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#5 Properties and Perfectly Polymeric Sodas

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I. INTRODUCTION

Description

The following activities can be used in the instruction of physical properties, chemical properties, interfaces, and forms of plastic. The concepts of thermoplastic and thermosetting materials will also be introduced and related to recycling. Students will use polycaprolactone to demonstrate a thermoplastic material and physical changes. Epoxy putty is used to demonstrate a thermosetting material and a chemical reaction. The students will also create a foam (a "perfectly polymeric soda") to study interfaces and multiple forms of plastics.

Student Audience

These activities can be used from a basic science class to university level chemistry or chemical technology.

Goals of the Experiment

The student will:

- differentiate between thermosetting and thermoplastic materials,
- differentiate between physical changes and chemical reactions,
- identify how the thermoplastic nature of plastics relates to recycling,
- create a soda from 7 plastics and 7 forms of plastics, and
- identify interfaces.

Recommended Placement in the Curriculum

This investigation is recommended for use in the discussion of any of the following topics:

- physical and chemical properties of polymers,
- interfaces,
- recycling, and
- forms of plastics.

II. STUDENT HANDOUT

Properties and Perfectly Polymeric Sodas

Scenario

You are employed by the Research Lab of the Novelty Toy Company. The company has been approached by representatives of the I Scream Ice Cream Company to produce a novelty item to be given out at the company's annual corporate sales meeting. The I Scream line of products includes not only ice cream but also related items such as syrups and various toppings. You decide to make a polymer version of an ice cream soda using different polymers to represent the different products made by I Scream. Prior to doing this, you investigate the properties of various polymers.

Industrial Application

The following activity helps demonstrate the two characteristic responses of plastics to heating. The majority of plastics used are thermoplastic in nature, meaning that after they are formed they can be heated and reformed again and again. This basic physical property is the basis of our ability to process and reprocess (recycle) plastics. Polycaprolactone will be used to demonstrate thermoplastics since it has a melting point of approximately 140 °F and will soften in boiling water.

Thermosetting polymers, on the other hand, are formed into products but cannot be remelted and reformed. Reheating a thermoset results in the material scorching rather than melting which is an attribute where heat resistance is important in an application. Vulcanized rubber, polyurethane, and epoxy are common thermosetting polymers which are familiar to most people. The two part epoxy will be mixed and a chemical reaction will occur in this activity. The resulting polymer cannot be softened again after it has completely cured.

The response of polymers to heating is one of the determining factors for the methods used to process the material into products. There are approximately nine forms of plastic materials which include: molding compounds, adhesives, extruded dimensional or profiles, films, fibers and filaments, coatings, castings, cellular or foamed plastics, and composites. The diversity of plastics is demonstrated in the "perfectly polymeric soda" which contains 7 different forms of plastic and 7 different polymers. After the soda is complete, the various interfaces that have been created will be identified.

Safety, Handling, and Disposal

- If your hands are rough and dry, use lotion before using the polycaprolactone.
- Wetting your hands before handling the material makes it easier to handle and prevents sticking.
- Be careful to avoid burns while working with the boiling water.
- Do not form polycaprolactone around fingers or wrists. The material shrinks slightly when it cools and would need to be cut off.
- Read the label on the epoxy putty carefully. Gloves are highly recommended when mixing the epoxy whether the manufacturer mentions them or not . If gloves are not worn, wash hands immediately after mixing. Use rubbing alcohol or alcohol swabs to remove any material which remains on the hands.

- Epoxy is an adhesive, do not press it on books, counter tops, etc.; it will stick!
- Heat the epoxy putty only in a fume hood.
- Read the Material Safety Data Sheet for precautions when using the polyurethane foam kit. Goggles and gloves must be worn when performing this activity. This demonstration or experiment should only be performed in a well-ventilated area. Persons with a history of respiratory problems or known sensitivity to organic isocyanates should avoid this activity. The liquid reagents used in this activity are irritating to the skin, eyes, and respiratory system. If Part A, Part B, or the mixture comes in contact with the skin, wash immediately with soap and water. Avoid contact with the foam for about 24 hours; there may be some unreacted starting material on the surface of the foam that can irritate the skin. After about a day of curing in a well-ventilated area, the hardened foam is safe to handle.
- Any excess chemicals for the polyurethane should be mixed together and reacted before disposal.
- Follow all local ordinances when disposing of chemicals.

