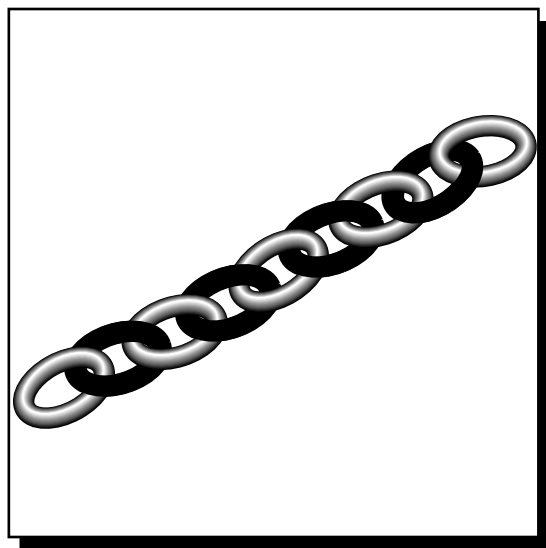


A SourceBook Module

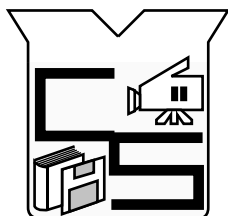
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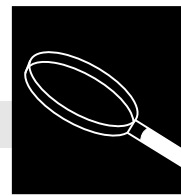
POLYMERS



ChemSource

*Instructional Resources for Preservice and
Inservice Chemistry Teachers*

Topic Overview



CONTENT IN A NUTSHELL

History is often described in terms of the materials employed in making useful items—the Stone Age, the Bronze Age, and the Iron Age. The 20th century is appropriately known as the Polymer Age, since most items we use daily are made from polymers.

Natural polymers have existed since the beginning of life itself—polymers such as DNA, RNA, proteins, cellulose, and starch. Over two thousand years ago, the Chinese developed paper making; Central American natives learned how to make rubber balls from the juice of certain trees. In the 1800s scientists and inventors began to convert natural polymers into products with useful properties. Charles Goodyear learned how to vulcanize rubber; Christian Schonbein changed cellulose into nitrocellulose; John Hyatt made celluloid from nitrocellulose and camphor; Louis Chardonnet produced artificial silk from nitrocellulose.

Large-scale production of purely synthetic polymers began in 1909 when Leo Baekeland developed the phenolic resin he called Bakelite. The polymer industry grew exponentially, and today it is almost impossible to list all the various polymers available. In the 1920s, the term “plastics” was used to describe these new materials. It is estimated that 75% of all chemists working today are in some field of polymers and plastics.

Simply described, polymers are giant molecules made up of long chains of repeating units. *Poly* means “many” and *mer* means “part.” All polymers are made from small units, called **monomers**, joined in long chains by covalent bonds. For example, polyethylene is made from many ethylene molecules, and polystyrene is made from styrene molecules.

The process of polymerization can proceed in two general ways: addition and condensation, depending upon the types of monomers used. In **addition polymers** (chain-growth polymers), one monomer simply adds to the next, which adds to another, and another, *etc.* Chains of polyethylene can have 10,000-20,000 ethylene units. In **condensation polymers** (step-growth polymers), two different monomers are joined together with the elimination of a small molecule, like water. Nylon and polyester are examples of condensation polymers.

If the polymer chains are cross-linked, the product will usually be much more rigid and resistant to heat. **Thermoplastic polymers** can be heated and remolded many times, and **thermoset polymers** cannot be remolded once they have been originally shaped because they are cross-linked. Heat does not soften thermosets; they simply char if exposed to flame. Polyethylene and nylon are thermoplastics; Formica™ counter tops and epoxy putty are thermosets. Toothbrush handles are made of a thermoplastic polymer, while handles of kitchen utensils are fabricated from thermoset polymers.

PLACE IN THE CURRICULUM

This is an enrichment module. The material could be presented in conjunction with a unit on organic chemistry.

CENTRAL CONCEPTS

1. **Polymers** are large molecules made up of long chains of repeating units called **monomers**.
2. The monomers are held together by covalent bonds.

3. Polymers are formed by two general types of reactions, addition (chain-growth polymers) and condensation (step-growth polymers).
4. Natural polymers include rubber, cellulose, starch, DNA, proteins, *etc.*
5. The physical properties of polymers are affected by cross-linking; therefore, thermoplastic and thermoset polymers have different physical properties.
6. We live in an age of polymers. Most products we use daily are polymers, and would be missed if eliminated. Disposal of some polymers is an environmental concern.

1. Covalent bonding
2. Basic organic chemistry (tetravalent carbon; single, double, and triple bonding; organic compounds containing nitrogen, halogens, and oxygen)
3. Catalysis
4. Hydrogen bonding

1. Writing structural formulas for organic compounds.
2. Good observational skills.
3. Ability to follow directions.

After completing their study of polymers, students should be able to:

1. give the names of common polymers.
2. combine monomers to form addition and condensation polymers.
3. explain the difference between thermoplastic and thermoset polymers, and give examples of both.
4. explain the meaning of cross-linking.
5. discuss the importance of polymers in our lives.
6. discuss problems of solid waste disposal and recycling of polymers.

RELATED CONCEPTS

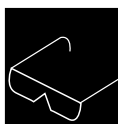
RELATED SKILLS

PERFORMANCE OBJECTIVES

Concept/Skills Development



LABORATORY ACTIVITY: STUDENT VERSION



Activity 1: Thermoplastic and Thermoset Polymers

Introduction

Two general types of polymers and their properties are:

Type	Properties
Thermoplastic	Can be molded and remolded many times, using heat
Thermoset	Once set, cannot be remolded

Thermoplastic polymer chains are not connected to each other, while thermoset polymer chains have numerous cross-links that bond them into rigid networks.

Purpose

To observe properties of a thermoplastic polymer, Friendly Plastic™, and a thermoset polymer, epoxy putty.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Thermoplastic activity: You will be using boiling water; observe normal precautions. Do *not* make a bracelet or ring out of the Friendly Plastic™. Also, do *not* put the plastic in your mouth.
3. Thermoset activity: While working with the epoxy putty, *do not* put your fingers in your mouth or eyes. Clean your hands with rubbing alcohol when finished.

Procedure

Thermoplastic Activity

1. Pour about 300 mL tap water into a 400-mL beaker; bring the water to a boil. Then turn off the burner or hot plate.
2. Hold one end of a strip of Friendly Plastic™, and dip the other end into the hot water until it softens. Keep it away from the sides of the beaker. Remove it from the water and—with *wet* fingers—grasp the softened end (it will not burn you). Dip the other end in the water until it is also softened.
3. Remove the strip from the water bath, and quickly mold the Friendly Plastic™ into a design of your own choosing—*not a bracelet or ring!* If the polymer becomes too hard, dip it in hot water to soften it.
4. Let the material cool on the counter top.
5. Thoroughly wash your hands before leaving the laboratory.

Thermoset Activity

1. Obtain a 2-cm piece of epoxy putty from your teacher. Note that it is composed of two colored components.
2. Knead the putty until the two components are thoroughly mixed.

3. Quickly shape the putty into a design of your choosing.
4. Let the putty harden on a paper towel or piece of plastic bag. Do *not* let the putty harden on the counter top; it may be very difficult to remove.
5. As the putty is hardening, test its temperature with your finger tips. Does the sample change temperature? Describe what you observe.
6. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

1. In your words, describe the differences between thermoplastic and thermoset polymers.
2. List at least ten items of each type of polymer that you have used or seen.

Implications and Applications

1. Which of these two types of polymers could be more readily recycled?
2. In what applications would a thermoset polymer be most desirable?
3. Which polymer type would you choose for:
 - a. Microwave dish
 - b. A plastic bag
 - c. Toothbrush handle
 - d. Child's toy (doll or game)
 - e. Dinnerware



LABORATORY

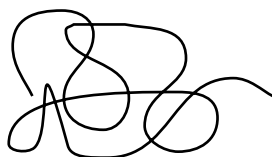
ACTIVITY: TEACHER NOTES

Activity 1: Thermoplastic and Thermoset Polymers

NOTE: Most of these activities require substances that are not normally in school stockrooms. Plan ahead!

Major Chemical Concept

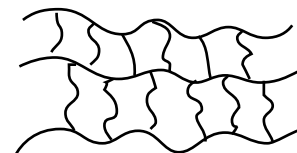
The two general polymer types differ in properties because a thermoplastic polymer has only long, unconnected chains (randomly coiled), while a thermoset polymer has many cross-links, leading to a very rigid structure. Thermoplastic polymers can be heated and molded over and over again; thermoset polymers can be molded only once. Polymer types are shown in Figure 1.



Linear random coil



Branched polymer



Cross-linked polymer

Figure 1. Models of linear random coil, branched, and cross-linked polymers.

Level

Basic/general

Expected Student Background

Students should know:

1. how polymers are formed from monomers.
2. the terms thermoplastic and thermoset.
3. how thermoplastics and thermosets differ in structure.
4. everyday examples of thermoplastics and thermosets.

Time

40-50 min

Safety

Read the *Safety Considerations* in the *Student Version*. Emphasize that students must *not* make bracelets or rings from these polymers, since the plastic will harden and become very difficult to remove. Also, students must *not* put any of the polymers in their mouths because it will stick to metal such as orthodontic braces. Provide rubbing alcohol to clean hands after using the epoxy putty. **CAUTION: Rubbing alcohol is flammable.**

Materials (For 24 students working in pairs)

- 12 Sticks of Friendly Plastic™ (May be obtained in art supply stores or from AMACO Co., Indianapolis.)
- 12 Beakers, 400-mL
- 12 Burners or hot plates
- 1.5 Epoxy putty sticks (approximately 1.4 kg) or any similar product (found in the plumbing section of hardware stores)

Advance Preparation

Cut each epoxy putty stick into 1-in long pieces.

Pre-Laboratory Discussion

Review the structures of thermoplastic and thermoset polymers.

