - 0.93 |
| HDPE—high density polyethylene | 0.94 - 0.96 |
| PS—polystyrene | 1.04 - 1.11 |
| PVC—polyvinyl chloride | 1.20 - 1.55 |
| PET or PETE—polyethylene terephthalate | 1.38 - 1.40 |

Materials for each group of 4 students

* Six solutions of known densities, labeled 1-6
* Six 150 x 25-mm test tubes
* Test tube rack
* Method for labeling test tubes
* 25-mL graduated cylinder
* Three samples of plastic, large enough to be cut into six 4-mm squares
* Scissors capable of cutting plastic samples
* Glass stirring rod
* Paper towels

Safety

* Safety glasses/goggles must be worn at all times
* Keep all solutions away from heat sources and be careful in handling solutions
* After lab activity is completed and lab area is cleaned, wash hands with soap

Procedure

1. Add about 15 mL each of solutions 1 – 6 to a different test tube in a test tube rack. Label each tube with the relevant solution number.
2. Prepare 6 samples of each plastic. Each sample should be a square of approximately 4 x 4 mm. You may organize your samples by placing them in separate piles on a paper towel. Make sure you know which sample is which, either by labeling each with a code letter, or by noting the color. Record sample code or color in **Table 3**.

**Table 3:** Sink and Float Data on Unknown Polymers

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sample | Solution 1  0.79 g/cm3 | Solution 2  0.91 g/cm3 | Solution 3  0.94 g/cm3 | Solution 4  1.00 g/cm3 | Solution 5  1.15 g/cm3 | Solution 6  1.38 g/cm3 | Plastic |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |

1. Add a sample of each plastic to each of the 6 solutions, so that each tube has samples of three different plastics.
2. Use a glass rod to stir the contents of each tube and to remove all air bubbles. Wash and dry the glass rod between each tube. Observe whether the plastics float or sink. A sample will sink if its density is greater than the density of the solution.
3. For samples that sink, write the letter S in the appropriate rows and columns of **Table 3**. You may wish as well to write the letter F for those that float, so that you can check you have noted every sample tested.
4. There are seven kinds of plastics in all, each is which identified by a code or color. After you fill in the first three rows of **Table 3** with the data from the three plastics you tested, report your data to the class. Review the class data and fill in remaining rows of **Table 3** with data from other groups. The table should now show data from all seven samples.
5. In discussion with the teacher and the rest of the class, you should be able to identify the polymer in **Table 2** from which each plastic sample is made. When you have decided what a sample is made of, write the name in the last column of **Table 3**.

# Polymer Structures

From the lab you just completed, you learned that different plastics could be identified because of large variations in their density. From **Table 2:** Polymer Densities, you learned that a single kind of plastic has small variations in its density.

Why would the same kind of plastic have variation in density? Plastics that are identified by the SPI code have the same monomer—but different variants can be made by altering an aspect of the polymer chain. **Figure 2** shows two types of variations that occur in polymer structures, arrangement of chains and shapes of chains.

|  |  |
| --- | --- |
| **Chain Arrangement** | |
| Amorphous | Crystalline |
| Amorphous and crystalline chain arrangements. | |

|  |  |  |
| --- | --- | --- |
| **Chain Shape** | | |
| Linear | Branched | Cross-linked |
| Linear, Branched, and Cross-linked chain shapes. | | |

**Figure 2:** Polymer chains have variations in arrangement and shape.

What aspects of polymer chains affect densities? Density of a polymer is related to how tightly the polymer chains can pack together in three-dimensional space. The arrangement of chains, the shapes of chains, and the attractive forces between chains are the aspects of a polymer that affect density.

Questions

For the following pairs of polymers, predict which is more dense. Visualize the polymer chains in three-dimensional space as you make your predictions.

1. Two polymers have the same chemical composition; one polymer was cooled quickly and has tangled chains (amorphous) and the other was cooled slowly and has chains ordered in rows (crystalline). Which polymer is more dense? Explain your choice.
2. Two polymers have the same chemical composition; one polymer has linear chains and the other has chains with lots of branches. Which polymer is more dense? Explain your choice.
3. Two polymers have linear chains of the same length; one polymer has polar chain molecules and the other has non-polar chain molecules. Which polymer is more dense? Explain your choice.

