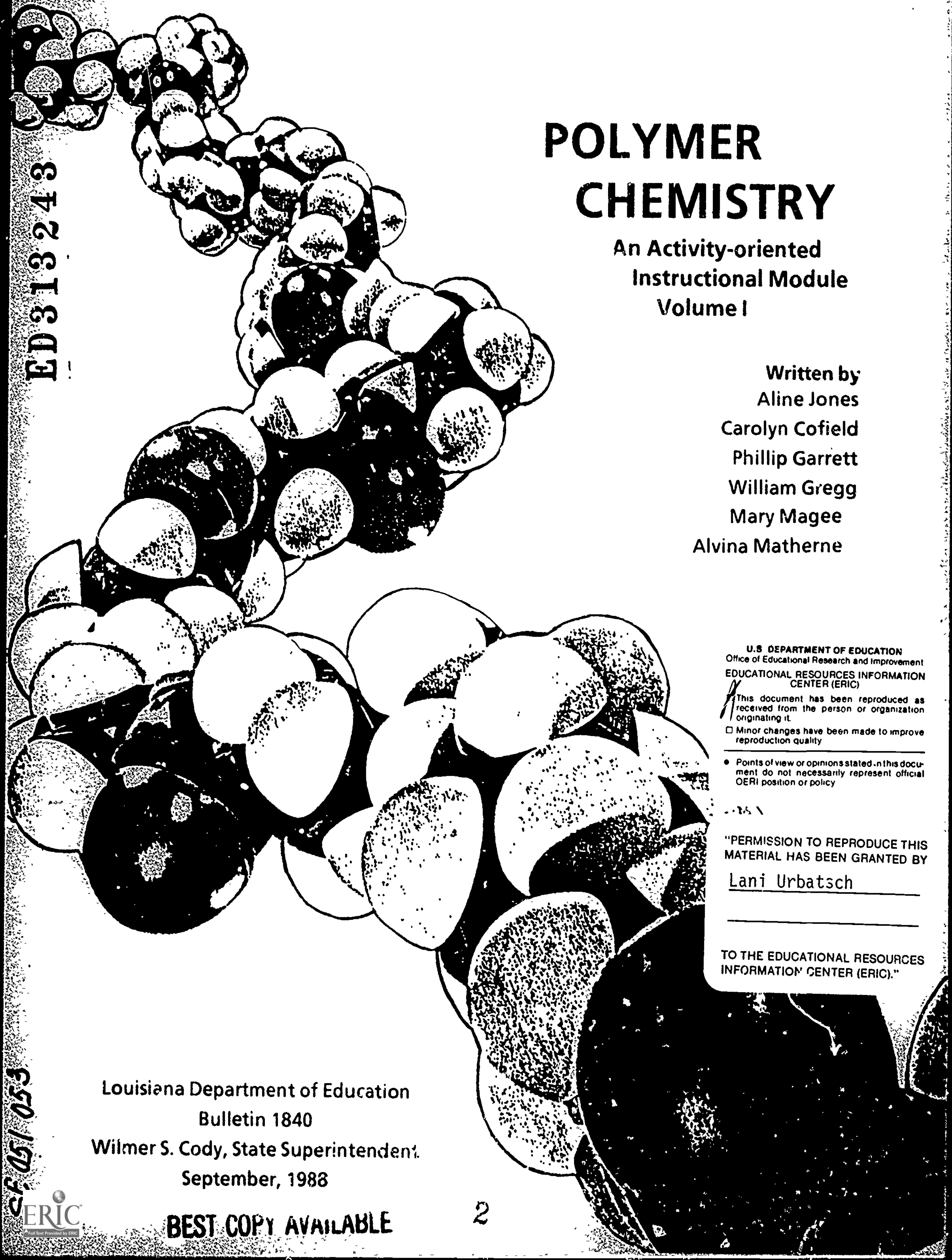
DOCUMENT RESUME

ED 313 243 SE 051 053

AUTHOR	Jones, Aline; And Others
TITLE	Polymer Chemistry. An Activity-Oriented Instructional Module. Volume 1. Bulletin 1840.
INSTITUTION	Louisiana State Dept. of Education, Baton Rouge.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	Sep 88
NOTE	60p.
PUB TYPE	Guides - Classroom Use - Guides (For Teachers) (052)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	*Chemistry; Laboratory Experiments; *Laboratory Procedures; *Polymers; *Science Activities; Science Curriculum; Science Materials; Secondary Education; *Secondary School Science