Materials

Activity #1
Per student
- glass cup or beaker
- polycaprolactone strips or pellets
- metal spoon or scoopula
- boiling water
- heat resistant gloves or beaker tongs
- tongs

Activity #2
Per student or group
- gloves
- 1/2-inch strip or chunk of two part epoxy putty
- Bunsen burner or torch
- rubbing alcohol or alcohol swabs

Activity #3
Per class
- polyurethane foam kit
- white glue
- brown pellets
- plastic snow
- (optional) food color and flavoring oils

Per student or group
- goggles
- gloves
- 1 5-ounce cup
- 2 short straws or coffee stirrers
- red acrylic pompon

Procedure

Activity #1: Thermoplastic Material

1. Place a strip or about 1 tablespoon of polycaprolactone in a glass bowl or beaker and cover with boiling water. Do not stir. **Be careful to avoid burns while working with the boiling water.**
2. Watch as the plastic turns from translucent to transparent. Is the change which occurs endothermic or is it exothermic? When all the material has turned transparent carefully pour off the water using heat resistant gloves or beaker tongs.
3. Using the spoon or scoopula, gather up the material. Wet hands with cold water and while the material is still warm but not too hot to touch, mold, and shape the material. The polycaprolactone will remain in the rubbery state for several minutes. To reshape, return material to glass bowl and add boiling water.

Activity #2: Thermosetting Material

1. Remove any plastic film protecting the epoxy putty. Knead and mix the two part putty to form a uniform color. Is the change which occurs endothermic or is it exothermic?
2. Mold the putty into a shape and set aside to cure. Remember to gently place the epoxy on a piece of paper or plastic so it does not stick on any surfaces. Curing will vary from 5–30 minutes depending on type of epoxy used.

If gloves are not worn, wash hands immediately after kneading the epoxy; any remaining epoxy can be removed with rubbing alcohol or an alcohol swab.

3. After the material is set, demonstrate its thermosetting nature by holding the cured epoxy with tongs into a Bunsen burner or torch flame in a fume hood. Note the material scorches but does not soften or melt. All plastics will burn, therefore do not leave in flame until epoxy ignites but only long enough to see it scorch.

Complete this step in a fume hood. Epoxy may release small amounts of hydrogen cyanide gas when burned.

Activity #3: Perfectly Polymeric Soda

1. Read and follow ALL safety and handling precautions listed in the MSDS for Part A and Part B of the polyurethane foam kit. Reread the safety precautions included in this write-up (above).
2. Measure 1 teaspoon of Part A into a 5-ounce transparent (not opaque) polystyrene cup (not foamed polystyrene).

Do not use more than 1 teaspoon of either Part A or Part B.

3. (optional) Add 3–4 drops of food color and two drops of flavoring oils and mix well using two coffee stirs or cocktail straws.
4. Add 1 teaspoon of Part B and mix until blended.

5. Hold the straws in place while the foam begins to expand. This is a step growth addition polymerization. Addition because unlike most step growth reactions it does not produce a small molecule by-product (e.g., H_2O, HCl). Is the reaction endothermic or is it exothermic?
6. When the foam stops expanding and begins to harden, dip the top of the "soda" into white glue and then into the shredded plastic film, sprinkle with pellets, and top off with a pompon cherry. You have created a "soda" made of 7 different polymers and 7 different forms of plastics.

Questions

1. Describe several physical properties of the polycaprolactone and explain how this activity is an example of physical change.
2. What is the structure of caprolactone and the repeat unit of polycaprolactone?
3. Describe the changes that are occurring in the polycaprolactone samples on the molecular level after the boiling water has been added.
4. What are some commercial applications of polycaprolactone?
5. Describe how the epoxy activity represents a chemical reaction.
6. What are the structures of a diepoxy and a diamine (not necessarily the ones used in the activity and portions not involved in the reaction may be represented by -R) used to produce an epoxy resin? What is the basic structure of the resulting epoxy resin?
7. What are some commercial applications of epoxy?
8. For each of the parts of the "soda," identify the polymer and the form of plastic used.
9. Identify the interfaces in the "soda."