Demonstration

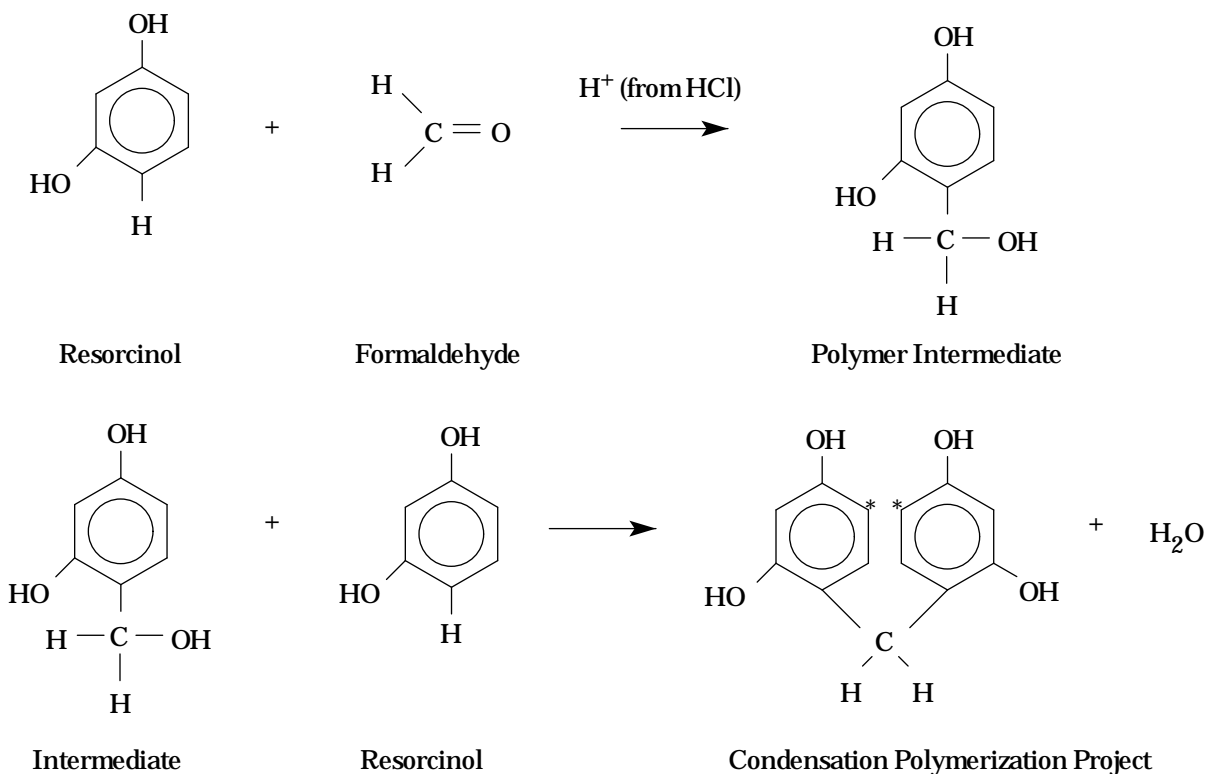
Boil 400 mL water in a 600-mL beaker. Place a clear plastic cup (which is not foam or recycle code #6 plastic) and the handle end of a kitchen tool such as a spatula into the boiling water. Let stand in the boiling water for 2-3 min. Remove the cup with tong and show that it can be molded into a new shape. Then remove the kitchen tool to show that the handle does *not* soften or bend. This represents two types of polymers.

How do the properties of these two kinds of polymers determine their uses? Elicit examples of items in students' homes that would be in each category.

Optional Demonstration

Making a thermoset polymer: *Take care in the use of resorcinol and formalin. Both substances are toxic. Formalin is also an irritant.*

1. Weigh approximately 2 g of resorcinol (1,3-dihydroxybenzene) into a 50-mL beaker. Add 3 mL 37% formaldehyde (formalin).
2. Place the beaker in a water bath; keep the water bath at 50 °C until all the resorcinol has dissolved. Stir while dissolving.
3. Remove the stirring rod; replace with a loop of copper wire.
4. Remove the beaker from the water bath. Add dropwise 6-8 drops concentrated hydrochloric acid, HCl, until a reaction occurs. *Caution: Reaction is very exothermic!*
5. Pull the cooled product from the beaker with the wire. Examine it. Wash hands if you handled the product.





Condensation in this way will continue at the ortho-benzene positions (adjacent to the -OH) to produce long chain-like molecules; reaction at the para-benzene positions (directly opposite the -OH) results in cross-linking of the long chains to yield a rigid thermoset polymer. [These positions are marked with asterisks in the structure.] In commercial processes, the extent of cross-linking can be controlled to suit the requirements of the final product.

Teacher-Student Interaction

Thermoplastic Activity

1. Why is it necessary to heat Friendly Plastic™ in order to shape it? *[To give the polymer chains enough energy to slip and slide over one another.]*
2. Is this an exothermic or endothermic change? *[Endothermic]*
Is this a physical or chemical change? *[Physical]*
3. How many times can this material be remolded? *[Many times, as long as the polymer chains stay intact.]*
4. How could this material be used? *[For art sculptures and in industrial molds as for temporary support for small objects.]*

Thermoset Activity

1. Why are the two epoxy putty components separated? *[To prevent premature reaction.]*
2. Why are two components kneaded? *[Because the reaction will not take place without mixing the components.]*
3. As the epoxy putty sets, does it feel hot or cold? *[Hot]*
4. Is this an exothermic or endothermic reaction? *[Exothermic]* Is it a physical change or chemical reaction? *[Chemical reaction]*
5. Could you remold this material if you do not like the first effort? Explain. *[No. This chemical reaction yields a rigid, new product by cross-linking.]*

Anticipated Student Results

Thermoplastic Activity

Students will be able to mold a piece of low-melting Friendly Plastic™, and discover that it can be molded repeatedly. They should be able to list a number of household items made from thermoplastic polymers, and conclude that thermoplastics are more easily recycled.

Thermoset Activity

Students will be able to mold a piece of epoxy putty and observe that it gives off heat as it sets. They should be able to draw a diagram of the cross-linking process. They should give examples of household items made from thermoset polymers. They should be able to predict what will happen when a thermoset polymer is placed in boiling water.

Answers to Data Analysis and Concept Development

1. Thermoplastics can be repeatedly molded, but thermosets cannot (see Figure 1 for molecular-scale models).
2. Items made of polyethylene, nylon, polyester, polyvinyl chloride, polystyrene are thermoplastics. Examples include clothing, and plastic packaging material, such as bottles and bags. Thermosets are used in bowling balls, Formica™ table tops, auto body parts, and kitchen utensils.

Answers to Implications and Applications

1. Thermoplastic polymers can be recycled; all that is necessary is to melt them again. (You should point out that polymers have to be *sorted*, however, and that the plastics industry has initiated a voluntary labeling program for all thermoplastics. See *Appendix* for plastic bottles codes.)
2. Where strength and heat resistance are important.
3. (a) Thermoset; (b) Thermoplastic; (c) Thermoplastic; (d) Thermoplastic; (e) Thermoset

Post-Laboratory Activities

1. Students may have made jewelry items (pendants or earrings) from the Friendly Plastic™. Holes can easily be drilled in this material. Try drilling a hole in a piece of Friendly Plastic™; compare with drilling a hole in Epoxy Putty. Is there any difference?
2. Both polymer types can be painted with acrylic paints or permanent colored markers.

Extensions

1. Test the flammability of a small piece of Friendly Plastic™. [*It is flammable, but it melts first.*]
2. Test the resistance of epoxy putty to a burner flame. [*It is nonflammable. It doesn't melt; it chars.*]
3. How does environmental temperature affect the epoxy putty's setting time? This is a good homework activity to test student observations. Have students observe the sample in a freezer, a refrigerator, at room temperature, and in a warm incubator. Also, try to set it under water.

Assessing Laboratory Learning

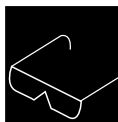
1. Draw "pictures in the mind" of how polymer chains in the Friendly Plastic™ look before and after being molded. Imagine spaghetti (see Figure 1).
2. Draw "pictures in the mind" of how the polymer chains in the epoxy putty might look, both before and after molding. Imagine "floppy" ladders (see Figure 1).

References

- Thermoset polymer demonstration: Ferguson, Schmuckler, Caro, and Siegelman. (1973). *Laboratory Investigations in Chemistry*, Teacher's Edition. Silver Burdett. (Also contains information on variations in the activity.)
- Epoxy molecular structure: *Encyclopedia of Science and Technology*, Vol. 10. (1974). New York, NY: McGraw-Hill.



**LABORATORY
ACTIVITY:
STUDENT
VERSION**



***Activity 2: Preparation and Properties
of a Cross-Linking Polymer***

Introduction

Solutions of the polymer polyvinyl alcohol (PVA) and polyvinyl acetate can be made into gels by addition of a borax solution. Borax cross-links the polymer chains. In this activity you will investigate interesting properties of gels. “Slime” is a polyvinyl alcohol polymer. “Gluep” is a polyvinyl acetate polymer. Your teacher will indicate which you will prepare.

Purpose

To observe the effects of cross-linking polyvinyl alcohol and polyvinyl acetate chains with borax. (*OPTIONAL: To observe the reversal of the cross-linking process.*)

Safety

1. Wear protective goggles throughout the laboratory activity.
2. The polyvinyl alcohol and borax solutions are nontoxic, but wash your hands when finished. Keep the gel in a plastic bag; keep off clothes and carpets.

Procedure

Part I. Making “Slime”

1. Obtain 20 mL PVA solution in a disposable cup.
2. Obtain a wooden stirring stick—a glass stirring rod does not work as well—and stir the PVA solution. Note its viscosity. Is it more or less viscous than water?
3. If desired, add one drop food color to the PVA. Stir well.
4. Measure 5 mL borax solution in a 10-mL graduated cylinder, or use a plastic teaspoon, which holds approximately 5 mL.
5. Pour the borax solution into the PVA. Stir vigorously until the gelling is complete.
6. Scrape the gel into your hands. Pat and knead it thoroughly to completely mix the components.
7. Test its properties as directed by your teacher (density, viscosity, malleability, resistance to pressure).
8. Take the sample home in a zip-closure plastic bag.
9. Thoroughly wash your hands before leaving the laboratory and each time you handle “slime.”

Alternate Part I. Making “Gluep”

1. Mix white glue 50:50 with water. Stir well. (Your teacher may have done this.)
2. Measure two tablespoons (30 mL) glue mixture into a cup.
3. Add color and stir well with a stick.
4. Add two teaspoons (10 mL) borax solution and stir vigorously. (The “gluep” will cling around the stick and can be pulled out, usually in one blob, without much being left in the cup.)

5. Knead the “gluep” well, and observe its properties as before and compare to properties of slime.
6. Store “gluep” in a tightly sealed zip-closure bag. Throw away when it gets moldy.
7. Thoroughly wash your hands before leaving the laboratory and each time you handle “gluep.”

Part I. Implications and Applications

1. Is covalent or hydrogen bonding responsible for the cross-linking?
2. Why is borax $[B(OH)_4]^-$ is the active ingredient], an effective cross-linker?
3. Draw a representation of the polymer chains:
 - a. before cross-linking.
 - b. after cross-linking.

(Be sure to include some water molecules in your drawing; after all, both solutions are 96% water!)

Part II (Optional). Effect of Acid and Base on “Slime”

8. Place a dime-sized piece of slime on a watch glass or Petri dish. Add 2 M HCl dropwise, stirring well with the stick after each drop. When a change is noticed, record your observations.
9. Add 2 M NaOH dropwise to the same sample, stirring well with the stick after each drop. When a change is noticed, record your observations. (Repeat the procedure, if you wish.)
10. Thoroughly wash your hands before leaving the laboratory.

Part II. Data Analysis and Concept Development

1. How many drops of HCl were necessary to “break the gel?”
2. How many drops of NaOH were required to re-gel the polymer?
3. Write the equation for the reaction of HCl with NaOH.



**LABORATORY
ACTIVITY:
TEACHER
NOTES**

***Activity 2: Preparation and Properties
of a Cross-Linking Polymer***

Major Chemical Concept

Borax (sodium borate, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) can be used to cross-link chains of polyvinyl alcohol polymer in water. The resulting network of cross-linked chains produces a gel that traps water molecules. This gel has fascinating properties when handled, squeezed, stirred, poured, or stretched. It can be used to demonstrate acid-base reactions and equilibrium.

Level

Appropriate for students at basic, general and honors levels.

Expected Student Background

Students should know:

1. how polymers are formed from monomers.
2. the functional organic alcohol group, $-\text{OH}$.
3. the concept of hydrogen bonding.

Optional:

4. acid-base reactions.
5. the concept of equilibrium,

Time

40-50 min

Safety

Read the *Safety Considerations* in the *Student Version*. The polyvinyl alcohol (PVA) solution, borax solution and gel are not toxic. However, students should be cautioned not to make a mess with the gel and not to let young children play with it. Mention that if the gel develops mold, it should be discarded.