ABSTRACT

This teaching module was developed by the project "Recent Developments in Science and Technology with Applications for Secondary Science Teaching." Premises about students and their learning and generalizations about content are described. Chapters included are: (1) "Introduction"; (2) "Monomers into Polymers"; (3) "Natural Polymers"; (4) "Thermosets and Thermoplastics"; (5) "Synthesis of Polymers"; (6) "Polymer Structure"; (7) "Common Polymers--Their Use and Properties"; (8) "Polymers--Their Impact on Modern Life"; and (9) "References" (including teacher resources, student resources, multimedia materials, and useful materials to order). Many activities, demonstrations, experiments, and transparencies are provided in each chapter. (YP)



POLYMER CHEMISTRY

An Activity-oriented Instructional Module

Volume I

Written by
Aline Jones
Carolyn Cofield
Phillip Garrett
William Gregg
Mary Magee
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Louisiana Department of Education
Bulletin 1840
Wilmer S. Cody, State Superintendent
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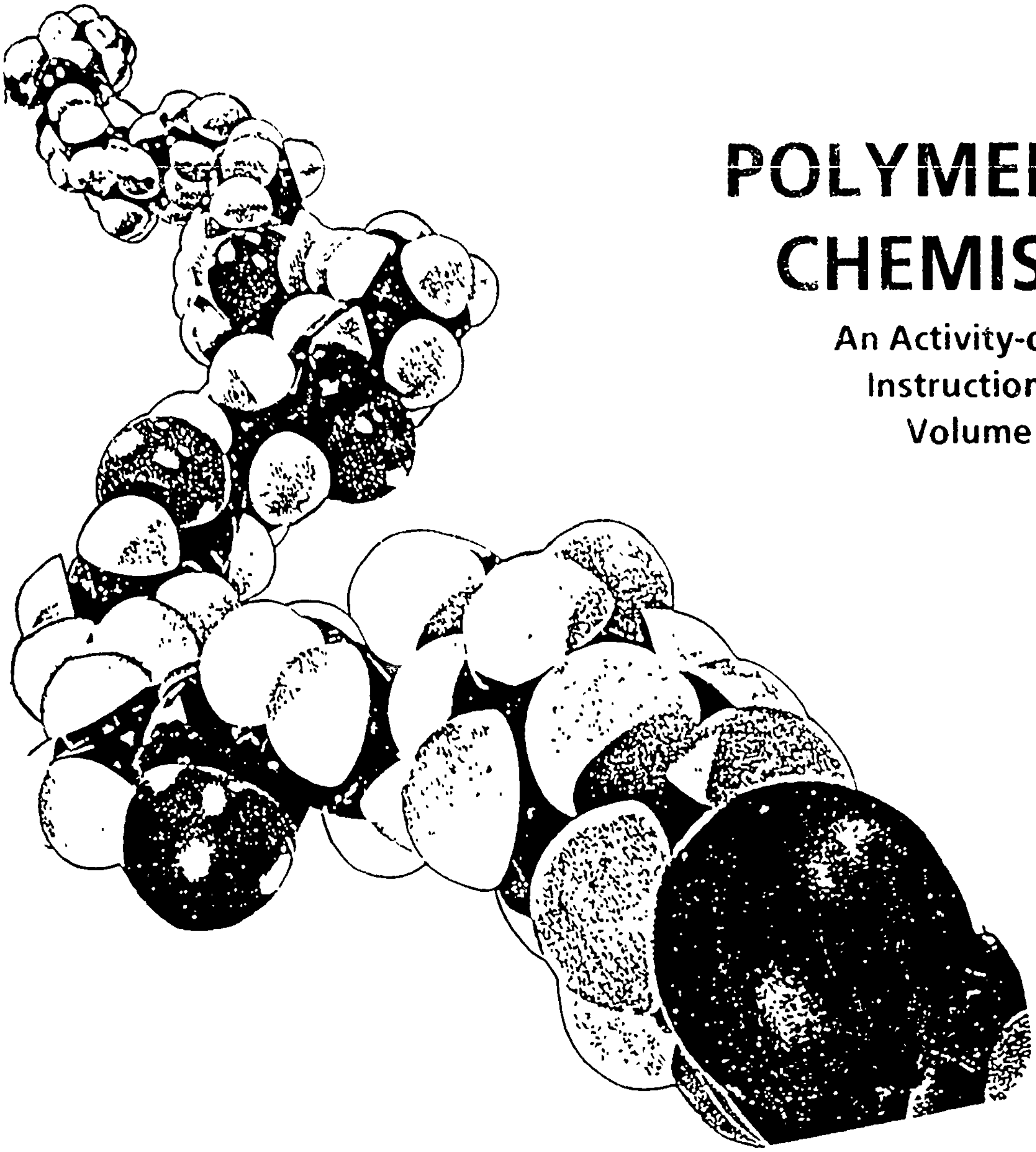

