Synthesizing Polymers

B-8

2 40- to 50-minute sessions

ACTIVITY OVERVIEW

Having investigated the properties of several common plastics, students now will create a new plastic material from white glue (containing polyvinyl acetate) and sodium borate. Students will compare the properties of the reactants and products. Then they will examine how the properties of the cross-linked polymer made from the white glue are altered by "compounding" it with a natural polymer—starch.

KEY CONCEPTS AND PROCESS SKILLS

The students will:

1. Synthesize a new plastic material (DESIGNING AND CONDUCTING INVESTIGATIONS).
2. Investigate the effects of cross-linking a polymer on the physical properties of reactants and suggest uses for the new product (DESIGNING AND CONDUCTING INVESTIGATIONS).
3. Understand that plastics are a class of materials whose properties can be altered to fit specific needs (UNDERSTANDING CONCEPTS).

KEY VOCABULARY

cross-linking

molecule

monomer

polymer

polymerization

product

reactants

MATERIALS AND ADVANCE PREPARATION

For the teacher:

- * 1 piece of PVC pipe
- * 1 overhead projector (optional)

For each student:

Student Sheet B8.1, "Some Common Plastics and Synthetic Fibers"

For each group of four students:

- 1 120-mL bottle of white glue
- 1 30-mL bottle of 4% sodium borate solution
- 1 30-mL container of calcium carbonate powder
- 1 60-mL bottle of liquid starch
- 1 bottle of food coloring (optional)

For each pair of students:

- 1 9-ounce clear plastic cup half filled with water
- 1 stir stick
- * paper towels
- 2 graduated cups

**Not supplied in kit*

Have students bring baggies or empty 35-mm film containers from home if you intend to send the polymer home with them (see Teaching Suggestions, Step 2). Display the pieces of pipe made from PVC (polyvinyl chloride) during this activity. It will be particularly useful to contrast the piece of PVC pipe with the plastic strips used in the last activity. This helps illustrate the effects of compounding.

If you wish to do the optional demonstration (see page B-83), gather together the materials.

Make copies of Student Sheet B8.1.

SAFETY NOTE

Have students wear protective eyewear. Immediately clean up any spilled materials with water. While the synthesized polymers are considered non-toxic, be sure to label any samples that are taken home.

TEACHING SUMMARY

DAY ONE

1. Introduce plastics as a type of polymer.
2. Students cross-link a polymer in white glue and compare the reactants and products.
3. The class discusses the answers to the questions on cross-linking polymers.

DAY TWO

4. Students compound the cross-linked polymer they made in the previous session.
5. The class discusses the differences between the polymer and the compounded polymer and brainstorms uses for each of them as "designed" materials.
6. Summarize the results of the investigation.

BACKGROUND INFORMATION

The Structure of Polymers

Polymers in their pure state are called *resins.* After being manufactured, resin beads or flakes are shipped to a processor for compounding. To suit various needs and product specifications from the end manufacturer, the compounder can add a variety of materials to the resin, heat it, and add a solvent to help combine ingredients, or chemically change the resin through additional reactions.

Polymers can be classified as *linear, branched,* or *cross-linked,* depending upon how their monomer subunits are arranged.

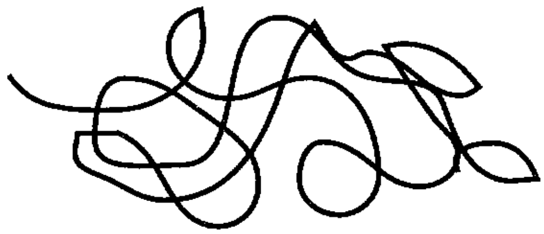
LINEAR POLYMERS

A linear polymer has all of its monomer molecules arranged in one long chain, such as is the case for high-density polyethylene, the material from which garbage bags are produced. The structural formula for polyethylene looks like this:

$$...\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}CH_2\text{-}...$$

A polyethylene molecule may have 25,000 carbon atoms in its chain and would have a molecular weight of approximately 350,000. Polystyrene and polypropylene are also linear polymers.