Materials (For 24 students working in pairs)

Making "Slime"

- 4% Polyvinyl alcohol, PVA, 240 mL (see *Advance Preparation*)
- 4% Borax, 100 mL (4.0 g household Borax diluted to 100 mL)
- 12 Plastic or paper cups
- 12 Plastic teaspoons or 10-mL graduated cylinders
- 12 Popsicle sticks or tongue depressors
- Food coloring
- 24 Zip-closure plastic bags
- 12 Graduated cylinders, 50-mL
- 12 Watch glasses or Petri dishes

Making "Gluep"

- Elmer's™ (or any other white) glue, 200 mL
- 4% Borax, 100 mL (4.0 g household Borax diluted to 100 mL)
- Food coloring or tempera colors
- 12 Stir sticks (craft sticks)
- 12 Plastic or paper cups, 6 or 10 oz.
- 24 Zip-closure plastic bags
- 12 Teaspoon measures
- 12 Tablespoon measures

Effect of Acid and Base on PVA (Optional)

2 M Hydrochloric acid, HCl, 100 mL (16 mL conc. HCl diluted to 100 mL)

2 M Sodium hydroxide, NaOH, 100 mL (8 g NaOH per 100 mL solution)

Advance Preparation
For “Slime”

PVA Solution: Use 99% hydrolyzed polyvinyl alcohol powder. (Can be ordered from Fisher 91-92 EK 153 9709.) To prepare a 4% solution, weigh 40 g 99% hydrolyzed polyvinyl alcohol. Gradually heat one liter of tap water. When it reaches 40-50 °C, gently sprinkle the powder into the water while constantly stirring (or use a magnetic stirrer). Keep heating gently and stirring until about 95 °C is reached; do not overheat or allow to boil. The solution will look cloudy until it reaches 85-90 °C; then it will clear. Remove from heat; cover with aluminum foil, and allow to cool overnight. Store in plastic bottles. It will keep for a long time.

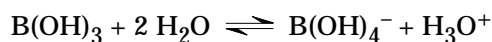
For “Gluep”

50:50 Glue Solution: To make 50:50 glue solution, empty the bottle of glue into a container, letting it drain well. Then fill the glue bottle with water, shake, and empty into the container. (It is easier to make this ahead of time than to have students prepare the solution.)

Prepare other solutions in advance as well. A mixture of liquid starch and glue also works, but you need to determine the appropriate amounts of each by trial and error.

Pre-Laboratory Discussion

Show students the dry PVA powder and the 4% Borax solution. Demonstrate the solution’s viscosity by pouring from one beaker to another. Explain how PVA and borax solutions were made. Show the structural formula of polymer chains and borate ion. In water, the borax hydrolyzes to form a borate-boric acid buffer system:



The B(OH)_4^- ion is believed to cross-link the polymer chains as shown in Figure 2.

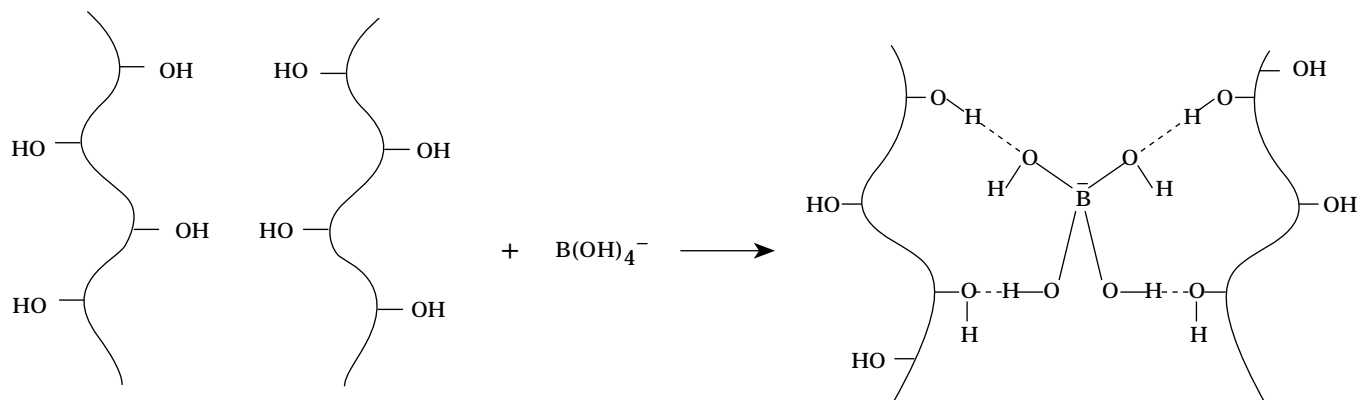


Figure 2. Structure of “slime”

Demonstration: “People-Polymers”

1. Arrange four students in a line holding hands; put four other students in a second line behind the first line. These represent the PVA chains. Can they move freely?



2. Ask two other students to walk between the lines, and take hold of a student on each side. These students represent the borate ions. Can the PVA chains move freely now? If there were water molecules between the chains, what would happen to them? (They would be trapped in a three-dimensional network, which we call a gel.)

Teacher-Student Interaction

Part I

1. Why is PVA solution so viscous? [*Because long polymer chains cannot move freely.*]
2. Try to imagine the many long chains of molecules, being pushed around as you stir it. It is sort of like a bucket full of eels.
3. After the cross-linking, why does the gel have to be kneaded thoroughly? [*To provide complete mixing.*]
4. How is the gel like a liquid? [*It flows, has no definite structure, takes any shape.*] How is it like a solid? [*It can be broken with a sharp pull; it bounces.*]
5. Be sure students understand what was seen: PVA chains cross-link with the $\text{B}(\text{OH})_4^-$ ion, forming a gel that traps water molecules.

Part II

6. Why does acid destroy the properties of the gel? [*Hydronium ions break hydrogen bonds between chains.*]
7. How have the properties changed after addition of NaOH? [*It again becomes a gel—stretches, bounces, drips.*]
8. Why does base restore the gel's properties? [*It neutralizes hydronium ions, permitting cross-linking to reoccur.*]

Anticipated Student Results

Students produce a gel (colorful—if food coloring has been added) that has interesting properties: it can be dripped, stretched, patted, rolled into a ball, bounced on a *clean* surface, *etc.* Students should be expected to observe these properties and record them. Students will notice how rapidly the cross-linking takes place. Encourage them to ask the question, “If the borax solution is diluted to 1% or 2%, will the gelling occur as fast?” Then try it!

Optional Activity

When one drop of 2 M HCl solution is placed on a dime-sized piece of gel, the gel starts to dissolve in a few seconds. Adding one or two drops of 2 M NaOH solution restores the original properties of the gel.

Answers to Part I. Implications and Applications

1. Cross-linking occurs by hydrogen bonding, not covalent bonding.
2. Because $-\text{OH}$ groups of the borate ion can hydrogen bond with $-\text{OH}$ groups of PVA polymer chains (see Figure 3). Hydrogen bonding is so weak that this could account for the ease of stretching and dripping, and the other observed properties.

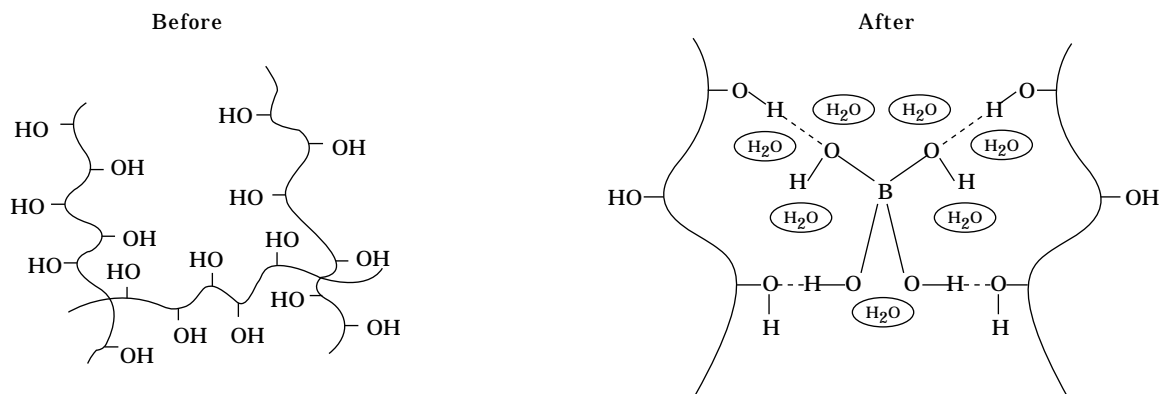


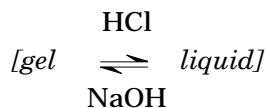
Figure 3. Hydrogen bonding in slime.

Answers to Part II. Data Analysis and Concept Development

1. (Observation)
2. One more drop than drops of HCl
3. $\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{HOH}$

Post-Laboratory Discussion

1. Ask students to list the properties of PVA solution before and after gelling. [Before gelling: syrupy, liquid. After gelling: if pulled suddenly will break, malleable, semi-solid.]
2. How does hydrogen bonding explain the gel's properties (that is, how it can be squeezed, dripped, stretched, etc.)? [Hydrogen bonds can be more easily broken and reformed; covalent bonds are too strong to cause these properties.]
3. How do you explain the effect of HCl and NaOH, in terms of equilibrium?



4. Can you think of other uses for the gel other than a toy? [Special effects in motion pictures, e.g. people's faces melting in "Raiders of the Lost Ark."]

Extensions

1. Allow some gel to dry in air, and observe its properties [becomes brittle and curls around the edge]. Can it be rehydrated? [No]
2. Let students color some clear gel with fluorescent highlighter pens. Then observe under ultraviolet light. (CAUTION: Protect eyes from ultraviolet light!). [Glows brilliantly!]
3. Try using 2% PVA solution and 2% borax solution (or other proportions). [No satisfactory gel is formed.]
4. Will other acids and bases have the same effect as HCl and NaOH? [Yes]

Assessing Laboratory Learning

1. Draw "pictures in the mind" of the polymer before and after gelling. Include some water molecules in your picture.



2. Describe the viscosity of the PVA solution before and after gelling. [*Higher after gelling.*] Can it still be poured? [*Yes. It will run through the funnel.*]
3. In this activity, why is it not critical to use “exactly” 20 mL of PVA solution and “exactly” 4 mL of the borax solution? Why is it important in other activities to be *very exact* in your measurements? [*The extent of cross-linking depends on the amount of borax. The properties of “slime” depend on varying the number of cross-links.*]

References

- Casassa, E. Z., Sarquis, A. M., and Van Dyke, C. H. (1986). The gelation of polyvinyl alcohol with borax. *Journal of Chemical Education*, 63, 57.
- Sarquis, A. M. (1986). Dramatization of polymeric bonding using slime. *Journal of Chemical Education*, 63, 60.
- CHEM FAX. Polyvinyl alcohol, preparation of a 4% solution for the ‘slime’ activity. Flinn Scientific. (131 Flinn Street, Batavia, IL 60510. Call (708) 879-6900 to be put on their mailing list.)

DEMONSTRATIONS

Caution: Use appropriate safety guidelines in performing demonstrations.

Demonstration 1: Making Nylon Rope

Purpose

To prepare a condensation polymer and demonstrate how it grows.