POLYMER CHEMISTRY

An Activity-oriented Instructional Module
Volume I

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FOREWORD

This teaching module was developed by the project "Recent Developments in Science and Technology with Applications for Secondary Science Teaching" through support from the National Science Foundation, Louisiana State University College of Education, Louisiana State Department of Education, and selected Louisiana industries. Among those supporting industries and organizations were Dow Chemical U.S.A., I. E. Dupont, CIBA-GEIGY Corporation, Allied Corporation, Freeport McMoran Company, Shell Chemical and Shell Oil Companies, Louisiana Association for Business and Industry, and the Louisiana Chemical Association.

The project involved the participation of 50 outstanding Louisiana secondary science teachers in a series of symposia at Louisiana State University by research scientists on recent developments in science and technology during the summer of 1986. Each teacher became a member of a curriculum team for one of the symposia topics and developed an instructional module on one of the topics. Modules for the topics were produced and printed under the Louisiana Department of Education bulletin numbers listed. For information regarding these modules, please write to the Science Department, Louisiana Department of Education, Post Office Box 94064, Baton Rouge, Louisiana 70804-9064.

VOLUME NUMBER	TOPIC	BULLETIN NUMBER
1	A.I.D.S.	1846
2	AQUACULTURE	1843
3	BIOTECHNOLOGY: GENETIC AND EMBRYO ENGINEERING	1847
4	COASTAL ECOLOGY	1848
5	LASERS	1845
6	NUCLEAR RADIATION	1842
7	POLYMER CHEMISTRY	1840
8	SPORTS/HEALTH SCIENCE	1844
9	WASTE RECYCLING	1840

The project was directed by Dr. William Leonard, Professor of Science Education, Louisiana State University, Baton Rouge, Louisiana (now at Clemson University, Clemson, South Carolina) and by Gayle M. Ater, Chemistry and Physics teacher, L.S.U. Laboratory School, Baton Rouge, Louisiana. The project directors made arrangements for the symposia and edited each of the modules.

This work was written as part of the NSF project and was supported by a National Science Foundation grant. Any opinions, findings, and conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Educational Rationale

The rationale for any curriculum is based on the developer's beliefs about students, student learning, and the course content. These modules are based on certain premises.

Premises about Students and How They Learn

1. Students learn better when the impetus and the responsibility for learning are internal rather than external. Most students respond favorably when they have some choice of what and how they learn. This approach often yields greater student satisfaction, commitment, and learning than when all the decisions are made by the instructors.
2. Cooperation improves the quality and quantity of learning. Interaction among students, instructors, and resource people in the community can result in a level of learning and insight superior to that attained in courses where the only sources of data are books and lectures.
3. Instruction should begin with what the students already know.
4. Each student is unique. The curriculum must provide opportunities for the expression and development of the student's individual abilities.
5. Students learn and grow best in an atmosphere of trust and respect.

Generalizations about Content and Subject Matter

This project aimed at specialized problems, technologies, or problem solving is being used. These generalizations relate to science, social studies, Language Arts and mathematics.

1. The content is not an end in itself, but a means to an end. Students should be encouraged to evaluate facts and ideas pertinent to a problem as the student perceives it. Information is a necessary tool for problem solving, but it is not enough.
2. Students must gain experience in dealing with issues that have a changing base of knowledge and a strong component of social values. Finding solutions to complex problems related to environmental quality are among the highest priorities.
3. Pervasive questions about the use of these technologies cannot be answered within the realm of a single discipline. They require information from history, political science, economics, sociology and the physical and biological sciences.
4. All knowledge is tentative. A curriculum must provide opportunities for students to discover the incomplete nature of what is known.
5. An inquiry into science technology and society issues is an ideal vehicle for accomplishing the teaching and learning goals implied by all the previous assumptions. Those problems serve as common denominators for an educational experience in research, problem analysis, and decision making, which use process skills.