# Examine Plastics

To become more familiar with the different categories of plastics, examine at least five plastic items in your home. In **Table 4**, describe each item in terms of use, texture, gloss or shine, transparency, color, flexibility, relative hardness, and SPI code.

**Table 4:** Plastic Items

|  |  |
| --- | --- |
| Description | SPI Code |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

**Safety, Convenience and Quality Drive Barrier Packaging Trends**by Don Rosato, <http://www.multibriefs.com/briefs/exclusive/barrier_packaging_1.html#.VOJf3bDF8Zs>

[As you read, underline the problems that an improved food packaging will address.]

With an increasingly global food retailing customer base, food packaging must meet longer shelf-life requirements and adherence to international food safety/quality standards. Growing demand for convenience foods and "ready meals" created by busier lifestyles and increased disposable income are reflected in high growth in food packaging.

Changing global demographics, lifestyles and consumer preferences means global demand for food packaging — estimated to be $120 billion for 2013 — is expected to experience an average growth rate of 3.8 percent over the next five years. In addition to product protection from packaging, consumers want to see the food they buy; they want it to stay fresh for a longer period; they want it to be safe to eat; and, above all, they want it to be tasty.

Food-purchasing decisions are based on taste and appearance as well as convenience, making excellent barrier quality to maintain product freshness vital in food packaging — not only to extend shelf life, but also to protect brand image. Number one with the public is food safety, and active or barrier packaging that can help prevent spoilage or contamination is in strong demand.

Recalls can be particularly damaging to brand image and the company's bottom line. Most companies understand the added expense of improving packaging to help prevent recalls or a liability case is often far less than the cost of losing many customers because of an unhealthy or unsafe product.

Consumers want easy-to-open, see-through economic packaging that also protects against oxygen, water vapor and aromas. Nanotechnology is enabling new food and beverage packaging technologies to address the needs for longer shelf life and the ability to monitor food safety and quality based upon international standards.

Government policy and regulations are also impacting barrier plastic packaging design. The use of nano-based packaging for food products has raised various safety, environmental and regulatory issues with the European Food Safety Authority (EFSA) and the Food and Drug Administration (FDA) in the U.S.

Packaging waste is a growing environmental concern, and consumers are seeking more sustainable packaging choices, driving food packagers to look for bioplastic materials with good barrier properties. The presence of O2-sensitive unsaturated fats are also fueling development of active and barrier packaging in flexible and rigid formats. This results from the trend toward natural/organic foods featuring heart-healthy fats.

The functional additives and barrier coatings market is expected to be worth $752 million in 2014. Barrier coatings will grow 4.6 percent annually on average, while functional additives are expected to expand at a slightly more modest 3.9 percent. The growing footprint of large retail chains in developing markets is expected to stimulate the sales of packaged food including barrier packaging.

Functional and barrier coatings cover a broad spectrum of materials that are coated onto substrates to provide a barrier of some sort to protect the materials inside, and/or to enable the substrate to act as a suitable package for its contents. Although the market is broad in scope and application, over 60 percent of the market for functional and barrier packaging covers a wide range of food stuffs. Barrier requirements for food packaging include protection against water and water vapor; oil and grease; oxygen and aroma.

Material developments and new packaging processes are allowing food to be kept fresh much longer without altering taste or aroma. While traditional barrier materials extend product shelf life by impeding O2 migration into a package, O2 scavengers go one step further "capturing" O2 present within a sealed package to ensure it does not react with the food product. By combining active and barrier packaging, processors can increase shelf life, protect flavor profiles and maintain food's appearance without adding preservatives. Antimicrobials as a coating or compounded into the plastic are helping address outbreaks of foodborne illnesses.

Question

Working with a partner, describe at least four problems that an improved food packaging film will address.