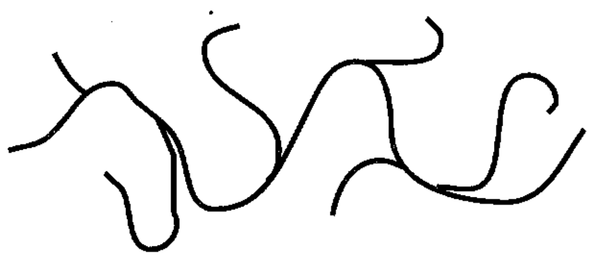
Even though these molecules are called linear, you should not think of them as straight lines, but rather as long strands that are bent and twisted, resembling a plate of spaghetti:



Because the long chains are randomly coiled together, these polymers tend to possess both orderly sections that are almost crystalline in nature, and also sections that exhibit less order (that is, sections that are random, or amorphous). This unique property of the molecules gives plastic some of its properties, such as clarity and flexibility.

BRANCHED POLYMERS

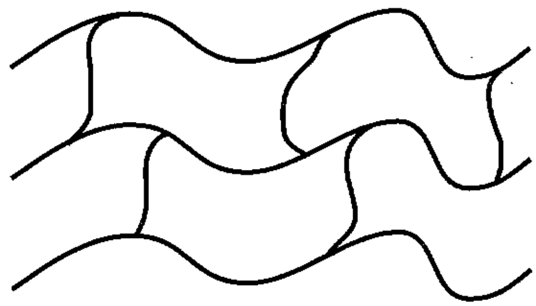
Branching occurs when sections of monomer molecules stick out along various points in the chain, as follows:



Branched polymers can form random coils, too. The branching produces a structure that has a less regular arrangement of molecules and is therefore less crystalline. Because the branching keeps the molecules from packing as tightly, branched polymers tend to have less strength and lower density than the linear polymers of the same molecular weight. A good example is low-density polyethylene.

CROSS-LINKED POLYMERS

Polymer units may also be cross-linked:



The ability to form orderly structures similar to crystals is an important property of polymers that makes them both hard and tough, yet flexible. They are not brittle like glass. Imagine a polyethylene molecule. In it are embedded many small crystalline sections arranged side by side with amorphous sections. These two components are not merely mixed, but are mechanically connected. Polymer fibers are some of the strongest materials known because the amorphous sections provide deformability, and the crystalline sections provide hardness and inflexibility. This quality is incorporated in the manufacture of high-density polyethylene film, allowing the garbage bags the students may investigate in Activity B-9 to stretch more in one direction than another.

As a polymer is stretched, its molecules move from an unoriented (random) state to a more oriented state that is more crystalline. This can be modeled by stretching some of the sections of the linear paper clip polymers into straight lines. In a piece of plastic bag, this structural change is observed as a color change in the black plastic trash bag, progressing from black to clear with actual parallel lines where molecules are lining up.

TEACHING SUGGESTIONS

■ DAY ONE

1. Introducing plastics as long chains of polymer molecules

Begin by asking the students what the names of the four plastics they just investigated all had in common. (Write the names of the plastics on the board or on an overhead.) They share the prefix, "poly-." Distribute Student Sheet B8.1, "Some Common Plastics and Synthetic Fibers." Point out that the names of many other plastics begin with the same prefix.

Ask, ***What does the prefix "poly-" mean?*** It means "many." Write the word "polymer" on the board or overhead and tell students that all plastics are considered a type of polymer. The root word "-mer" means "part." Define the term *polymer* for the class. A polymer is a chemical substance whose molecules are made by linking many smaller molecules together—in effect, a polymer is a molecule made up of many smaller, repeating parts.

NOTE: We assume the students have been introduced to molecules before. If not, tell them that a molecule is a group of atoms that has its own identity. Molecules are the smallest part of many pure substances. Therefore, many chemicals can be looked at as being just a collection of molecules.

Explain that the process of linking *monomers* (one-part molecules) together is called *polymerization,* and that typically 1,000 to 10,000 monomers may be linked to form a polymer. Now point out how polymer names are formed by adding the prefix "poly-" to the name of the monomer; i.e., polystyrene, polyethylene, polyvinyl chloride, polypropylene. Refer again to Student Sheet B8.1. Ask, ***How many of these plastics do you know by name?*** If you have not done so already, introduce common names such as Teflon, Lucite, and nylon.

