SYNTHETIC PROPERTIES

Level of Difficulty: 4
Grade Range: 9-12
Activity Time: 45-60 min
Business Category: IT (Manufacturing)
Topic: Properties of Matter

OVERVIEW

In this activity, students will compare samples of monomers and polymers in powder and thread form (sugar/cotton candy and cotton flock/cotton balls). Students will measure and record solubility, melting point, water absorption, and tensile strength and relate macroscopic properties to microscopic structure. They will then develop a paper slide video to communicate their results.

STEM LESSON FOCUS

Engineering Design Cycle	21st Century Skills
• Communicating Results	• Collaboration

OBJECTIVES

Students will be able to:

- **Compare** the effects of polymerizing a small molecule (monomer) into a large molecule (polymer).
- **Relate** microscopic properties to microscopic structure.

MATERIALS

For this lesson, students will need:

- ***Helpful Terms Student Worksheet***
- ***Synthetic Properties Testing Student Worksheet***
- ***Sample Testing Station Directions: Teacher Resource***
- Sugar
- Cotton candy

SYNTHETIC PROPERTIES

- Cotton flock (micro fibers)
- Coton balls
- Cups of water
- Beakers (4 per group)
- Graduated cylinder
- Stirring rods
- Rulers
- Stopwatch
- Pipettes
- Watch glasses (4 per group)
- Balance
- Thermometer
- Evaporating dish
- Paper/plastic cups
- Pennies

HAVE YOU EVER WONDERED...

What plastics, wood, proteins, and nylon have in common? It turns out all of these materials are made of polymers, huge molecules made of long repetitive chains of shorter identical molecules called monomers.

SYNTHETIC PROPERTIES

MAKE CONNECTIONS!

How does this connect to students?	How does this connect to careers?	How does this connect to our world?
Polymers permeate our lives! Next time you're at the dentist having a tooth filled, watch how the dentist mixes a sticky putty and then cures it using ultraviolet light. This new material -- made up of space-filling polymers of all different colors and textures -- will fill the clean cavity in your mouth.	**Polymer scientists** are chemists who manipulate polymers to create useful materials such as Teflon, Kevlar, fiberglass, polyester, and biodegradables. **Organic chemists** study molecules that contain carbon by characterizing, synthesizing, or finding applications for these molecules. Typically, they work in teams and use chemistry lab equipment as well as advanced computer-driven equipment. **Materials engineers** specialize in working with particular materials such as metals, plastics, ceramics, semiconductors, composites, etc. They develop, process, and test these materials to create products ranging from aircraft wings to computer chips.	Manufacturers from around the world have been involved extensively in research and development efforts geared toward producing a huge range of new products. One example is synthetic paper, which is water and tear resistant, scuff resistant, and easy to print on. According to a report by Grand View Research, Inc., the global synthetic paper market is projected to reach $454.5 million by the year 2024.

If you want students to further explore career opportunities connected to this topic, please allow for more classroom time.

BLUEPRINT FOR DISCOVERY

Follow the instructions below to complete the activity.

1. Divide Introduce the lesson by telling students that they will investigate how macroscopic materials depend on their microscopic structure. As an activator that piques interest, show the following videos:

- University of Wisconsin-Madison Professor of Food Engineering: Cotton Candy
- How It's Made: Cotton Swabs

2. Randomly select students to share what they learned from the videos. Emphasis should be placed on how simpler units are processed into more complicated substances. Ask the class to compare/contrast the processes of making cotton candy and cotton swabs. One similarity is that fibers or fine strands are collected or bundled in a continuous mass. However, the two processes rely on different substrates or starting materials. In the case of cotton candy, as the strands are collected on a cone, they are not packed close together. As air gets trapped between the layers, the cotton candy increases in volume and takes on a light and fluffy texture.

3. Write or display the following terms on the board:
   - monomer
   - polymer
   - solubility
   - flexibility
   - melting point
   - tensile strength

   Tell the class that they will be working in small groups to investigate the properties of sugar, cotton candy, cotton flock, and cotton balls. Before they can do that, they need to have working definitions of the terms written on the board.

4. Provide an opportunity for students to Think-Pair-Share as they develop definitions for the terms. Call on students using equitable strategies to share their definitions with the rest of the class. Make sure students have written down accurate definitions similar to the ones shown below.
   - **Monomer:** a molecule that is able to bond in long chains; "mono" means single unit
   - **Polymer:** many monomers that are combined to form macromolecules or large-sized molecules; "poly" means many units
   - **Solubility:** a property of a substance that refers to its ability to dissolve in a solvent at a given temperature
   - **Water absorption: t**he amount of weight gain experienced by a material after immersion in water for a specified length of time
   - **Melting point:** the temperature at which a given solid will melt
   - **Tensile strength:** the amount of stress that a material can withstand while being stretched or pulled before breaking

     Teacher note: Alternatively, a ***Helpful Terms Student Worksheet*** is provided for students. This worksheet includes the terms and definitions and asks students to put the definitions in their own words and to make a quick sketch.