# Criteria and Constraints for an Improved Food Packaging Film

Complete the following sections working with a partner. Refer back to the reading “Safety, Convenience and Quality Drive Barrier Packaging Trends**”** as needed.

1. *Criteria* are specific outcomes for a product. Criteria should answers the questions “What do you want it to do?” and “How well do you want it to be done?” List three criteria for an improved food packaging film. Do the following for each criterion:

* Give a reason why this criterion is important.
* If applicable, make your criterion quantitative, for example: can withstand extremes of temperatures from zero degrees to fifty degrees Celsius.

1. *Constraints* are limits, such as cost, safety, reliability, and aesthetics. List at least two constraints for an improved food packaging film. Do the following for each constraint:

* Give a reason why this constraint is important.
* Explain how the constraint limits a possible solution.

# Compiling Criteria and Constraints

Your class will carry out a discussion that will result in prioritized lists of criteria and constraints for an improved food packaging film.

Learning how to contribute to a productive discussion is an important skill. As you complete steps 1 through 3 below,place a check in **Table 5** to show what part of the discussion you contributed to. Try to contribute to the discussion at least four times.

**Table 5:** Contribution to Class Discussion

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Report out | Combine | Categorize | Critique | Prioritize |
| Criteria |  |  |  |  |  |
| Constraints |  |  |  |  |  |

Complete the following steps.

1. Report out your criteria and constraints. Have one partner in your pair report out your criteria and one partner report out your constraints.
2. Study the class list of criteria. Contribute to a class discussion on criteria by doing the following:
3. Point out any criteria that you think are equivalent and can be combined into one criterion.
4. Categorize criteria; an example of a category is food safety.
5. Critique any criterion that you think is unclear. Suggest a way to improve the wording.
6. To help prioritize the list, state your ideas about which criteria are more important and which are least important.
7. Study the class list of constraints. Contribute to a class discussion on constraints by doing the following:
8. Point out any constraints that you think are equivalent and can be combined into one constraint.
9. Categorize criteria; an example of a category is resource limitations.
10. Critique any constraint that you think is unclear. Suggest a way to improve the wording.
11. To help prioritize the list, state your ideas about which constraints are more important and which are least important.

# Structure-Property Relationships in Polymers

[As you read, identify five examples of structure-property relationships.]

The design, synthesis, and production of new materials that meet high-performance specifications are major activities of the chemical industry. The most versatile category of designed materials is polymers, which includes plastics and bioplastics.

Most polymers are organic molecules made primarily of the elements of carbon and hydrogen. The carbon atom has four valence electrons in its outer shell and each of these electrons can form a covalent bond, including bonds to other carbon atoms. Polymer chains have many carbons bonded together to form a “backbone.” Other elements found in side groups attached to the polymer chain are oxygen, chlorine, fluorine, nitrogen, silicon, phosphorous, and sulfur.

How is it possible for scientists to make new polymers designed for specific purposes? Scientists can create new polymers by creating variations in the complex structure of polymers. Aspects of polymers that can be varied are:.

* The atomic composition of the monomer(s) can vary. This determines if the polymer chain is polar or nonpolar. (Recall that polarity is caused by covalent bonds with an unequal distribution of charge. Unequal distribution creates some areas of the molecule that are more positive and some areas that are more negative.)
* The atomic composition of the monomer(s) also determines if there are bulky side groups on the chain. Bulky side groups can impede tight packing of chains and the ability of chains to easily slide over each other.
* The polymer chain length can vary from hundreds to a million monomers.
* Due to the geometry of the covalent bonds, carbon atoms can rotate to one side or another, allowing the very long polymer chains to bend. How the chains bend determines their arrangement. The arrangement varies from completely unordered (*amorphous*) to completely ordered (*crystalline*). Most plastics are mainly amorphous and have smaller or larger regions of crystallinity. Chains that do not flow easily over each other do not crystallize.
* The overall geometry, or shape, of the polymer chains can vary. Chains can be linear, branched, or cross-linked. The shapes of the chains form during the reaction that makes the polymer. The shapes the chains can form depend on the atomic composition of the monomer(s) and the parameters of the reaction.
* The chains can vary in how strongly they are held together. Cross-linked polymers have covalent bonds between chains. Non-cross-linked polymers have intermolecular bonds between chains; these bonds are approximately 200 to 400 times weaker than covalent bonds. Chain polarity, length, and shape, and size of the side groups affect the strength of intermolecular bonds.