Safety

Do not let any reagent touch skin. Sodium hydroxide is caustic and causes burns. This demonstration should be performed in well-ventilated areas.

Materials

NOTE: All of these solutions may be purchased from Flinn Scientific or other suppliers. Because of difficulty in preparation these commercial solutions should be used.

5% Hexamethylenediamine (1,6-hexanediamine); 5 mL hexamethylenediamine in 95 mL H₂O

20% Sodium hydroxide solution (NaOH); 20 g NaOH in 80 mL H₂O

4% Sebacyl chloride in hexane (or 5% adipoyl chloride in cyclohexane); 4 g sebacyl chloride in 96 mL hexane

Beaker, 50-mL

Procedure

Pour 10 mL 5% aqueous hexamethylenediamine (1,6-hexanediamine) into a 50-mL beaker. Add 10 drops 20% NaOH. Tilt the beaker and carefully pour 10 mL 4% sebacyl chloride down the side of the beaker. Two layers will form with a polymer film between them.

Prepare a 15-cm piece of copper wire with a bend at one end. Hook the polymer film in the center, and raise slowly so nylon forms continuously as a rope. This can be many feet long. Break the rope by pulling faster. Rinse the rope several times with water and dry on a paper towel.

Demonstration 2: Plastic Packaging “Peanuts” in Acetone

Purpose

To illustrate properties of a plastic product.

Materials

Packaging “peanuts”
Acetone

Safety

CAUTION: Acetone is flammable. Acetone use is discouraged for safety reasons; however, some fingernail polish removers contain acetone and may be used, but do not work as well because they are too dilute. Test any solutions before demonstrating.

Procedure

A small volume of acetone softens a very large number of these packaging peanuts because they are air-filled foam. Using a large beaker, add the packaging peanuts to acetone while swirling. You may also soften a Styrofoam™ cup in acetone.

Demonstration 3: Super Slurper

Purpose

To illustrate properties of a plastic product.

Materials

Sodium polyacrylate (Super Slurper™, available from Flinn Scientific Co.)
Table salt (Sodium chloride, NaCl)
Disposable diaper

Procedure

1. Sprinkle about 1/2 teaspoon of the Super Slurper into 1/2 cup water. Observe the reaction. Try to pour it out of the cup. Take out a piece and try to squeeze out the water.
2. Put another piece of the gel into a separate cup and shake some table salt (NaCl) on top. Wait a few minutes and notice the consistency. Salt has a greater affinity for water than does the polymer and can break down the gel.
3. Using the material in a disposable diaper show the properties of this compound. The powder can be removed by cutting the diaper into 10 cm² pieces. Place the pieces in a plastic bag, close the bag and shake out the powder. This powder may then be treated as Super Slurper.

Remarks

Super slurpers, originally produced from starch and acrylonitrile, were invented at the Department of Agriculture Research Laboratory at Peoria, IL; however, the polyacrylate polymer is more efficient.

Demonstration 4: Properties of Natural Polymers

Purpose

To illustrate properties of natural polymers.

Materials

Latex rubber samples (Flinn Scientific)
Vinegar
Water
Petri dish



Safety

Sample is dissolved in ammonia. Smell carefully and do not spill.

Procedure

Pour a small amount of latex into the Petri dish and allow to dry. Notice its elasticity and other properties. Add some latex to water. Have a student cautiously smell the latex and identify the base in which it is dissolved (NH_3). Addition of vinegar will coagulate the rubber. Make a ball with the neutralized latex by pouring a small amount of latex into vinegar and hold product under water while kneading to form a ball.

Demonstration 5: Properties of Polymers

Purpose

To illustrate the properties of polymers.

Materials

Zip-closure plastic bag
Pencils

Procedure

Fill a plastic bag with water and seal. Push very sharp pencils through the bag. You are pushing apart the chains of the polymer as you put in the pencils. Pull out the pencils over a sink, and the water will gush out. Practice first.

Demonstration 6: Making Polyurethane Foam

Purpose

To make a synthetic polymer.

Safety

Isocyanates are toxic. This demonstration must be performed in a well-ventilated area. It is important that hardened foam not be handled for 24 hours to evaporate excess isocyanate. Store in a fume hood.

Materials (Available at a hobby store, from Flinn Scientific, or Edmund Scientific)

Polyether polyol, 50 mL
Poly-functional isocyanate, 50 mL
Container (paper cup, beaker or flat bottomed ice cream cone)
Wooden stir stick

Procedure

Mix equal volumes of the two components; stir well with wooden stirrer. As the reaction occurs, carbon dioxide gas is released and makes the polymer rise. The two reactants may be mixed in a beaker, a paper cup, or in a flat bottomed ice cream cone. This exothermic reaction illustrates the formation of a rigid, cross-linked material.

Demonstration 7: Polymers Have Different Directions

Purpose

To study the properties of polymers.

Materials

Tinted plastic bags
Polarized sheets
Overhead projector
Saran™ wrap

Procedure

Using tinted plastic bags show that polymers have different directions. Look through bags in a strong light. Cut rectangular strips lengthwise and crosswise. Stretch slowly and observe the different ways they separate. Stretch kitchen wrap (other than Saran™ wrap) between polarized sheets on an overhead projector. Notice the colors produced. Test the cellophane from cigarette packages in the same manner.

Demonstration 8: “Moon Blob”

Purpose

To illustrate the properties of a synthetic polymer.

Materials

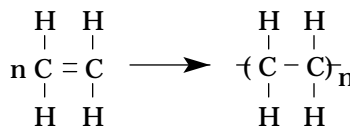
“Moon Blob” (Edmund Scientific, Barrington, NJ; (609) 573-6250)
Beakers

Procedure

Mix dry powder with specified amount of water. Mix thoroughly. Pour the “Moon Blob” (polyethylene oxide) slowly from one beaker to another and note its properties. It will not break apart.

Key Questions

1. Name some natural polymers. [*Cellulose, proteins, rubber, starch*]
2. Name some synthetic polymers. [*Nylon, orlon, rayon, dacron, etc.*]
3. What is a condensation (step-growth) polymer? Write an equation for the formation of a condensation polymer. [*A polymer formed from two different monomers that are joined together with the elimination of a small molecule. Nylon is a condensation polymer.*]
4. What is an addition (chain-growth) polymer? Write an equation for the formation of an addition polymer. [*A polymer formed from the addition of one monomer to another monomer without the loss of atoms. Polyethylene is an addition polymer formed as follows:*]



5. Describe crosslinking. What is the difference between the bonds formed in crosslinking and those formed in polymer synthesis? [*A process that makes a polymer more rigid and resistant to heat. As shown in Figure 3, the cross-links in slime are hydrogen bonds. In the case of butadiene, the vulcanization process with sulfur cross-links the polybutadiene chains with covalent bonds as shown in Figure 4. (See also Group Discussion—additional suggestions about vulcanization.)*]

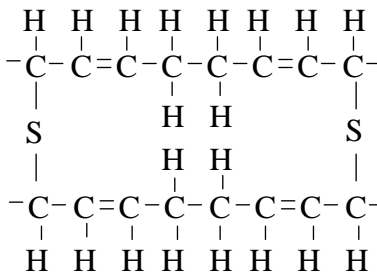


Figure 4. Vulcanized rubber.

6. What is the difference between thermoset and thermoplastic polymers? [*A thermoset polymer cannot be remolded; a thermoplastic polymer can be heated and remolded.*]

GROUP AND DISCUSSION ACTIVITIES



Counterintuitive Examples and Common Student Misconceptions

1. **“All polymers are products of chemical industries.”**

Rubber, starch, cellulose, proteins, and fibers like cotton and linen are all examples of natural polymers. These products are made in nature by chemical reactions.

2. **“All polymers are the same substance.”**

Compare the reaction of a polystyrene and a polyethylene cup to heat. Even all plastic kitchen wraps are not the same.

3. **“Automobiles are mostly metal.”**

In order to reduce mass and increase strength, modern automobiles contain a large proportion of polymeric materials in bumpers, steering wheels, upholstery, tires, windshields, paint, adhesives, *etc.* Some auto bodies, such as the Corvette™, are constructed of fiberglass.

4. **“Paper degrades under all conditions.”**

In landfills, where paper is covered by other waste, paper degrades very slowly. Urban archaeologists can date portions of landfills by noting the dates on newspapers and telephone books buried there.

5. **“Some plastic garbage bags are degradable.”**

“Biodegradable” bags contain cornstarch. Microorganisms can break down the bags into small pieces that degrade more quickly. However, landfills do not have the right conditions for this to occur, and the time required for degradation is many years.

Metaphors and Analogies

1. Polymers may be pictured as paper clip “chains,” pop beads, or coupled freight train cars. Draw polymers starting with monomers, then chains, then cross-linked chains.
2. Play the polymer game. Have five to ten students form a line, standing about one arm’s length apart with hands clasped in front of their chests. Each student represents an ethylene molecule. Act as the initiator, using a chalkboard eraser to represent a free radical. Unclasp the hands of a student on one end of the line (break the double bond), and hand the student the eraser. The student’s free hand represents an unpaired electron, and the student now represents a free radical. This student unclasps the hands of the next student holding the closer hand and causing the second student to have an “unpaired electron.” The chain is terminated by placing another eraser in the hand of the student on the other end [See Tarazona, M. P., and Satz, E. (1990). Happy polymer party. *Journal of Chemical Education*, 64, 238.]
3. Magnetic marbles on the overhead are a good illustration of chain formation. Pop beads may also be used.

Pictures in the Mind

Polymers may be pictured using analogies such as paper clip “chains,” pop beads, or coupled freight train cars.

Group Discussion

This module lends itself well to discussion activities. Students could bring samples of plastics and discuss their uses (*e.g.*, empty margarine bowls, 2-L pop bottles, 1-gal milk containers, caulking compounds, insulation, super glue). They might discuss their daily life without plastic products. (See also introductory activity in *Appendix*.)

The problem of solid waste disposal and recycling could be discussed. Current periodicals are excellent sources of information. Students can prepare posters, give group reports or write papers to coordinate with Writing Across the Curriculum program (see *References* for sources of information or consult the school librarian).

Additional suggestions for discussion and research:

1. What are the advantages and disadvantages of using plastic containers rather than paper, metal or glass containers?
2. Consult local newspapers and discuss your community's efforts to recycle plastics and other materials.
3. General Electric Company has made a polyethylene plastic ice rink. After consulting magazine articles, comment on the use of this material and how it has changed hockey.
4. How did AstroTurf™ change football?
5. Canoes made of Kevlar™ are very lightweight and strong. Discuss these with a local dealer and give a class report.
6. What are the advantages and disadvantages of using polyester or rayon blends as clothing?
7. Discuss the uses of plastics in medicine. Examples include pacemaker and hearing aid cases, balloons in angioplasty, replacement joints, and plastic surgery implants.
8. Vulcanization is the treatment of rubber with sulfur in the presence of a catalyst. Compare the properties of natural rubber, vulcanized rubber and synthetic rubber. Are tires made of natural rubber now? If not, why not? Natural rubber is *cis*-poly(1,3-butadiene), isoprene. The *trans* form produces gutta-percha, a harder, more brittle compound. Both are extracted from trees. Some synthetic rubber is also polyisoprene, but neoprene is 2-chloro-1,3-butadiene polymer. In vulcanization, sulfur forms cross-links between polymer chains to make the natural or synthetic rubber harder.
9. Discuss water absorbing polymers such as polyacrylamide, which is a soil additive, and polyacrylate, which is used in diapers.
10. Nylon was first used as a material for toothbrushes, and soon revolutionized the hosiery industry. During World War II, the U. S. government reserved all nylon for the war effort to make parachutes. Nylon hosiery was introduced at the New York World's Fair in 1939, but was not manufactured again until 1946.
11. Recycled plastics are used to make "bricks" for use in gardens and parks, and for benches in public areas. Identify parks or playgrounds in your community containing these plastic products. These products are more likely to be used outside because of the danger of harmful emissions being released during a fire.