OPTIONAL DEMONSTRATION

Use a group of small magnets, Legos, or paper clips to model the one-part-to-many-parts idea of joining monomers to form polymer molecules. Tell students that in Activity B-9, they will be investigating a paper clip model of the plastic they create in this activity in order to better understand the physical properties of the material. Some teachers prefer to do Activity B-9 before Activity B-8.

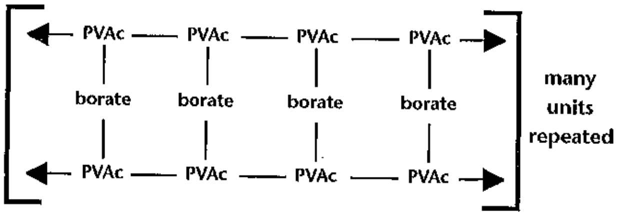
2. Doing the experiment

The experiment involves the preparation and observation of a cross-linked polymer. The cross-linked polymer is formed when polyvinyl acetate (PVAc), a linear polymer found in white glue, is cross-linked by sodium borate. PVAc is commonly used in paints, glues, and sealers.

Have students open to Student Book page B-55, "Cross-Linking a Polymer." Distribute the necessary materials. Remind students to remove the new polymer and wash the plastic cup with water to remove any unreacted white glue. They can then place the polymer in their hands to test it and form it into a ball. Stress the importance of cleaning the work area and equipment to remove any traces of glue.

NOTE: There are no known toxic effects from handling these chemicals, but students should thoroughly wash their hands after finishing. You may want to allow students to take their polymer home, but caution them not to allow young children to play with it or allow anyone to ingest it. The material should be placed in a labeled plastic bag or 35-mm film container.

The cross-linked chain may be pictured as shown here:



The following word equation describes the reaction:

polyvinyl acetate + sodium borate → cross-linked polyvinyl acetate

3. Discussing the answers to the questions on the polymerization experiment

When the groups finish, remind them that they are again examining a chemical change. Tell them that you are very interested in evidence that the reactants are really different from the products. Use the following suggested answers to the questions on Student Book page B-56 as guidelines for your discussion of the chemical change that occurs in the polymerization of polyvinyl acetate. Expected results are shown in the table below.

Question 1: How is the material you made different from the white glue?

The material is solid, bouncy, and not sticky.

Question 2: The synthesis of a polymer involves a chemical change. What evidence do you have that a chemical change occurred?

There was a change in temperature; the mixture became cooler. There was a change in physical properties. The viscosity of the polymer is greater than that of the glue—a gummy solid. As polymer molecules are linked together and cross-linked, the material tends to become more viscous, eventually becoming a solid.

Question 3: What could you use this new material for?

The material could be used as a toy, or in any application where flexibility without regard to strength or rigidity is required. Try to elicit imaginative uses from students. If they take the material home, have students ask their parents this question and share responses during the next class session.

Question 4: What physical properties would you like to change in the material? Why?

List all responses on the board. Have the class discuss how they might go about changing the physical properties. Suggest that this might happen when the polymer is mixed with other materials or when it is chemically reacted to form another new material.

Comparing Reactants and Products of the Cross-Linking of a Polymer Reaction

Properties of Reactants		Properties of Product
White glue	**Sodium borate**	**New polymer**
slightly viscous, opaque white liquid	colorless, clear solution	opaque white solid; bounce; stretches greatly when pulled slowly; not as sticky as glue

Show the class the piece of PVC pipe that you have on display. Stress how the polymer synthesized in this activity is like the softer PVC strips used in the last activity. Tell students that tomorrow they will do another experiment to investigate how the flexible cross-linked polymer they produced can be changed into a rigid polymer like the PVC pipe used for farm irrigation and household purposes.

■ DAY TWO

4. Compounding the polymer

Review with the class how monomers combine to make polymers with new properties. Today students will see how polymers may be combined with other materials to produce plastic products with "designer" properties. In this case, students will see how their flexible white glue polymer can be changed to a more rigid form (see the Background Information).