The large number of possible variations of polymer structures makes it possible to design different polymers with specific properties. What are some polymer structure-property relationships?

In **Lesson1**, you were introduced to polymer structure-property relationships for density.As you learned at that time, **density** is related to the packing of polymer chains. Linear chains attracted to each other by strong intermolecular forces will pack more compactly and may form regions of crystallinity. These polymers are more dense. Chains that are less attracted to each or that have branches or large side groups will pack more loosely. These polymers are less dense.

An example of the changes in density due to branching is the two plastics, HDPE (high density polyethylene, SPI code 2) and LDPE (low density polyethylene, SPI code 4). Both plastics are made from the same monomer but extensive branching of the LDPE polymer chains results in a large difference in density.

The properties of **melting point** and **hardness** are related to the strength of the bonds among polymer chains. Cross-linked polymers with covalent bonds between chains have the highest melting points and hardness.

Polymers with strong intermolecular bonds between chains have intermediate melting points and hardness. Strong intermolecular bonds are due to polar chains or to very long chain lengths.

Polymers with weak intermolecular bonds between chains have the lowest melting points and hardness. Weak intermolecular bonds are due to nonpolar chains or to an arrangement such as branching that prevent chains from getting close enough to form bonds.

**Flexibility** of a polymer is related to how easily chains move over each other. While intermolecular forces connect chains, they allow sliding to occur. Polymer chains that have long branches, large side groups, or are cross-linked cannot slide as easily over each other. One way to increase flexibility in a polymer is to add a small compound called a *plasticizer*. The plasticizer helps polymer chains slide over each other more easily.

**Optical properties** are related to polymer arrangement. Amorphous polymers are transparent. As crystallization is increased, the polymer becomes more opaque.

# Modeling Polymers

An important way to understand how the structure of a substance at the atomic level affects its properties at the bulk scale is to make and study models. Paper clips can be used to model monomers and then connected in different ways to model polymer chains’ arrangements and shapes. Observing how these models pack, slide, and fold helps illustrate the structure-property relationships of polymers.

Materials for each group of 4 students

* 64 silver paper clips
* 12 colored paper clips
* Small resealable plastic bag
* Double-sided tape

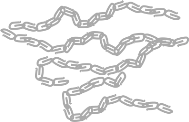
Procedure

1. You will build six models of polymer structures that each contains four polymer chains of 16 paper clips each. For each model do the following and record your observations in **Table 6**. You can compare Models 2 through 5 to what you observed for Model 1.

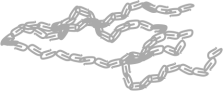
* Place the model in the plastic bag and seal
* Shake gently for 10 seconds and observe how much the chains move around
* See how tightly the chains are packed after shaking
* See how easy it is to bend the plastic bag back and forth
* Open the bag and see how easy it is to gently pull a chain from the bag

1. Instructions for building each model:

Model 1: Make four linear chains of 16 paper clips each.



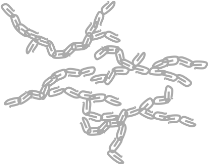
Model 2: Using double-sided tape, wrap four of non-adjacent paper clips in each chain to make them “sticky.”



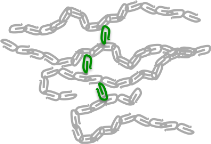
Model 3: Take one of the chains from Model 2 and bend it several places so that the paper clips stack. Use the double-sided tape to hold the arrangement in the place. Leave the other three chains as they were with the tape still on them.



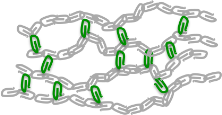
Model 4: Remove all the tape from the paper clips and make four branched chains of 16 paper clips each.