5. Assign structured, cooperative-learning roles to each group member (by letter) to keep everyone productive and on task. Examples of structured cooperative learning roles include the following:
   - Role A: Group Supervisor: keeps group on task
   - Role B: Time Manager: serves as time keeper
   - Role C: Clean Up Manager: facilitates clean up
     Role D: Lead Investigator: moderates discussion

6. Ask the lead investigator of each group to come to the front of the class to pick up the following materials:
   - sugar
   - cotton candy
   - cotton flock (micro fibers)
   - cotton balls
   - cups of water
   - beakers (4 per group)
   - graduated cylinder
   - stirring rods
   - rulers
   - stopwatch
   - pipettes
   - watch glasses (4 per group)
   - balance
   - thermometer
   - evaporating dish
   - paper/plastic cups
   - pennies

   Distribute the ***Synthetic Properties Testing Student Worksheet*** for students to capture their data. Monitor the class as they go through the following steps of the experimental procedure. They will conduct the following tests on four samples (granulated sugar, cotton candy, cotton flock, and cotton balls):

   - The solubility test will be performed by adding the samples to separate beakers with 50 mL of water and stirring the samples using the stirring rod. Record observations related to how much of each sample has been dissolved.

   - The melting point test will be performed by adding an equal mass of each sample into an evaporating dish and heating it until it starts to melt. Measure and record the melting temperature.

   - The water absorption test will be performed by obtaining an initial mass of each sample placed on a watch glass and then pipetting 5 mL of water onto each sample.

After 30 seconds, each sample is massed again to determine the weight gain as a percentage using the following formula:

[(final mass – initial mass) / (initial mass)] x 100%

Record your observations and calculations.

- Lastly, the tensile strength test will be performed by forming strings (of roughly equal cross-sectional areas) out of cotton candy fibers and cotton. Punch a hole in the paper/plastic cup and thread the string through the hole tying off the end. Tape the other end of the string to a table and add a book on top for added support. Add pennies (2.5 gram masses) one at a time into the cup until the string breaks. Record how many pennies had been added when the string broke and calculate the total mass by multiplying the number of pennies by the weight of each penny (2.5 g). For example, if 4 pennies were required to break the string, then the total mass added would be 4 x 2.5 g = 10.0 grams. Repeat this procedure for the other material and then record the mass required to break the second string. After recording all observations and measurements, instruct students to clean up.

  All of the experimental procedures are also listed on ***Sample Testing Station Directions: Teacher Resource.***

7. Next, students will prepare a paper slide video to communicate their results.

In addition to making claims from actual evidence/data, students will be required to relate the macroscopic properties they observed to the microscopic structures of monomers/polymers. Students should be prepared to answer the following key questions in their video presentations:

- What factors do the physical properties of polymers depend on?

  Examples include chain length, branching, side groups, cross-linking

- Why was the cotton able to absorb so much water?

  The cellulose structure of cotton consists of polymers that are negatively charged and hydrophilic (attract dipolar water molecules). In addition, cotton fibers are able to draw in water like a straw through capillary action.

- How does solubility and melting point depend on the chemical structure of the sample?

  Cotton, which is a pure form of cellulose, has extensive hydrogen bonding between the chains which raises its melting temperature to above its combustion temperature. It is also insoluble and indigestible. On the other hand, sugar and cotton candy which consists of polymers of sugars are highly soluble in water. The reason is that when sugar enters water the polar bonds of the water molecules begin to pull away and separate the individual sucrose

molecules. The force of attraction between the water and sucrose molecules is stronger than the attractions between the sucrose molecules themselves, which causes the individual molecules of sugar to separate and bond with the water causing the sugar to dissolve into a solution. Although cotton has a high resistance to degradation by heat, cotton candy starts to melt at around 88 degrees Celsius.

- What caused the tensile strength to differ in the cotton candy fibers versus the cotton ball fibers?

  The experiments show that cotton is a moderately strong fiber that does not stress very easily. It has an elongation at break of 5-10%. Cotton fiber's strength is primarily due to its high degree of polymerization and the fact that the cellulose molecules are closely packed and parallel to one another. Cotton candy fibers are less tightly packed and less rigid due to air being trapped between the strands giving it a light and fluffy texture.