References

Richardson, T. *Industrial Plastics: Theory and Application;* Delmar Publishing: New York, 1986.

Shah, V. *Handbook of Plastics Testing Technology;* John Wiley and Sons: New York, 1984.

Department of Polymer Science at the University of Southern Mississippi Web Site, the Macrogalleria, Epoxy Resins; http://www.psrc.usm.edu/macrog/epoxy.html (accessed 25 September 1997).

Department of Polymer Science at the University of Southern Mississippi Web Site, the Macrogalleria, Making Polyurethanes; http://www.psrc.usm.edu/macrog/uresyn.html (accessed 23 June 1998).

III. INSTRUCTOR NOTES

Properties and Perfectly Polymeric Sodas

Purpose

The first two activities introduce various chemical and physical properties of different plastics including how they are affected by heating. The third activity investigates the various forms of plastics and the interfaces created in the activity.

Time Required

All three activities can be completed in approximately 2 hours. In the high school setting this could be done at stations over two class periods.

Suggested Group Size

These activities can be done with any size group.

Materials

Activity #1

Per student

- glass cup or beaker (Foil cups can also be used but will get very hot and are more difficult to handle without burns. Foil cup cake pans can be cut apart and a foam cup nested into each well. This is more heat safe but can be top heavy.)
- 1 polycaprolactone strip or 1 tablespoon pellets (Purchase at craft stores.)
- metal spoon or scoopula
- boiling water
- heat resistant gloves or beaker tongs
- tongs

<u>Activity #2</u>

Per student or group

- gloves
- 1/2-inch strip or chunk of two part epoxy putty (Available at most discount and hardware stores in the adhesive or plumbing sections. A 4-ounce package can be cut into 10–12 pieces.)
- Bunsen burner or torch

<u>Activity #3</u>

Per class

- polyurethane foam kit (A quart kit will make approximately 60 sodas. Parts A and B of a polyurethane foam system can be purchased from toy or craft stores under the name Mountains in Minutes™ Polyfoam or from a chemical supply company such as Flinn Scientific, P.O. Box 219, Batavia, IL 60510-0219, 800/452-1261; catalog number C0335.)
- white glue
- brown pellets (Plastic pellets can be obtained from compounders and processors. Be certain to identify the polymer content of the pellets. 1–2 pounds will make hundreds of sodas.)

- plastic snow (Shredded film is generally available at craft stores during the Christmas season as "snow." Plain white is generally low density polyethylene (LDPE) and the pearlescent is cellulose acetate.
- (optional) food color and flavoring oils (Flavoring oils are available in cake and candy supply stores as well as many drug and grocery stores.)

Per student or group
- 1 5-oz. cup
- 2 short straws or coffee stirrers (Cocktail straws or plastic coffee stirs are available in party stores, grocery beverage departments, or wholesale food distributors.)
- red acrylic pompon (Available at craft stores.)

Safety, Handling, and Disposal
- If your hands are rough and dry, use lotion before using the polycaprolactone.
- Wetting your hands before handling the material makes it easier to handle and prevents sticking.
- Be careful to avoid burns while working with the boiling water.
- Do not form polycaprolactone around fingers or wrists. The material shrinks slightly when it cools and would need to be cut off.
- Read the label on the epoxy putty carefully. Gloves are highly recommended when mixing the epoxy whether the manufacturer mentions them or not . If gloves are not worn, wash hands immediately after mixing. Use rubbing alcohol or alcohol swabs to remove any material which remains on the hands.
- Epoxy is an adhesive, do not press it on books, counter tops, etc. it will stick!
- Heat the epoxy putty only in a fume hood.
- Read the Material Safety Data Sheet for precautions when using the polyurethane foam kit. Goggles and gloves must be worn when performing this activity. This demonstration or experiment should only be performed in a well-ventilated area. Persons with a history of respiratory problems or known sensitivity to organic isocyanates should avoid this activity. The liquid reagents used in this activity are irritating to the skin, eyes, and respiratory system. If Part A, Part B, or the mixture comes in contact with the skin, wash immediately with soap and water. Avoid contact with the foam for about 24 hours; there may be some unreacted starting material on the surface of the foam that can irritate the skin. After about a day of curing in a well-ventilated area, the hardened foam is safe to handle.
- To store unused polyurethane reagents, cap the cans tightly. Use the solutions within one year of purchase; otherwise they may polymerize within the cans. If a non-food refrigerator is available, store the reagents there to extend their lifetime.
- Any excess chemicals for the polyurethane should be mixed together and reacted before disposal.
- Follow all local ordinances when disposing chemicals.