Model 5: Make four linear polymer chains of 16 paper clips each. Attach the four chains together using just 3 of the colored paper clips.



Model 6: Take Model 5 and attach the four chains together in more places using the remaining 9 colored paper clips.



**Table 6:** Observations of Polymer Models

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
| How much do the chains move around? |  |  |  |  |  |  |
| How tightly are the chains packed? |  |  |  |  |  |  |
| How easy is it to bend the bag back and forth? |  |  |  |  |  |  |
| How easy is it pull out a chain from the bag? |  |  |  |  |  |  |
| What kind of bonds, if any, holds the chains together? |  |  |  |  |  |  |

Questions

Refer to the reading *Structure-Property Relationships in Polymers* as needed.

1. Describe polymer arrangement, polymer shape, and types of bonds, if any, between chains in each model.

Model 1:

Model 2:

Model 3:

Model 4

Model 5

Model 6:

1. Density is higher when polymer chains pack together more tightly and take up less space. Divide the models into two lists, models that are more dense and models that are less dense.
2. Properties of melting point and hardness are related to the strength of bonds among polymer chains and the ability of the chains to move around. Which models had bonds among the chains?
3. How did arrangements, shapes, and bonds between chains affect the ability of chains to move around and to be pulled out of the bag?
4. Flexibility is represented in the model by bending the bag back and forth. Divide the models into two lists, models that are more flexible and models that are less flexible.

Claim

Present a claim, evidence, and explanation on how an aspect of polymer structure relates to a specific property.

# Introduction to Bioplastics

[As you read, underline ways to modify bioplastics to improve their properties.]

Plastics are the world's most versatile materials. But they have significant drawbacks. Plastics are made from oil, a nonrenewable resource. And the properties of durability and stability that make plastics so useful also mean that they stick around. It’s estimated that most plastics take 500 years to break down. Discarded plastics clutter up the landscape and are a danger to animals.

Public demand for more ecofriendly products has led to extensive research and development of *bioplastics*. Bioplastics are polymers made from monomers derived from plants or microorganisms rather than from oil. Bioplastics have two advantages: they are made from renewable resources and they are more likely to be biodegradable, which means they can be decomposed by bacteria or other living organisms. But bioplastics’ functional limitations have so far restricted their widespread application in food packaging. They tend to be brittle, degrade at different temperatures (heat instability), have high gas and water permeability, are opaque, and can dissolve in water.

Researchers are exploring *nanotechnology* to improve bioplastics. Nanotechnology is the manipulation of matter on a very small scale, between 0 and 100 nanometers (nm). For comparison, a human hair is about 80,000 nm wide. Particles made at the nanometer scale are called nanoparticles. These particles are larger than molecules, but are still extremely small. A material that incorporates nanoparticles is called a *nanocomposite.*

Bioplastic nanocomposites are currently being developed that incorporate three kinds of nanoparticles, clay nanoplatelets, cellulose nanofibers, and carbon nanofibers. Evenly yet randomly dispersed clay nanoplatelets aligned with a bioplastic film improve the bioplastic’s strength, heat stability, and transparency, and decrease solubility and the permeability of gas and water. (See **Figure 3.)** Cellulose nanofibers and carbon nanofibers increase the strength of a bioplastic, and cellulose also decreases solubility.

Figure 3: When small plate-shaped clay nanoparticles are distributed as shown in a bioplastic film, water and gas molecules can only move through the material along a “tortuous path.”

**Figure 3:** When small plate-shaped clay nanoparticles are distributed as shown in a bioplastic film, water and gas molecules can only move through the material along a “tortuous path.”

Another way to change bioplastics at the nanometer scale is to change the polymer structure. Citric acid added to starch films decreases permeability of gas and water. Heating can make starch film more water resistant and flexible. Crosslinking improves tensile strength and slows degradation.