TIPS FOR THE TEACHER

Language of Chemistry

1. Glossary

addition polymer (chain growth polymer) polymer made by the addition of one monomer to another without the loss of atoms.

biodegradable capable of being degraded by microorganisms.

condensation polymer (step-growth polymer) polymer in which two different monomers are joined together with the elimination of a small molecule, like water.

cross linking two polymer chains linked together by bonding.

gel semi-rigid colloidal dispersion of a solid in a liquid.

monomer small unit making up polymers.

polyfunctional containing more than one functional group.

polymer large molecule made up of repeating units called monomers.

thermoplastic polymer polymer that can be heated and remolded many times.

thermoset polymer polymer that cannot be remolded after being shaped.

2. **Polymers** are “giant molecules” formed from repeating units (*poly* = many and *mer* = parts). The individual units are called **monomers**; thousands of these are linked together to form a polymer molecule. “Giant molecules” have high molecular weight. For example, natural rubber has a molecular weight of 12,000; starch, 40,000; and proteins, 1000-1,000,000.

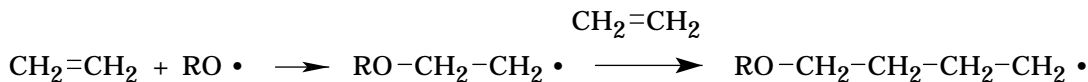
3. **Monomers** are usually made of carbon and hydrogen atoms. Oxygen, halogen, and nitrogen atoms can be present. Typical monomers are ethylene, $\text{CH}_2 = \text{CH}_2$, vinyl chloride, $\text{CH}_2 = \text{CHCl}$, vinyl acetate, $\text{CH}_2 = \text{CHO}_2\text{CCH}_3$.

4. **Addition polymers** are formed by monomers just “adding on” to each other without loss of atoms. All monomers forming addition polymers, have C=C bonds (carbon-carbon double bonds). These double bonds open up as the monomers join in chains 1000 to 10,000 units long. For example, ethylene molecules can join together (under the proper conditions of temperature, pressure, and catalyst) to form polyethylene:

(See structures of monomers and addition polymers in *Appendix*.)

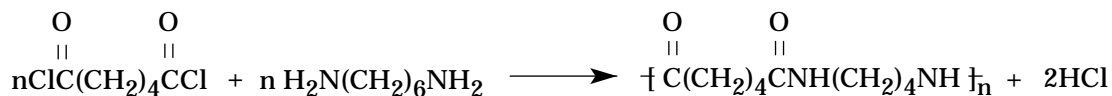
$$n\text{CH}_2=\text{CH}_2 \xrightarrow{\text{O}_2, \text{ heat, pressure}} (\text{CH}_2-\text{CH}_2)_n$$

5. Usually an **initiator** is used to start this polymerization reaction. The initiator is a compound that can form a free radical (a substance that contains an unpaired electron). When free radicals react with a double bond, a chain reaction occurs, which could theoretically continue as long as there is monomer material present. In the equation below, **RO•** is a generalized symbol for a free radical initiator.



Other addition polymers include polymethyl methacrylate (Lucite™ or Plexiglass™), Teflon™, polyvinyl alcohol, polystyrene, polyvinyl chloride (PVC), polyacrylonitrile (Orlon™), and natural rubber (see *Appendix*).

6. **Condensation polymers** are formed when the monomers react with each other so that a small molecule, such as H_2O or HCl , is eliminated as a product each time a monomer reacts with another monomer. The formation of Nylon and Dacron are shown.



Nylon



Dacron

There must be at least two functional groups on each reacting monomer in order for the reaction to continue to form a chain. After each elimination, reacting groups are available for additional condensations. Other examples of condensation polymers are polyurethane foam, epoxy glue, peptides and proteins (see table in *Appendix*).

7. Polymers are produced as long chains that sometimes have connections between them. If the chains are *not* connected to one another, the polymer typically can be melted and reshaped repeatedly. These polymers are called **thermoplastics**. Examples are polyethylene, nylon, polyester, polyvinyl chloride, and polystyrene. If the long chains are joined together with cross-links, the material becomes extremely rigid; once formed, these polymers do not soften or melt when heated. These polymers are **thermosets**. Examples are the plastics used to manufacture bowling balls, handles on kitchen utensils, Formica™ table tops, and some auto bodies.

Pattern Recognition

“Polymers are everywhere.” Recognize the importance of polymers to chemical industry (see *Appendix—A List of Common Polymer Products*).

Problem Solving

1. Have students write equations for formation of polymers using unfamiliar monomers (see *Appendix—Polymers from Monomers*).
2. Ask students to determine the number and kind of monomer units from the structural formula of a polymer.

Decision Making

1. List five polymer items used each week that could be made from other materials. Would you be willing to give up these polymer items for a substitute? Would the substitute last longer, be cheaper, be easier to dispose of than polymers? Consider these and other aspects before deciding.
2. Brainstorm ways to persuade your community to recycle plastics. What incentives would be necessary? What collection methods could be used? Propose a stepwise plan to carry out your ideas. Ask a grocery store to help recycle bags. Meet with a local fast food restaurant representative to discuss its plans for recycling.



HISTORY: ON THE HUMAN SIDE

The history of polymers provides some excellent examples of serendipity. When Goodyear allowed a mixture of rubber and sulfur to touch a hot stove, he was surprised that it did not melt, but charred. Vulcanization was invented. The synthetic rubbers Neoprene and Thiocol were discovered accidentally. The usefulness of nylon fibers was discovered because chemists were trying to see how far they could stretch a ball of this new synthetic substance.

In his search for a nontoxic refrigerant, R. J. Plunkett of duPont opened a cylinder of tetrafluoroethylene, but no gas came out. Because the weight of the tank showed there was something inside, he sawed the tank open and found a white powder with inert properties. He discovered that the tank valve was the material that catalyzed polymerization of the gas to form the useful product Teflon™. It should be noted, however, that these serendipitous discoveries were made by scientists who were interested in these compounds and could recognize the conditions under which they were produced. It is true that “chance favors the prepared mind.”

Wallace Hume Carothers (1896-1937) was the person primarily responsible for the development of nylon. This Iowa youth was fascinated by tools and mechanical devices. In 1915, he entered Tarkio College (Missouri) and excelled in chemistry, and became a chemistry instructor before he graduated. Eventually Carothers attended the University of Illinois where he completed his Ph.D. in organic chemistry in 1924 and was appointed to the faculty. In 1926, he moved to Harvard University but left two years later to join DuPont and participate in a new program of fundamental research. At DuPont, Carothers headed the organic chemistry division and played a prominent role in laying the foundations of polymer chemistry. By the age of 33, he had become world-famous and was the first industrial chemist to be elected to the National Academy of Sciences.

Carothers was a lover of poetry and classical music. Unfortunately, he suffered from severe bouts of depression that finally led to his suicide in a Philadelphia hotel at the age of 41. Despite his early death, Carothers' accomplishments were many, and he is considered one of America's greatest chemists.

I'm into plastics.

HUMOR: ON THE FUN SIDE

1. **CHEMTOON** $\text{CH}_2=\text{CH}_2$
CHEM 13 NEWS, February 1985, p. 5
2. **Message on a bumper sticker:** Polymer chemists do it in chains!
3. **Word Search** (see *Appendix* for master copy)

C	Q	L	N	N	H	I	I	S	H	M	R	D	F	G	B	H
I	K	Y	O	M	R	N	B	P	M	T	L	O	N	P	Q	E
T	S	K	B	L	J	I	H	B	E	H	Q	E	D	R	H	C
\$	R	A	R	T	I	T	T	Q	G	G	J	A	E	V	L	C
A	S	D	A	D	D	I	T	I	O	N	Y	Z	G	I	Y	F
L	Y	R	C	V	I	A	T	I	F	J	L	X	C	X	B	L
P	R	Q	Z	Y	F	T	S	T	E	S	O	M	R	E	H	T
O	U	F	W	P	R	O	T	E	I	N	P	R	E	F	W	A
M	O	N	O	M	E	R	Q	K	P	Q	Q	H	M	R	V	F
R	K	W	S	Q	O	J	O	W	P	X	E	G	Y	P	Y	S
E	R	T	M	G	A	J	A	F	A	Q	J	I	L	N	O	F
H	D	N	N	O	I	T	A	S	N	E	D	N	O	C	K	L
T	W	S	T	D	T	X	P	E	M	A	I	M	P	E	B	U

Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Giant molecule formed from repeating units.
2. Individual unit of which polymers are made.
3. Compound used to start a polymerization reaction.
4. Type of polymer where repeating units "add on" to each other with no loss of atoms.
5. Type of polymer formed with the loss of a small molecule as monomers react.
6. Polymers that do not soften or melt when heated.
7. Polymer that can be melted and reshaped repeatedly.
8. Backbone element of most polymers.
9. Root word meaning "many."
10. Biological condensation polymer where amino acids are the monomers.

Answers: 1. POLYMER 2. MONOMER 3. INITIATOR 4. ADDITION
5. CONDENSATION 6. THERMOSETS 7. THERMOPLASTIC 8. CARBON
9. POLY 10. PROTEIN

4. See cartoons at end of module.

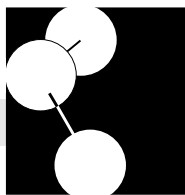
1. The World of Chemistry videotape "Number 22: Polymers." World of Chemistry Videocassettes. Annenberg/CPB Project, P.O. Box 1922, Santa Barbara, CA 93116-1922; (800) 532-7637; World of Chemistry Series, Atlantic Video, 150 South Gordon Street, Alexandria, VA 22304; (703) 823-2800 or QUEUE Educational Video, 338 Commerce Drive, Fairfield, CT 06430; (800) 232-2224.
2. The Plastic Packaging Division of Mobil Chemical Company, 100 North Street, Canandaigua, NY 14424-1089 has two video cassettes on recycling, "Do the Right Thing: RECYCLE" and an interview with William Rathje by Connie Chung.
3. Philip Dail, 1416 Ewing Drive, Garner, NC 27529 has written a computer program on polymers that he will copy and send on request.
4. "Passing Through," informative and entertaining video introduction to plastics chemistry and technology. 27 min. Provided by National Plastics Center & Museum through Newtel Associates, 172 Lincoln Street, Worcester, MA 01605; (508) 791-8403.
5. Software published by *JCE*: Software, a publication of the *Journal of Chemical Education*, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).

Viscosity of Polymer Solutions, by Gary L. Bertrand. Vol. V A, No. 2, for the Apple II computer.