POLYMER CHEMISTRY
TABLE OF CONTENTS

I. INTRODUCTION

- I-1 POLYMERS: How Common Are They? (activity)
- I-2 POLYMERS: History and Development (activity)

II. MONOMERS INTO POLYMERS

- II-1 Paper Clip Polymer Simulation (demonstration)
- II-2 "Monster Molecules" (demonstration)
- II-3 Nylon Rope (demonstration)
- II-4 Some Common Monomers (transparency)
- II-5 Some Common Polymers (transparency)
- II-6 Some Common Polymers (transparency)

III. NATURAL POLYMERS

- III-1 The Incredible Edible Polymer (activity)
- III-2 Peanut Brittle (experiment)
- III-3 Natural and Synthetic Rubber (experiment)
- III-4 Rubber (transparency)

IV. THERMOSETS AND THERMOPLASTICS

- IV-1 Does it set? (demonstration)
- IV-2 Characteristics of Thermosets & Thermoplastics (experiment)

V. SYNTHESIS OF POLYMERS

- V-1 Condensation and Addition Polymerization: A Simulation (demonstration)
- V-2 Preparation of an Addition Polymer (experiment)
- V-3 Polymerization (transparency)

VI. POLYMER STRUCTURE

VI-1 Polymer Structure (transparency)

VI-2 Hands-On Polymers (activity)

VI-3 Creepy Crawly Slime - A Cross Linked Polymer (experiment)

VII. COMMON POLYMERS: Their Use and Properties

VII-1 Identification of Polymers (experiment)

VII-2 Topics and Projects (activity)

VII-3 How Long Can It Last? (activity)

VII-4 What Makes It Gummy? (activity)

VIII. POLYMERS: Their Impact on Modern Life

VIII-1 Consumption by End Use Market (transparency)

VIII-2 Recycling Methods (transparency)

VIII-3 Graphing Statistics on Polymers (activity)

VIII-4 Research on the Impact of Polymers on Modern Life

IX. REFERENCES

IX-1 Teacher Resources

IX-2 Student Resources

IX-3 Multimedia Materials Available

IX-4 Useful Materials to Order

INTRODUCTION

Throughout time, scientists have classified man according to the main materials he used for making tools. At first, stone was by far the most common material for this purpose. The Stone Age lasted until about 3000 B.C. when man started using metals and learned how to melt and cast them. He discovered that copper when melted with tin to make bronze, was a stronger material than stone for making tools. This brought man into the Bronze Age, which was short-lived because the scarcity of tin and copper made bronze an expensive alloy. Iron was more abundant and it was soon discovered that a strong metal could be made from iron. During the Iron Age, steel was developed.

If we wanted to give such a name to the age in which we live today, it would be appropriate to call the latter 19th, 20th and 21st centuries the Polymer Age or the Plastic Age. Most of our "tools" are made from polymer materials. Polymers (from the Greek words "polus" and "mer" meaning many parts) are giant molecules, abundant in our lives and surroundings. All of the proteins in our bodies, including our hair and nails, the clothes we wear (cotton, rayon, polyester, and wool), the carpets we walk on, the plastic bottles and styrofoam cups we use and throw away, the video tapes we watch and the records we listen to, are all polymer products.

Polymers, sometimes called macromolecules, are not anything new - they have been around a long time, at least as long as life itself! Natural polymers include biological polymers such as the myriads of proteins, polysaccharides, starch, cellulose, and DNA. Natural fibers like cotton, silk and wool, and natural rubber are also macromolecules. Even though these substances have been known for many years, it was only in the early 1900's that scientists began to understand their structures.