# Making and Testing Properties of Bioplastics Films

Source: <http://www.ccmr.cornell.edu/wp-content/uploads/sites/2/2015/11/PolymerInvestigations.pdf>

Plastics have become a vital part of our everyday existence. Plastic technology has evolved into an exact science with plastics for any use imaginable. Different plastics also have different properties that make them suitable for a variety of uses. Currently, we rely on the use of fossil fuels to produce plastics. In an effort to reduce our dependence on finite resources, new research has discovered natural materials that can be made into plastics. Some of these plastics are comparable to synthetic plastics in their behavior under certain conditions. Do these bioplastics really share enough of the same properties to substitute them for synthetic polymers?

## Part A: Making the Bioplastic

The objective of this activity is to make a biodegradable plastic film.

 Materials for each group of four students

* Starch
* Agar
* Gelatin
* 100 mL of 1% glycerol solution
* 400-mL or 600-mL beaker
* 100-mL graduated cylinder
* Digital balance
* Plastic weighing dish
* Stir bar or small paper clip
* Glass stirring rod
* Hot plate with magnetic stirrer
* Thermometer
* Stand and clamp to hold the thermometer
* Hot-hands or oven mitts
* Teflon nonstick pan (~38cm x 25cm)

Safety

* Safety glasses/goggles must be worn at all times
* Use caution when heating with the hot plate. To prevent burns never handle heated materials. Always use hot-hands or oven mitts to handle the beakers once heating begins.
* Use caution when handling the thermometer
* After lab activity is completed and lab area is cleaned, wash hands with soap

Procedure

1. You teacher will assign you to make one of the three bioplastic films in **Table 7**. Write the bioplastic you are making here: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. Use the table to measure the correct amount of reagents needed to make your bioplastic.

**Table 7:** Recipes for Making Bioplastic Films

|  |  |  |  |
| --- | --- | --- | --- |
| Reagent | Agar film recipe | Gelatin film recipe | Starch-gelatin-agar film recipe |
| Agar | 2.25 g |  | 0.25 g |
| Gelatin |  | 2.25 g | 0.50 g |
| Starch |  |  | 1.50 g |
| 1% glycerol | 100mL | 100 mL | 100 mL |

1. Once all reagents have been measured, mix all of the dry materials in a clean 400-mL or 600-mL beaker.
2. Add the stir bar or a small paper clip to the beaker and place on to a hot plate with magnetic stirrer. Do not turn the heat on at this time.
3. Slowly add the glycerol to the beaker while mixing using the magnetic stirrer. Continue to mix until all solid material has dissolved in the glycerol. You may have to break up larger chunks using a glass stirring rod.
4. Once all solids are in solution, use the stand and clamp to position the thermometer in the reaction solution. Make sure the bottom of the thermometer is above the stir bar.
5. Heat the mixture until it begins to froth. DO NOT allow the temperature to go above 95 °C.
6. Turn off the heat after reaction solution has begun to froth. Remove the thermometer and continue to stir with the glass stirring rod for 5 minutes. No visible lumps should be present.
7. Once the mixture has cooled slightly, carefully pour the mixture into a level Teflon pan. The film will need to dry overnight.

## Part B: Testing the Bioplastic

The objective of this activity is to test properties of the bioplastic you made and of two plastics. Record data in **Table 8**.

Materials for each group of 4 students

* One sample of bioplastic and two samples of plastics
* Digital balance
* Plastic weighing dish
* 100-mL graduated cylinder
* Scissors
* Penny
* Iron nail or other iron piece
* Steel file
* Tongs
* Two 200-mL beakers
* 0°C water
* 80°C water
* Watch glass
* Two plastic pipettes
* 2.0 M HCl
* 2.0 M NaOH
* Wooden stir stick

Safety

* Safety glasses/goggles must be worn at all times
* Take care handling acids and bases and if a spill occurs, alert your teacher immediately
* After lab activity is completed and lab area is cleaned, wash hands with soap

## Procedure

*Observation of each sample*

1. Describe the sample’s texture, gloss or shine, transparency, color, and SPI code.

*Density of the bioplastic sample only*

1. Using the balance, find the mass (in grams) of the bioplastic sample.
2. Fill a 100 mL beaker to the 40 mL mark. Place the bioplastic sample in the water.
3. Observe whether the bioplastic sample sinks or floats. Make sure there are no air bubbles sticking to the plastic.
4. Record the new volume of water. Subtract the original volume from the final volume.
5. Determine the density of the sample by using the equation: D=m/v.