MEDIA



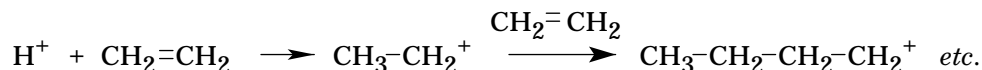
6. Software published by Project SERAPHIM, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 263-2837 (voice) or (608) 262-0381 (FAX).
 - a. For the Apple II computer running on ProDOS: AR 701
 - b. For the Apple II computer: AP 702, AP 705, AP 209
 - c. For IBM PCs and PC-compatibles: PC 3601, PC 4901
7. Videodiscs published by *JCE: Software*, a publication of the *Journal of Chemical Education*, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).
 - a. "From an Amino Acid to a Peptide Chain," "The Alpha Helix," "Hair and Silk," and "DNA Structure, Synthesis of Messenger RNA, Protein Synthesis," four chapters on *The World of Chemistry: Selected Demonstrations and Animations: Disc II* (double sided, 60 min.), Special Issue 4.
 - b. "Polymers," "Carbohydrates," and "Proteins," three chapters on the videodisc *Demonstrations in Organic Chemistry* (double sided, 60 min.), Special Issue 6.



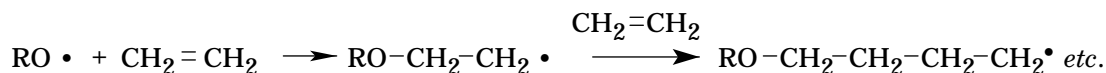
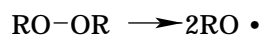
Links/Connections

WITHIN CHEMISTRY

1. **Organic Chemistry.** Addition polymers are formed from monomers that are alkenes. Various condensation polymers are formed from aromatic compounds, acid chloride, carboxylic acids and amines (see *Addition and Condensation Polymers Transparency*).
2. **Biochemistry.** Many molecules important to living systems are polymers; for example, proteins (insulin is a polymer of amino acids), some carbohydrates (glycogen—the storage form of glucose), and the nucleic acids (DNA and RNA, the chemicals of heredity, are polymers of deoxyribose and ribose, respectively, and phosphoric acid).
3. **Catalysts.** Various conditions (temperature, pressure, catalyst) can be used to cause a monomer to polymerize. The catalyst can be one that generates positively charged intermediates—carbocations. A proton-donor can convert ethylene into polyethylene, as shown:

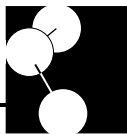


4. **Free Radicals.** Polymerization of alkenes can occur by a free-radical path. The reaction is initiated by O_2 or a peroxide (ROOR), as shown:



1. **Use of Polymers in Medicine.** Dacron (a polyester of exceptional strength) fabrics have been used in surgery to replace or repair blood vessel segments. Nylon, a polyamide, is used in specialized tubing, and as velour for surfaces contacted by blood. Nylon sutures were the first synthetic sutures.
2. **Use of Polymers by Engineers.** Sound engineers store sound on compact discs, long-play records, and magnetic-coated audio- and videotapes that are made of polymers.
3. **Genetic Engineering.** Genetic engineering—controlled production of genetic changes—has made revolutionary advances in agriculture, medicine, and pharmaceutical manufacture. DNA, which carries the genetic information of heredity, is a polymer with repeating sugar and phosphoric acid monomers. Each sugar carries a base and each set of three consecutive bases will code ultimately for an amino acid in a protein (another polymer consisting of amino acid monomers). Scientists can read and synthesize specific genetic messages and have discovered special enzymes that split double-stranded DNA at specific locations. A new gene (with appropriate base triplets) could then be added or spliced to the original DNA and the resulting modified DNA repaired. The DNA—a new polymer—contains a new gene, and therefore, different hereditary information. Insulin, interferon, and human growth hormone have been made by this process.

BETWEEN CHEMISTRY AND OTHER DISCIPLINES

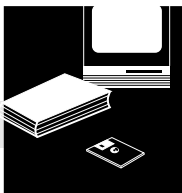


TO THE CONTEMPORARY WORLD

4. **Physical Properties of Polymers.** Polymers are amorphous (noncrystalline) or crystalline. Noncrystalline polymers consist of a tangled mass of continuous chains or branched chains. Soft rubber is a noncrystalline polymer. Crystalline polymers have order and are composed of continuous chains held together by hydrogen bonds or other dipole-dipole attractions. Hard, moldable plastics are crystalline polymers.
5. **Environmental Studies.** Discarded plastic contributes to the garbage problem. Most plastic materials are not biodegradable. However, cornstarch is added to some plastics during manufacture. Bacteria eat the starch and the plastic breaks apart into small pieces. This method reduces the decomposition time from decades to several years.

Some plastics—polyvinyl chloride and polyacrylonitrile—give off poisonous gases such as HCl and HCN when burned. Plastics are recyclable and are identified by codes (see *Plastic Container Code System for Plastic Bottles Transparency*). Such plastics can be separated from other plastics, remelted, and reused.

1. **Personal Use of Polymers** (see *A List of Common Polymer Products Transparency*). “Eco-Foam” is a new water-soluble starch which is now used as a packing material.
2. **Use of Polymers in Construction and Engineering.** Polymers are used to make numerous products that were formerly made of traditional materials like metals. Airplanes, boats, auto parts, chemical process equipment, appliance cabinets, electronic parts, business machine housings, and even caskets are now composed of polymers. Polymers are often lighter than the metal counterpart (less poundage), corrosion resistant (last longer), and parts can be consolidated so that a large complex part can be molded in one piece (rather than fabricated from many separate components, reducing assembly costs). In addition to the polymers, the materials used for these purposes are composites of reinforcing agents (for strength) and additives, such as flame retardants, flexibilizers, low-shrink agents, and pigments.
3. **Future of Polymers.** The raw materials for polymer manufacture come from petroleum and less from coal. These two fossil fuels are the main energy sources in the U.S. Consequently, polymers and energy are linked through these raw materials. Because the amount of these fossil fuels are limited, particularly petroleum, the items made of polymers derived from petroleum may have a limited lifetime.
4. **Field Trips.** Visit a solid waste facility and/or a recycling plant.
5. **Knowledgeable Individuals.** Invite environmentalists and representatives of industries and service organizations who recycle to speak. Invite a representative of your community government to speak on solid waste disposal. Invite an organic chemist or polymer chemist from academia or industry to speak on the chemistry of polymers.



References

Module developed by Jennifer Hubert, Jane A. Miller, and Marie C. Sherman, the Missouri team.

Alper, J. (1986). Polymers. *Chem Matters*, 4(2), 4.

History and current use and development of polymers. Especially focuses on synthetic ivory.

Butler, S., and Molote, S. (1981). Textile chemistry for the artist. *Journal of Chemical Education*, 58(4), 295.

Gives chemistry of textiles, especially fibers and color application, the knowledge of which can be valuable for artists, designers, and weavers.

Carragher, C. E., Jr., Hess, G., and Sperling, L. H. (1987). Polymer nomenclature— or what's in a name? *Journal of Chemical Education*, 64(1), 36.

Concentrates on naming of linear organic polymers. Four major types of names are also discussed: common, source-based, characteristic group, and structure based.

Cassasa, E. Z., Sarquis, A. M., and Van Dyke, C. H. (1986). The gelation of polyvinyl alcohol with borax. *Journal of Chemical Education*, 63(1), 57.

A novel class participation experiment involving the preparation and properties of a "slime."

Chiles, J. R. (1985, November). On land, at sea, and in the air, those polymer invaders are here. *Smithsonian*, 77.

Discusses the pervasiveness of plastics in every facet of our lives.

Cleary, J. (1986). Diapers and polymers. *Journal of Chemical Education*, 63(5), 422.

Illustrates how several polymers have been incorporated into the design of this "essential" product.

Cote, G. (1986). Polysaccharides. *Chem Matters*, 4(2), 12.

Different polysaccharides in food products. Focuses on seaweed polymers.

Deanin, R. D. (1987). The chemistry of plastics. *Journal of Chemical Education*, 64(1), 45.

Chemistry, development, and uses of plastic polymers.

Elliott, E. (1986). *Polymers and people*. Philadelphia, PA: Beckman Center for the History of Chemistry.

Prepared to accompany a travelling exhibit. For more information, contact: Chemical Heritage Foundation Publications, 215 South 34th Street, Philadelphia, PA 19104-6310.

Ihde, J. (1990). Fun audience participation polymerization demonstration. *Journal of Chemical Education*, 67(3), 264.

Several student participation demonstrations illustrating addition polymerization that can be used at primary, secondary, and tertiary levels.

Kirshenbaum, G. S. (1987). Polymer literature for classrooms. *Journal of Chemical Education*, 64(1), 47.

Gives names and addresses of societies and associations with information on different types of polymers.



Kolb, K. E., and Kolb, D. K. (1988). Classroom analogy for addition polymerization. *Journal of College Science Teaching*, 17, 230.

This exercise helps students understand the basic concept of addition polymerization of ethylene-type monomers.

Mark, H. F. (1966). *Life science library: giant molecules*. New York: Time.

The story of polymers, the centuries of progress in chemistry that led to their creation, and the growth of research and production in this area.

Marsella, G. (1986). Silly putty. *Chem Matters*, 4(2), 15.

History, development, and chemistry of polymer now called "silly putty."

Morris, P. J. T. (1986). *Polymer pioneers*. Philadelphia, PA: Beckman Center for the History of Chemistry.

Historical overview of polymer science and technology.

Polymer Chemistry. (1986). NSTA Publication.

Rathje, W. L. (1989, December). Rubbish! *The Atlantic*, 99.

An archeologist who excavates modern landfills argues that much of the conventional wisdom about solid waste in America may be misleading or downright wrong.

Reshaping Our Lives: Advanced Materials. (1989). *National Geographic*, 1176, 746.

Man's increasing ability to manufacture new materials, plastics, ceramics, composites, and alloys, by manipulating the atoms of existing materials.

Sarquis, A. M. (1986). Dramatization of polymeric bonding using slime. *Journal of Chemical Education*, 63(1), 60.

Helps students visualize the type of reaction involved in polymerization using PVA, "slime." Even first graders can understand it.

Scheinberg, S. P. (1986). Tyvek. *Chem Matters*, 4(2), 8.

History, development and chemistry of plastic polymer in many products called Tyvek.

Stahl, G. A. (1981). *Polymer science overview: A tribute to Herman F. Mark*. Washington, DC: ACS Symposium Series.

A short history of polymer science.

Tarazona, M. P., and Satz, E. Happy polymer party. *Journal of Chemical Education*, 67(3), 238.

Three experiments show the properties of polymers; presented in the form of a party to generate student interest.

USA Today. (1990, June 20). On artificial fibers.

Wood, C. J. (1987, October). Dissolving plastic. *Chem Matters*, 5(3), 12-15.

Chemistry and uses of a water soluble plastic polymer, polyvinyl alcohol.