The Polymer Age (the age of synthetics polymers and plastics) dawned shortly after the Civil War when the high cost of ivory led people who made billiard balls and other items from ivory to search for a substitute. John Wesley Hyatt, a printer and inventor in Albany, New York, developed a suitable billiard ball material, cellulose nitrate, which he called celluloid. It was the first plastic made in the United States. For many years, celluloid was the only plastic man could make. Then in 1909, the Belgian-American chemistry, Leo Baekeland, discovered phenol-formaldehyde, the first of a type of plastic called thermosetting plastic (plastic that hardens when heated). Baekeland named the new material Bakelite, after himself.

After 1909 the plastic industry grew steadily. Some new plastics were discovered, more and more uses were found for these materials. The term "plastic" was coined in the 1920's to describe the man-made products.

Dr. Herman Mark, and Austrian-born chemist, was a pioneer in using X-rays to determine the molecular structure of polymers. When Hitler marched into Austria, Dr. Mark moved his family to Canada and then to the United States. His work at the Polytechnic Institute of Brooklyn soon made it the center of polymer research in the Western Hemisphere.

Today, more than 50% of all chemists are polymer chemists. This science, however, is in its infancy. Its outreaches into medicine and manufacturing are only beginning to be fathomed. We are truly immersed in the Polymer Age.

ACTIVITY I-1 Polymers: How Common Are They?

Purpose: To make students aware of the prevalence of polymers in their lives and to give them experience in classifying polymers.

Procedures: Each of the following is a polymer or polymer product. Read through the list and circle those that you encounter in your daily activities. then answer the questions which follow.

Records
Food Processor
Celery
Saran Wrap®
Trash Bags
Baby Bottle
Styrofoam Cup
Bubble Gum
Bicycle Tires
Acrylic Sweater
Steering Wheel
Astroturf®
Hair
Floor Wax
Eyeglasses
Contact Lens
Eggs
Credit Card
Hair Dryer
Sofa
Honda CRX®
Buttons
Ski Rope
Supper Glue®
Lamp Shade
Street Sign
Skateboard
Hockey Puck
Wall Paper
Steak
Silly Putty®
Asphalt
Insulation
House Paint
Sun Visor
Billiard Ball
Syringe

Jello
Flour
Videc Tape
Slippers
Melmac®
Panty Hose
Wool Scarf
Scotch Tape
Balloon
Tennis Racket
Telephone
Jewelry
Volley Ball
Can Opener
Fingernails
Tennis Balls
Hairbrush
Wocden Desk
Tote Bag
Flea Collar
Bowling Ball
Hair Ribbon
Lipstick
Camera Case
Radio
Frisbee®
Apples
Hang Glider
Band-Aid®
Bread
Helmet
Asbestos
Space Suit
Rubber Band
Plywood
Garden Hose
Plastic
Explosives

He-Man® Figures
Tooth Brush
Barbie® Doll
Tennis Shoes
Computer Diskettes
Teflon Skillet
Ink Pen
Soft Drink Bottle
Formica Counter Top®
Corning Ware®
Talcum Powder
Foam Rubber Pillow
Silk Flowers
Cotton Bed Sheets
Photographic Film
Cold Capsules
Shampoo Bottle
Electrical Tape
Swatch® Watch
Big-Mac® Container
Vinyl Seat Covers
Barrette
Shower Curtain
Safety Goggles
Furniture Polish
Disposable Diapers
Mashed Potatoes
Lee® Press-on Nails
Skis
Chemistry Textbook
Guitar Strings
Roller Coaster®
Vinyl Siding
Fishing Rod
Walkman ®
Playing Cards
Egg Carton
Artifical Heart

QUESTIONS:

1. List additional items that are not included in the polymer list.

2. Classify the polymers into groups. How many different systems can you find? Example: Natural and synthetic fibers, plastics, rubbers, etc.

ACTIVITY I-2. Polymers: History and Development

Purpose: The student will become aware of the development and significance of polymer chemistry.

Procedure: Below is a list of possible topics for research. Have students choose one of the following and find their own topic of interest to research.