Have students open their Student Books to page B-57, "Designing a Material to Meet a Need." Review the Procedure with students. Provide for disposal of the polymer, or provide a way for students to take the polymer home to share with parents. Remind students that it is important not to spill any glue and to quickly clean up any accidents!

5. Discussing differences between the polymer and the compounded polymer

After students have carried out the activity and cleaned up, prepare a sample data table on the board, following the model of the table below. Review similarities and differences between the original polymer and the compounded one.

Now discuss what happened when one of the ingredients—either calcium carbonate or starch—was left out. Contrast the properties of the different products. Emphasize again that most polymers are compounded to suit different needs. They are truly "designer" materials.

Tell the students that as a pure polymer, PVC is clear and not very flexible. Even the PVC strip students used in class was compounded by mixing PVC resin with a plasticizer to make it more flexible. Develop the idea that compounding a flexible polymer can increase its strength and resistance to environmental forces such as mold, ultraviolet light, and corrosion. If placed underground, PVC pipe is practically indestructible. However, it quickly becomes brittle when exposed to sunlight and temperature changes.

6. Summarizing the Activity

Remind students of the difference between a monomer, a polymer, and a cross-linked polymer.

Comparing Reactants and Products of a Compounded Polymer

Properties of Reactants		Properties of Product
White glue + calcium carbonate and starch	Sodium borate	New compounded polymer
very viscous, opaque white liquid	colorless, clear solution	opaque white solid; less bouncy and more solid; stretches poorly; less sticky

Ask the class for their definitions. *Polymerization* is actually the synthesis of a new molecule. Stress that to *synthesize* something means to bring together or blend properties, materials, or ideas into a new creation. Emphasize the terms *reactant* and *product*. Ask students to contrast the properties of the *reactants* (liquids that are clear and of low viscosity) to the *products* (viscous, cloudy, semisolid). Ask, ***What proof do you have that an actual chemical reaction has taken place and that you have synthesized something new? How does the addition of another polymer affect the properties of the original polymer? Why might it be advantageous to compound PVC?***

EXTENSIONS

You can demonstrate the solidification of epoxy glue, silicone sealer, and butyl caulking compound. Spread these on aluminum foil and allow the polymerizations to happen overnight. Have the class observe the properties of the products compared to reactants.

The history of the development of plastics is fascinating. Consider suggesting that interested students explore this as a library research project.

Name ______________________ Date ______________

Some Common Plastics and Synthetic Fibers

Plastic name	Some common or trade names	Some uses
acrylic	Acrylan, Orlon	sweaters, carpets
cellulose acetate	Tenite, Chromspun, Celera	toys, plastic forks, double knits, curtains
nylon	Cantrece, Antron	clothing, carpets
polyacrylic acid	acrylic paint	cars, homes, art
polyacrylonitrile	Orlon, Acrilan	clothing fabrics
polybutadiene	Buna S, rubber	automobile tires
polycarbonate	Lexan, Merlon	football helmets
polyethylene	polythene, Alathon	sleeping bags, electrical insulation
polyethylene terephthalate (polyester)	Mylar, Dacron, PET, Avisco, Jetspun, Zantrel	soda bottles, photographic film, audio tapes, clothing fabrics
polymethacrylate	Lucite, Plexiglass	aircraft windshields
polypropylene	Herculon, Vectra	luggage, fabrics
polystyrene	Styrofoam	hot cups, videocassettes
polytetrafluoro ethylene	Teflon	stainproof coating on upholstery, cooking utensils
polyurethane	foam rubber	sofa cushions
polyvinyl acetate	Vinylite	chewing gum, adhesives
polyvinyl chloride	P.V.C., Naugahyde, Koroseal	raincoats, drain pipes, phonograph records
polyvinylidene chloride	Saran wrap	food wrapping
silicone	RTV 615, Silastic	water-repellent coatings, lubricants
spandex	Lycra, Spandelle	elastic waistbands, ski pants
viscose rayon sheet	cellophane	food wrapping