  Students can refer to their textbooks or navigate to these websites to help them answer the key questions:
  http://courses.chem.psu.edu/chem112/materials/polymers.html
  http://wwwcourses.sens.buffalo.edu/ce435/Cellulose_CB.pdf
  http://www.uwosh.edu/faculty_staff/mihalick/materials/Chapter5.pdf
  http://teachersinstitute.yale.edu/curriculum/units/2015/4/15.04.01.x.html
  https://ttu-ir.tdl.org/ttu-ir/bitstream/handle/2346/46986/HOSSEINALI-THESIS.pdf
  http://www.mtu.edu/materials/k12/experiments/tensile/

TAKE ACTION!

Investigate natural materials (bio-polymers) that can be made into plastics. Are the properties of these bio-polymers similar to synthetic plastics? The objective of the following experiment is to make a biodegradable plastic film and to test its properties. The protocol can be found on pages 13-15 of the following resource:

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

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NATIONAL STANDARDS

Next Generation Science Standards	HS-PS1-3. Matter and Its Interactions – Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
Computer Science Teachers Association	Collaboration (CL) Apply productivity/multimedia tools and peripherals to group collaboration and support learning throughout the curriculum. Collaboratively design, develop, publish, and present products (e.g. videos, podcasts, websites) using technology resources that demonstrates and communicate curriculum concepts.

Siemens STEM Day

SiemensStemDay.com

SYNTHETIC PROPERTIES

HELPFUL TERMS WORKSHEET

Word	Definition	In my own words	Sketch
Monomer	a molecule that is able to bond in long chains; “mono” means a single unit		
Polymer	many monomers that are combined to form macromolecules or large-sized molecules; “poly” means many units		
Solubility	a property of a substance that refers to its ability to dissolve in a solvent at a given temperature		
Water absorption	the amount of weight gain experienced by a material after immersion in water for a specified length of time		
Melting point	the temperature at which a given solid will melt		
Tensile strength	the amount of stress that a material can withstand while being stretched or pulled before breaking		

SYNTHETIC PROPERTIES

Sample Testing Station Directions: Teacher Resource

Display each set of directions with testing materials at each station.

Solubility Test

1. Add the samples to separate beakers with 50 mL of water and stir the samples using the stirring rod.
2. Record observations related to how much of each sample has been dissolved.

Melting Point

1. Add an equal mass of each sample into an evaporating dish.
2. Heating it until it starts to melt.
3. Measure and record the melting temperature.

Water Absorption Test

1. Obtaining an initial mass of each sample placed on a watch glass.
2. Pipette 5 mL of water onto each sample.
3. After 30 seconds, mass each sample again to determine the weight gain as a percentage using the following formula:

   [(final mass – initial mass) / (initial mass)] x 100%
4. Record your observations and calculations.

Tensile Strength Test

1. Form strings (of roughly equal cross-sectional areas) out of cotton candy fibers and cotton. Punch a hole in the paper/plastic cup and thread the string through the hole tying off the end. Tape the other end of the string to a table and add a book on top for added support.
2. Add pennies (2.5 gram masses) one at a time into the cup until the string breaks.
3. Record how many pennies had been added when the string broke and calculate the total mass by multiplying the number of pennies by the weight of each penny (2.5 g).

   For example, if 4 pennies were required to break the string, then the total mass added would be 4 x 2.5 g = 10.0 grams.
4. Repeat this procedure for the other material and then record the mass required to break the second string.

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Synthetic Properties Testing Worksheet

Use the table below to record your experimental results. Then, analyze your data using the summary questions.

Sample	Solubility	Melting Point	Water Absorption Test	Tensile Strength
Granulated sugar				
Cotton candy				
Cotton flock				
Cotton balls				

Summary Questions:

1. What factors do the physical properties of polymers depend on?
2. Why was the cotton able to absorb so much water?
3. How does solubility and melting point depend on the chemical structure of the sample?
4. What caused the tensile strength to differ in the cotton candy fibers versus the cotton ball fibers?

Website resources:

http://courses.chem.psu.edu/chem112/materials/polymers.html
http://wwwcourses.sens.buffalo.edu/ce435/Cellulose_CB.pdf
http://www.uwosh.edu/faculty_staff/mihalick/materials/Chapter5.pdf
http://teachersinstitute.yale.edu/curriculum/units/2015/4/15.04.01.x.html
https://ttu-ir.tdl.org/ttu-ir/bitstream/handle/2346/46986/HOSSEINALI-THESIS.pdf
http://www.mtu.edu/materials/k12/experiments/tensile/