John Wesley Hyatt
Leo Baekeland
Alexander Parks
Herman Mark
Wallace Carothers
Herman Staudinger
Emil Ficher
Hilarie DeChardonnet
Arnold Collins
Julian Hill

Dupont Corporation
I.G. Farben Co.
U.S. Rubber Co.
Hoerst Celanese
Dow Chemical Corporation
I.E. Dupont Corporation
Ciba-Geigy Corporation
Allied Chemical
Exxon Corporation

Nomex
Tyvek
Teflon
Plexiglass
Kevlar
Mylar
Bakelite
Nylons
Dacron
Holofil

Polymer Industries
Plastics
Fibers
Coatings
Adhesives
Rubbers

CONCEPT II. Monomers into Polymers

The term polymer means "many parts". Polymers are formed from single units called monomers. A simple monomer is ethylene.

$$CH_2 = CH_2$$

Ethylene monomers join to form the polymer, polyethylene.

$$-CH_2-CH_2-CH_2-CH_2-CH_2-$$

The number of repeating monomers in polyethylene is about 12,500. This results in a macromolecule consisting of about 25,000 carbon atoms with a molecular weight of around 350,000.

If the monomer is identically repeated throughout the structure, as in polyethylene, the polymer is a homopolymer. If two or more different monomers are polymerized, then the polymer is a copolymer.

Nylon 66 is an example of a copolymer composed of the monomers adipic acid and hexamethylenediamine.

$$\underset{\text{ADIPIC ACID}}{H-O-\overset{\overset{O}{\|}}{C}-(CH_2)_4-\overset{\overset{O}{\|}}{C}-O-H} \quad + \quad \underset{\text{HEXAMETHYLENEDIAMINE}}{H_2N-(CH_2)_6-NH_2} \longrightarrow$$

$$\underset{\text{NYLON 66}}{-\overset{\overset{O}{\|}}{C}-(CH_2)_4-\overset{\overset{O}{\|}}{C}-NH-(CH_2)_6-NH-} \quad + \quad \underset{\text{WATER}}{nH_2O}$$

ACTIVITY II-1. Paper Clip Polymer Simulation

Purpose To demonstrate to the student the difference between a homopolymer and a copolymer.

Materials:
200 Standard size paper clips (Monomer A)
100 Large or colored paper clips (Monomer B)
2 Large cans or boxes labeled Reactor #1 and Reactor #2
10 Brightly colored marbles (catalyst)

Procedure

1) Prepare a homopolymer by hooking together about 25 standard size paper clips. Place in the can marked Reactor #1.

2) Prepare a random copolymer by hooking together in random order 25 paper clips of each of the two sizes or colors. Place in the can marked Reactor #2.

3) Show students Monomer A (25 separate paper clips). Add these 25 monomers to Reactor #1 along with a few of the marbles as the catalyst. Shake vigorously (activation energy!) and pull out from the reactor the "homopolymer", that was stored there. The marbles are unaffected by the synthesis and may be reused.

4) Show student Monomer A and Monomer B. (25 of each of the two different types of unlinked paper clips). Place the two sets of unlinked monomers into Reactor #2 and add the marbles. Repeat the procedure as above and pull out the random copolymer.

ACTIVITY II-2. "Monster Molecules"

Purpose: To illustrate the difference in molecular weight and size between familiar organic molecules and polymers.

Materials:

10 liter plastic pail
4000 pop-it beads (carbon atoms)

Note: Paper clips could be substituted for the beads.

Procedure:

1) Assemble short chains of pop-it beads of from 1 to 8 beads in length. Five of each type is sufficient for the demonstration. These represent molecules of the alkane series, all of which have every day uses (natural gas CH_4 lighter fluid C_4H_{10} gasoline C_8H_{18}).

2) Spill out these short chain molecules from the bucket.

3) Assemble a long-chain (1000 to 4000) units long. This can be made to "siphon" out by hanging one end over the edge of the pail and holding the pail high above the floor. The time required for all the beads to appear is a dramatic representation of the high molecular weight of a polymer. A bowling ball represents a macromolecular polymer.

ACTIVITY II-3. Nylon Rope

Purpose: To demonstrate the synthesis of a polymer from two monomers.

Materials:
2.5ml Sebacoyl chloride or adipoyl chloride
50ml Perchlorethylene
Solution of 4.0g Na_2CO_3 and 2.2g hexamethlyenediamine in 50ml of H_2O
Rubber gloves
Forceps
400ml Beaker
Stirring rod or test tube

Hazards: Hexamethylenediamine (1,6 - diaminohexane) is an eye, skin, and respiratory irritant. The sebacoyl chloride or adipoyl chloride is also an eye, skin and respiratory irritant.

This experiment should be performed under a ventilation hood and gloves should be worn.