Points to Cover in Pre-Lab
- Discuss physical properties and changes, chemical properties and changes, and interfaces.
- Safety issues.

Procedural Tips and Suggestions:

Activity #1

- Be careful to avoid burns while working with the boiling water.
- Try this activity prior to giving it to the students in order to observe whether or not the specific material you use will turn transparent. The visual changes are, for example, difficult to observe with black and white samples of the polycaprolactone. If all the material has not turned transparent in 4–5 minutes, pour off water and add more boiling water. If it still does not turn transparent, try a different colored piece. Or, if the material does not become transparent, pour off the water and continue with the experiment.

Activity #2

- There are a several varieties of epoxy putty on the market for wood, plastic, and metal. The easiest to use is the yellow and blue 2 part putty, mixing results in a green final product. Student may mistake the color change as an indicator of chemical change but it is simply a mixing of pigments.
- During mixing students will notice a slightly exothermic reaction and a distinct odor. This odor is apparently due to the production of an amine based gas which, according to the manufacturer contacted, is not hazardous at the level produced.
- Packaging label will list cure time for the epoxy ranging from 5 to 30 minutes.
- Have students use a fume hood to heat the epoxy putty. Some references state that the epoxy may release small amounts of hydrogen cyanide when burned. The manufacturer consulted stated that this is highly unlikely. The charring of the cured epoxy putty can also be done as a demonstration in a well ventilated area.
- All plastics will burn, therefore be sure that the epoxy remains in the flame long enough to see it scorch.

Activity #3

- Read and follow the precautions listed in the Materials Safety Data Sheets for Parts A and B of the polyurethane foam kit.
- Flavoring oils are sold in drug stores and candy making supply shops for about 99 cents. Spice and mint flavorings work best. DO NOT use flavoring extracts.
- This is a fun way to produce a variety of interfaces as a demonstration or activity in chemistry class. It is also a good way to investigate various forms of polymers. A kit will make approximately 60 sodas which minimizes the cost per student or group.

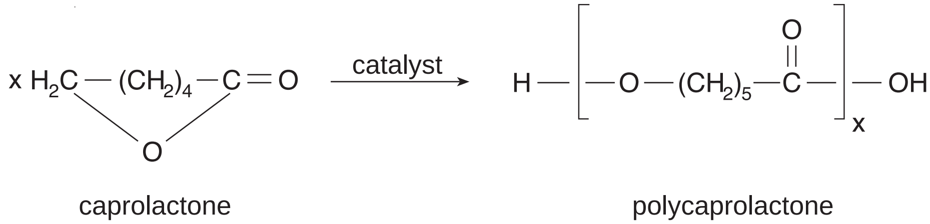
Plausible Answers to Questions

1. Describe several physical properties of the polycaprolactone and explain how this activity provides an example of physical change.

A: Physical properties might include color, shape, melting point, translucent or transparent, etc. There is a physical change as the polycaprolactone softens and changes shape. If the change from translucent to transparent is observed, this is also a physical change. No new substance is produced.

2. What is the structure of caprolactone and the repeat unit of polycaprolactone?

A:



3. Describe the changes that are occurring in the polycaprolactone samples on the molecular level after the boiling water has been added.

A: The boiling water is above the melting point of the polycaprolactone (58–60°C). As the kinetic energy of the material increases, the molecules move further apart. This can often be "seen" as the crystallinity is destroyed and the substance softens and changes from translucent to transparent. Very observant students will notice a very slight swelling of the material.