*Hardness of each sample*

1. Hardness is ability to withstand being scratched. A scratch is defined as a groove on the surface easily seen. Harder materials scratch softer ones. Measure with the Mohs scale:

* A penny is 3
* A piece of iron is 4.5
* A steel file is 7

1. Scratch the surface of the sample with the penny, iron, and steel file. Use the results and Mohs scale to rate the hardness of the material.

*Flexibility of each sample*

1. Take the sample and fold it in half. Check for folds, creases, cracks, or a color change in the sample. If the sample has none of these effects, continue folding until it does. Count the number of folds until effects are seen.
2. Repeat this test after exposing the sample to 0°C water (for 5 min) and hot water (for 5 min). The hot water should be at least 80°C. Remove the sample using tongs.

*Reaction of each sample with acid and base*

1. Place a small piece of each sample (at least the size of a penny) on the watch glass. Fill a pipet with 2.0 M HCl. Count the number of drops it takes before the sample begins to change. Check the sample using a wooden stir stick. Record your results. Rinse the sample with large amounts of water and dispose of in the trash.
2. Repeat the previous step using the 2.0 M NaOH. Record your results. Rinse the sample with large amounts of water and dispose of in the trash.
3. Wash your hands thoroughly.

**Table 8:** Properties of Bioplastic and Plastics

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample | Observations | Density | Hardness | Flexibility | Reaction with acid | Reaction with base |
| Bioplastic  \_\_\_\_\_\_\_\_\_\_\_ |  |  |  | RT  0°C  80°C |  |  |
| Plastic code  \_\_\_\_\_\_ |  | from **Table 2:** |  | RT  0°C  80°C |  |  |
| Plastic code \_\_\_\_\_\_ |  | from **Table 2:** |  | RT  0°C  80°C |  |  |

Questions

1. What differences did you note among the three samples?
2. Describe problems you had in synthesizing or measuring the properties of the biopolymer.
3. All the groups will report their data in a class table. If another group tested the same bioplastic or plastics that you did, compare your results. If there are differences, explain possible reasons.

# Compare Bioplastics and Plastics

Your class will carry out a discussion comparing bioplastics and plastics. You will work with a partner to describe your initial ideas and then share them with the class.

Learning how to contribute to a productive discussion is an important skill. As you complete tasks 1 through 3 below,place a check in **Table 9** to show what part of the discussion you contributed to. Try to contribute at least four times.

**Table 9:** Contribution to Class Discussion

|  |  |  |
| --- | --- | --- |
| Match tests and criteria | Compare properties | Compare structures |
|  |  |  |

Complete the following tasks.

1. Match each property you tested with one or more of the criteria developed in **Lesson 2**.
2. Study the class data on the properties of bioplastics and plastics. Compare the properties and identify differences.
3. Hypothesize how the structure of the bioplastic you synthesized differs from the structure of one of the plastics you tested. Consider:

* relative amount of crystallinity
* relative amount of branching
* relative strength of intermolecular bonds between chains

# Design Proposal

Food packaging designers begin by looking at the physical and chemical properties of the food to be packaged. They must consider what kind of protection the food needs and how the package will be manufactured, shipped, stored, displayed, used, and disposed of. In addition, they must meet the food manufacturer’s production, marketing, and cost specifications. Plastic or bioplastic films are a good choice for food packaging because they are economical and a high strength to weight ratio, which means that manufacturers can use less material. Development of new food packaging is a major business, as requirements change and new materials become available.

Your project in this unit is to propose a materials design for an improved food packaging film. You have a constraint, which is that the majority of the film must be made from one or more bioplastics. As you work on this project, refer back to the labs and readings in this lesson to review information about polymers that can help you make your choices for the design proposal. You may choose to look up additional information as well.

Complete the following steps.