The following industry groups are involved in the solid waste issue:

Center for Plastics Recycling Research
Rutgers, The State University of New Jersey
Busch Campus, Bldg. 3529
Piscataway, NJ 08855
(201)932-3683

Council for Solid Waste Solutions
1275 K Street, NW, Suite 400
Washington, DC 20005
(202)371-5319

Flexible Packaging Association
1090 Vermont Avenue, NW
Washington, DC 20005
(202)842-3880

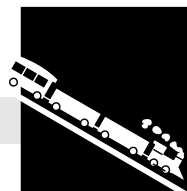
Keep America Beautiful, Inc.
Mill River Plaza
9 West Broad Street
Stamford, CT 06902
(203)323-8987

National Recycling Coalition
P.O. Box 80729
Lincoln, NE 68501-0729
(402)475-3637

National Solid Wastes Management Association
1730 Rhode Island Avenue, NW, Suite 1000
Washington, DC 20036
(202)659-4613

National Plastics Center and Museum
P.O. Box 639
Leominster, MA 01453
(508) 537-9529

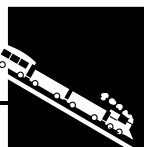
Appendix



- **Transparency Masters**
 1. Polymers from Monomers
 2. Addition and Condensation Polymers
 3. From Crude Oil to Plastics, I
 4. From Crude Oil to Plastics, II
 5. Plastic Container Code System for Plastic Bottles
 6. A List of Common Polymer Products
 7. Word Search
- **Humor**

Polymers from Monomers

Monomer	Polymer
Ethylene $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	Polyethylene $\begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$
Propylene $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{H} \quad \text{CH}_3 \end{array}$	Polypropylene $\begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 \end{array}$
Vinyl Chloride $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{H} \quad \text{Cl} \end{array}$	Polyvinyl Chloride (PVC) $\begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{H} & \text{Cl} & \text{H} & \text{Cl} & \text{H} & \text{Cl} \end{array}$
Styrene $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{H} \quad \text{C}_6\text{H}_5 \end{array}$	Polystyrene $\begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 & \text{H} & \text{C}_6\text{H}_5 \end{array}$
Acrylonitrile $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{H} \quad \text{CN} \end{array}$	Polyacrylonitrile $\begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{H} & \text{CN} & \text{H} & \text{CN} & \text{H} & \text{CN} \end{array}$
Methyl Methacrylate $\begin{array}{c} \text{H} \quad \text{CH}_3 \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{H} \quad \text{CO}_2\text{CH}_3 \end{array}$	Plexiglas™ or Lucite $\begin{array}{cccccc} \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{H} & \text{CO}_2\text{CH}_3 & \text{H} & \text{CO}_2\text{CH}_3 & \text{H} & \text{CO}_2\text{CH}_3 \end{array}$
Vinyl Alcohol $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{H} \quad \text{OH} \end{array}$	Polyvinyl Alcohol (PVA) $\begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{H} & \text{OH} & \text{H} & \text{OH} & \text{H} & \text{OH} \end{array}$
Tetrafluoroethylene $\begin{array}{c} \text{F} \quad \text{F} \\ \quad \\ \text{C} = \text{C} \\ \quad \\ \text{F} \quad \text{F} \end{array}$	Teflon (Polytetrafluoroethylene) $\begin{array}{cccccc} \text{F} & \text{F} & \text{F} & \text{F} & \text{F} & \text{F} \\ & & & & & \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\ & & & & & \\ \text{F} & \text{F} & \text{F} & \text{F} & \text{F} & \text{F} \end{array}$



Addition and Condensation Polymers

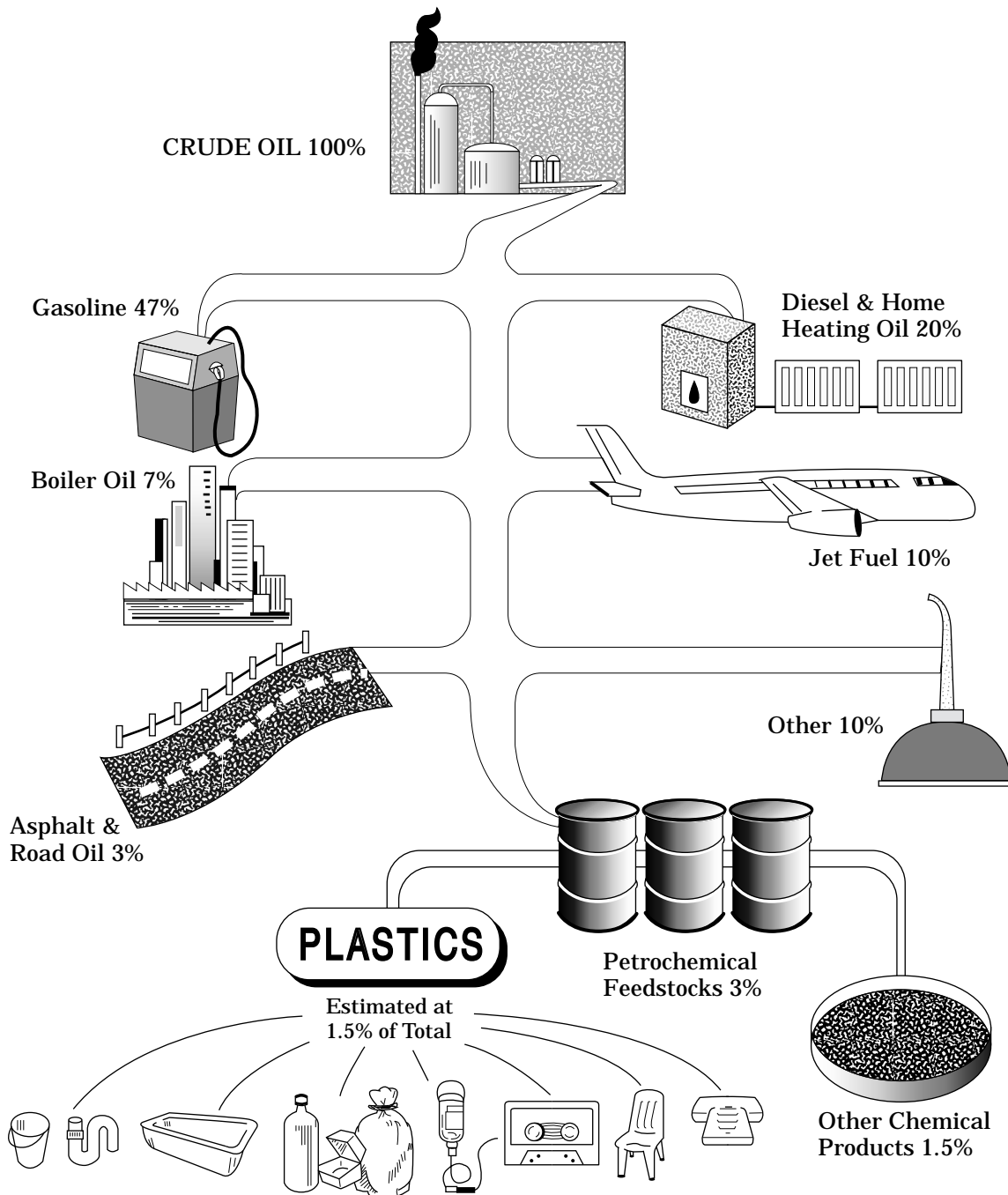
Addition Polymers

Monomer	Polymer	Uses
Ethylene	Polyethylene	Films, coatings, bottles, toys
Propylene	Polypropylene	Fibers, films, bottles, lab equipment
Vinyl chloride	Polyvinyl chloride (PVC)	Credit cards, phonograph records, floor tiles
Styrene	Polystyrene	Insulation, packing materials, coffee cups
Acrylonitrile	Polyacrylonitrile	Orlon, Acrilan, rug fibers
Vinyl acetate	Polyvinyl acetate	Latex paints
Methyl methacrylate	Polymethyl methacrylate	Glass substitutes, jewelry
Vinyl alcohol	Polyvinyl alcohol (PVA)	Glues
Tetrafluoroethylene	Polytetrafluoroethylene	Heat-resistant coatings

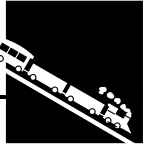
Condensation Polymers

Monomer	Polymer	Uses
Adipic acid, hexamethylene diamine	Nylon	Fibers, bearings
Orthophthalic acid, glycerine	Alkyd resins	Paints
Toluene diisocyanate, ethylene glycol	Polyurethane	Foam plastic, insulation
Dimethyl terephthalate, ethylene glycol	Dacron polyester Mylar	Fibers, plastic bottles

From Crude Oil to Plastics, I



Source: U.S. Energy Information Administration, *Petroleum Supply Annuals*










From Crude Oil to Plastics, II

Most crude oil is turned into fuel for transportation. Less than 2 % is used as feedstock in making plastics. Here's a breakdown of all the ways the United States uses crude oil.

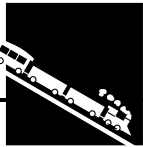
GASOLINE	Of all the crude oil refined for use in the United States, almost half (47%) becomes gasoline for automobiles, boats and other gasoline-driven motors.
JET FUEL	Airplanes consume 10%, in the form of jet fuel.
DIESEL FUEL AND HOME HEATING	Another 20% becomes distillate, two-thirds of which is diesel fuel for trucks, buses and other diesel engines, and one-third home heating oil.
BOILER OIL	Boiler oil, or residual fuel oil, which makes up 7% of crude oil consumption, is used on ships, in industrial boilers and in power plants to produce electricity.
ASPHALT AND ROAD OIL	Asphalt and road oil account for 3% of crude oil consumption.
OTHER	Some of the crude oil, about 10%, is used as non-energy feedstocks for manufacturing products such as lubricants, wax, coke for steel making, and naphthas that are used in the drycleaning process.
PETROCHEMICAL FEEDSTOCKS	Petrochemical feedstocks, products of the refining process, make up the remaining 3% of all crude oil consumption. Half are used to make PLASTICS (1.5% of the total) for thousands of items such as tableware, furniture, aircraft and automobile parts, luggage, surfboards, helmets, medical supplies and packaging. The remaining 1.5% is used to make products such as solvents, synthetic fibers for wearing apparel, synthetic rubber, paints and coatings.
IMPORTANT CONSIDERATION	Plastics bring about savings in energy use. For example, parts for cars and trucks are increasingly made of plastic to reduce their weight, and that means better fuel economy. Plastics packaging and other plastic products usually weigh less than their alternatives, and this saves fuel in shipping.

For more information contact (800) 333-0124, or write:
Mobil Chemical Company
Solid Waste Management Solutions
1159 Pittsford-Victor Road
Pittsford, NY 14534

Plastic Container Code System for Plastic Bottles

Code	Material
	PETE Polyethylene terephthalate (PET)*
	HDPE High-density polyethylene
	V Vinyl/polyvinyl chloride (PVC)*
	LDPE Low-density polyethylene
	PP Polypropylene
	PS Polystyrene
	Other All other resins and layered multmaterial

* Stand alone bottle code is different from standard industry identification to avoid confusion with registered trademarks.