4. What are some commercial applications of polycaprolactone?

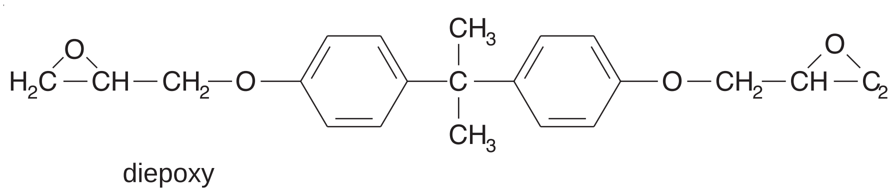
A: Polycaprolactone is a high priced material with only special niche applications. Because it is thermoplastic it can be melted, extruded, and molded. It is a biodegradable polyester which may be processed by various techniques including blown film, sheet extrusion, and injection molding. Applications include adhesive layers, biodegradable plastic bags, orthopedic casts, wound dressings, and shoe components.

5. Describe how the epoxy activity represents a chemical reaction.

A: Students should note the complete change in the material from soft and pliable to rigid (not the result of cooling), the release of a gas, etc. New substances have been produced. The color change in this case does not indicate a chemical change but a blending of pigments.

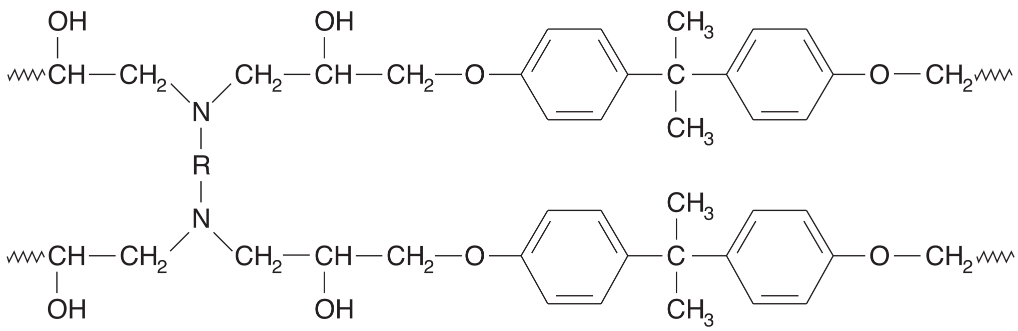
6. What are the structures of a diepoxy and a diamine (not necessarily the ones used in the activity and portions not involved in the reaction may be represented by -R) used to produce an epoxy resin? What is the basic structure of the resulting epoxy resin?

A: One example of a small diepoxy is:



The diamine would be something like: $H_2N\text{-}R\text{-}NH_2$.

The basic structure of the epoxy resin is shown below. Note that it is not a linear polymer but rather a cross-linked network. This structure has a major impact on its properties. (See answer to question 7.)



7. What are some commercial applications of epoxy?

A: Epoxy resins are excellent adhesives and, unlike most adhesives, they can be used on metals and glass. They are also used as protective coatings (e.g., epoxy paint for lab benches), in electronic circuit boards, for patching holes in concrete pavement, and to make composites. An epoxy adhesive is sold as two tubes of liquid or two strips of plasticene-like material. A low molecular weight diepoxy when mixed with a diamine forms a rigid cross-linked network that is very strong but can not be processed (i.e., molded or even melted). Epoxy resins contain many alcohol groups which allow it to bond well to glass. They do not absorb much water, do not shrink much when cured, and can be used at temperatures up to 160 °C.

8. For each of the parts of the "soda," identify the polymer and the form of plastic used.

A: The following may vary depending on the materials provided.

Part of "soda"	Polymer	Form
cup	polystyrene	molded
soda	polyurethane	foam
straws	polyethylene	extruded dimensional
glue	polyvinyl acetate	adhesive
topping	cellulose acetate	film
sprinkles	polypropylene	molding compound
cherry	acrylic	fiber

9. Identify the interfaces in the "soda."

A: The interfaces include cup to polyurethane foam, polyurethane foam to straws, polyurethane foam to glue, polyurethane foam to gas bubbles, etc.

References

Crossan, Dave, Safety and Industrial Hygiene, Polymeric Systems, Inc., personal communication (1-800-228-5548), March 24, 1998.

Richardson, T. *Industrial Plastics: Theory and Application;* Delmar Publishing: New York, 1986.

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Department of Polymer Science at the University of Southern Mississippi Web Site, the Macrogalleria, Making Polyurethanes; http://www.psrc.usm.edu/macrog/uresyn.html (accessed 23 June 1998).