1. Choose two of the criteria developed in **Lesson 2** to guide their design of a bioplastic-based food packaging film. Explain your choices fully.
2. Using the two criteria as a guide, choose one or two of the bioplastic(s) synthesized in **Lesson 4** as the starting material for your design. Explain your choice fully.
3. Using the two criteria as a guide, and using what you have learned about polymer structure-property relationships, propose changes to the polymeric structure of the bioplastic(s) you chose as your starting material. Include both words and drawings to illustrate your proposed changes. Explain your rationale fully.
4. Choose additional substances that will be part of your designed material, such as other polymers and nanoparticles. Explain your rationale fully.
5. List the tests you would run on the new material once it was developed.
6. Make a detailed labeled drawing of your designed material. Identify all materials and summarize any changes to polymeric structure of the bioplastic(s).

# Design Proposal Presentation

Create a presentation of your design proposal using a PowerPoint or poster, as directed by your teacher. The presentation must include the following parts:

1. A description of what is required in food packaging and why plastics are a good choice for food packaging. Include a summary of themolecular structure and general properties of plastics.
2. The specific criteria you choose and the constraint you worked under, with an explanation of their importance.
3. Your choice of starting material, with a rationale for its choice that relates to the criteria and constraint. You can choose one of the three bioplastics synthesized in the class, or you can carry out Internet research to identify another bioplastic choice. (NOTE: In the lab, you measured these properties of the three bioplastics: density, reaction with an acid and with a base, hardness, and flexibility, and you observed the optical properties of the bioplastic. If you identify an alternative bioplastic using the Internet, you must include similar information about its properties.)
4. Your proposed changes to the polymeric structure of the starting material, with a rationale for the changes. Include drawings of the new structure.
5. Your choice of nanocomposite additives (if any), with a rationale for the additions.
6. A detailed labeled drawing of your designed material.
7. A list of the tests you would run on the new material once it was developed.

The presentation should be organized and convey the information logically. It should also be appropriate for the audience, your classmates. The rubric for the presentation follows.

**Summative Assessment: Rubric for the Design Proposal Presentation**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Criteria** | **0** | **1** | **2** | **3** | **4** |
| Chemistry | Included no aspects of structure & properties of plastics to support their use in food packaging | Included few aspects of structure & properties of plastics to support their use in food packaging | Included some aspects of structure & properties of plastics to support their use in food packaging | Included many aspects of structure & properties of plastics to support their use in food packaging | Included & connected many aspects of structure & properties of plastics to support their use in food packaging |
| Design Proposal | Nano and molecular scale of design not presented & not connected to criteria & constraints. Rationale for choice of starting material & proposed changes unclear or missing. | Nano and molecular scale of design poorly presented & minimally connected to criteria & constraints. Rationale for choice of starting material & proposed changes mostly unclear. | Nano and molecular scale of design adequately presented & connected to criteria & constraints. Rationale for choice of starting material & proposed changes somewhat clear. | Nano and molecular scale of design well-presented & connected to criteria & constraints.  Rationale for choice of starting material & the proposed changes clear. | Nano and molecular scale of design well-presented & connected to criteria & constraints.  Rationale for choice of starting material & the proposed changes was very clear & concise. |
| Appropriate for Purpose, Audience, & Task | Organization, development, substance, & style were inappropriate | Organization, development, substance, & style were mostly inappropriate | Organization, development, substance, & style were somewhat appropriate | Organization, development, substance, & style were mostly appropriate | Organization, development, substance, & style were fully appropriate |
| Organization | Presentation of chemistry & proposal was incomplete & not clear. Listeners could not follow the line of reasoning. | Presentation of chemistry & proposal was unorganized & mostly unclear. Listeners had difficulty in following the line of reasoning. | Presentation of chemistry & proposal was somewhat organized & partially clear. Listeners were mostly able to follow the line of reasoning. | Presentation of chemistry & proposal was organized and clear. Listeners were able to follow the line of reasoning. | Presentation of chemistry & proposal was organized, clear, & concise. Listeners were able to follow the line of reasoning easily. |