A List of Common Polymer Products

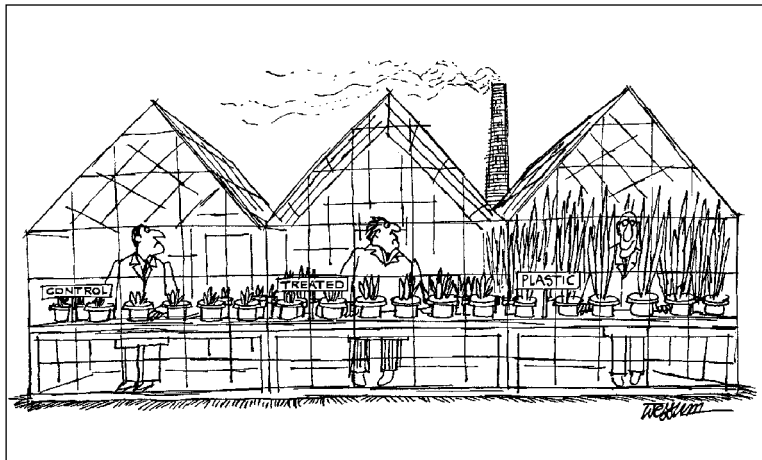
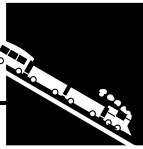
2-Liter pop bottle	fastfood container	movie film	snorkel
ashtray	fishing bobber	Nerf ball	sofa
Astroturf	fishing line	overhead projector	sousaphone
attache case	flag	pacifier	sponge
audio tape	flashcube	paint brush	store sign
awning	flea collar	pantyhose	street sign
baby bottle	floor "wax"	parachute	sun visor
baby rattle	floor mat	particle board	sunglasses
balloon	floor tile	patio screen	Super Glue
band-aid	flower pot	pencil case	supermarket meat tray
basketball	flute	pens	surfboard
beverage box	foam rubber pillow	photographic film	sweater
bicycle and automobile paint	folding door	photograph	sweater box
bicycle and automobile tire	food storage container	piano	swim fins
bicycle hand grip	food wrap	picture frame	synthetic fabric for clothing
boat	football	pillow case	table top
book bag	football helmet	ping-pong ball	tackle box
bubble gum	football pad	plastic flower	tape recorder
bubble pack	fork and spoon	plastic dishes	Teflon cookware
butane lighter	Frisbee	plastic glasses and cups	telephone
buttons	furniture polish	plastic knives	tennis ball
calorimeter cup (also for coffee)	galoshes	playing cards	tennis racquet and string
camera	garbage bag	plywood	tent
car battery	gears	Pontiac Fiero	tent peg
carpet	glasses	portable radio	test-tube brush
caulking	guitar string	pot handle	test-tube rack
ceiling light cover	Habitrail	protractor	thermos bottle
cellophane tape	hair curler	puppet	thread
chair seat	hair dryer	racquetball	thread spool
chapstick tube	hair spray	raincoat	toilet seat
checkers	hang glider	recorder	toothbrush
chemistry classroom desk	hearing aid	records	toothpaste tube
clarinet	hockey puck	reflector	transparencies
cleats	Honda CRX	refrigerator	trash can
coaster	house paint	rope	trophy
coffee mug	ice chest	rubber band	Tygon tubing
coffee stirrer	ice cube tray	rubber duckie	typewriter case
Colorforms	index tabs	rubber glove	typewriter ribbon
comb	insulated foam cup	rubber soles on shoes	umbrella
compact	insulation	rubber tubing	Velcro
computer disc	jewelry	ruler	venetian blinds
computer	junk food bag	safety glass	videotape
contact lenses	knapsack	safety glasses	vinyl siding
Corvette	lawn chair	sail	vinyl top
credit card	life raft	sailboat	vinyl wall covering
curtains	lifesaver	sandals	vitamin capsule
cushion	lipstick tube	sandwich bag	volleyball and net
dashboard	Lucite sculpture	school desk	waders
decorative fruit	luggage	seat cushion	wallet
dish pan	lunch box	shampoo bottle	watch face
disposable diaper	lunch tray	shoe box	water pipe
disposable razor	mannequin	shoe polish	Weed Whacker
dust brush	margarine tub	shoe string tip	welcome mat
earphone	measuring tape	shoe string	wet suit
egg carton	metallic balloon	shower door	whistle
electrical tape	microfilm	shrink wrap	wig
epoxy glue	microwave cookware	shuttlecock	windbreaker
eraser	milk jug	Silly Putty	windshield
exercise mat	model car	Silly String	windshield wiper
extension cord	model plane	skateboard wheels	yarn
false eyelashes	mop	slide	zipper
false teeth	motor oil bottle	Slime	
fan belt	motorcycle helmet	sneakers	

Word Search

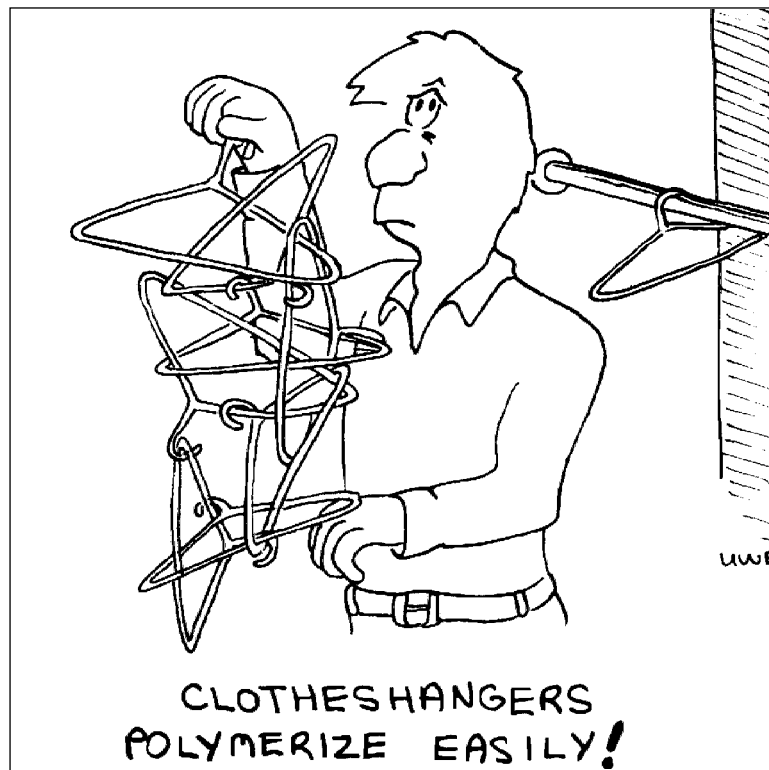
C Q L N N H I I S H M R D F G B H
I K Y O M R N B P M T L O N P Q E
T S K B L J I H B E H Q E D R H C
S R A R T I T T Q G G J A E V L C
A S D A D D I T I O N Y Z G I Y F
L Y R C V I A T I F J L X C X B L
P R Q Z Y F T S T E S O M R E H T
O U F W P R O T E I N P R E F W A
M O N O M E R Q K P Q Q H M R V F
R K W S Q O J O W P X E G Y P Y S
E R T M G A J A F A Q J I L N O F
H D N N O I T A S N E D N O C K L
T W S T D T X P E M A I M P E B U

Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Giant molecule formed from repeating units.
2. Individual unit of which polymers are made.
3. Compound used to start a polymerization reaction.
4. Type of polymer where repeating units “add on” to each other with no loss of atoms.
5. Type of polymer formed with the loss of a small molecule as monomers react.
6. Polymers that do not soften or melt when heated.
7. Polymer that can be melted and reshaped repeatedly.
8. Backbone element of most polymers.
9. Root word meaning “many.”
10. Biological condensation polymer where amino acids are the monomers.



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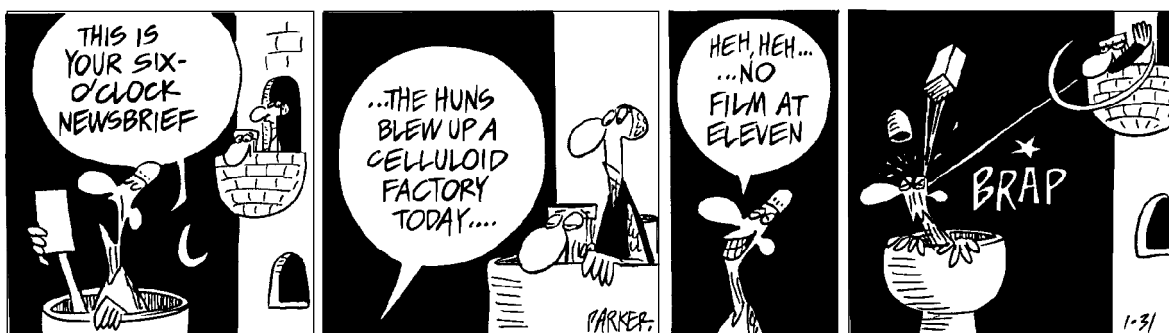
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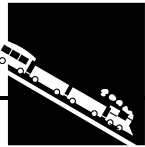
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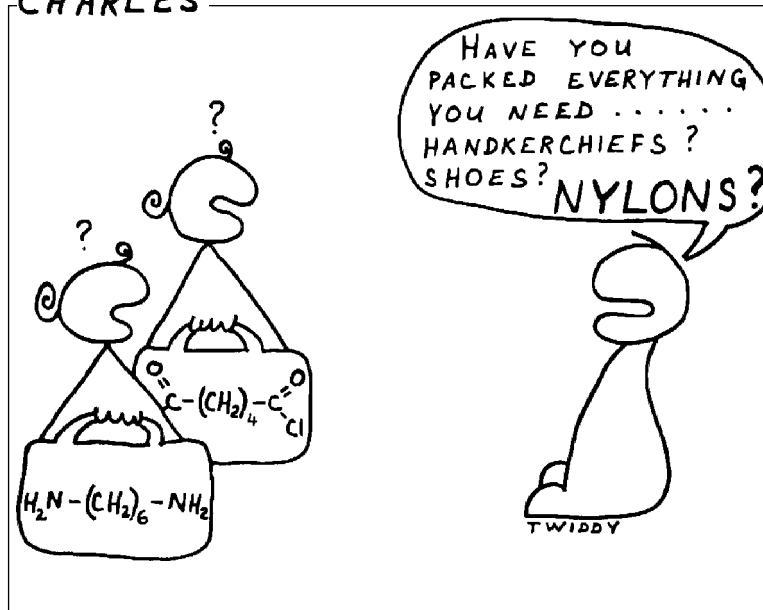
Brant parker and Johnny hart



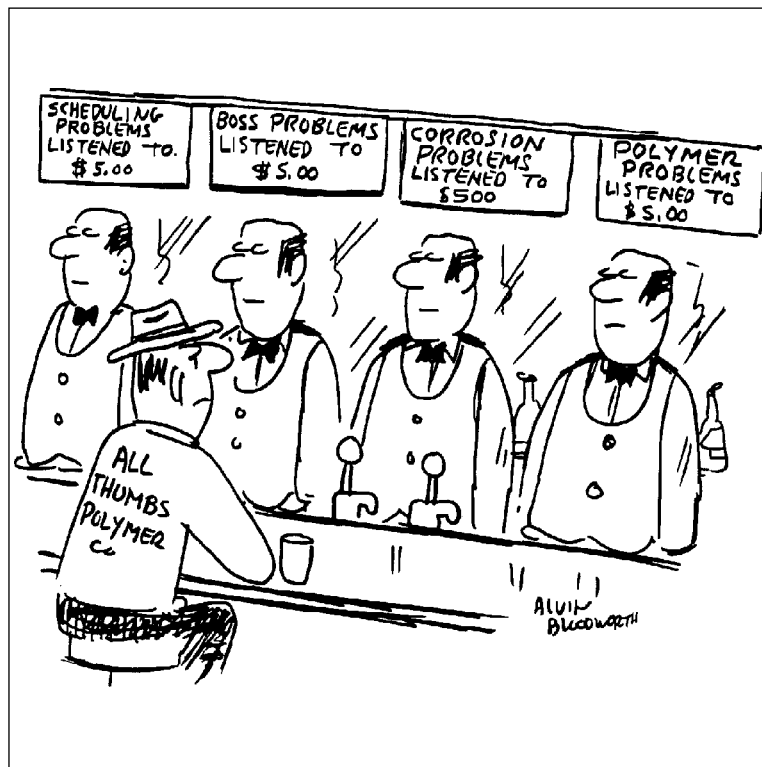
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CHARLES



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