Procedure:

1) Work in a well ventilated area, and wear gloves while performing the experiment.

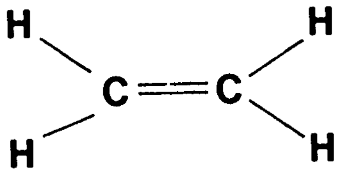
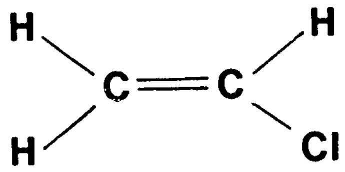
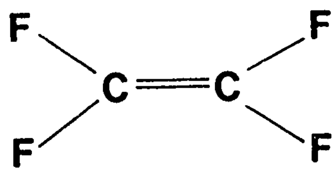
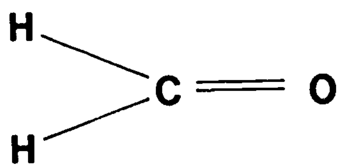
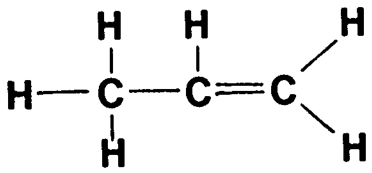
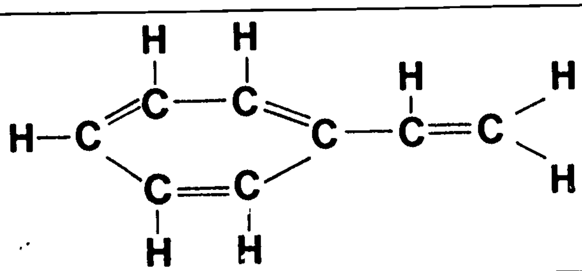
2) Pour 50ml of perchlorethylene into the 400ml beaker. Add the 2.5ml of sebacoyl chloride to this.

3) Very gently pour the solution of sodium carbonate-hexamethylenediamine over the solution in the beaker.

4) A milky film forms at the interface of the two liquids. With forceps, grasp the polymer film and pulling from the center of the beaker, wind the nylon rope around the stirring rod or test tube.

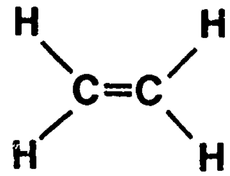
Disposal: The solid nylon should be washed before being discarded in a solid waste container. Stir the remaining liquid to produce nylon. Place any remaining liquid in a solvent waste container.

SOME COMMON MONOMERS

ETHYLENE	
VINYL CHLORIDE	
TETRAFLUOROETHYLENE	
FORMALDEHYDE	
PROPYLENE	
STYRENE	

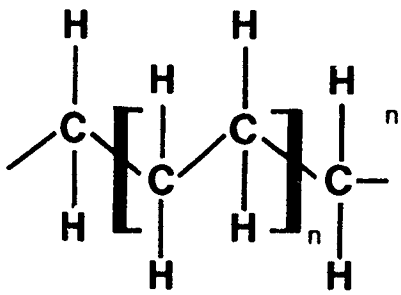
SOME COMMON POLYMERS

Polyethylene



MONOMER

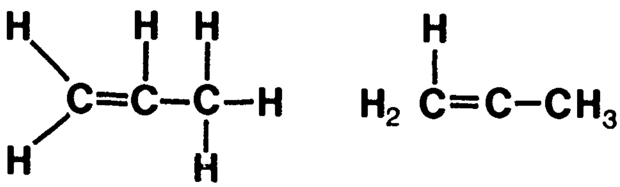
POLYMER



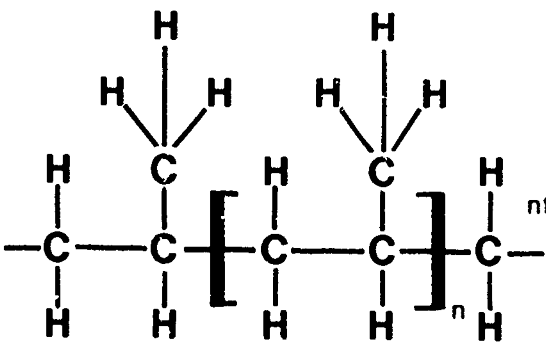
n=2500 to 5000

Polypropylene

MONOMER



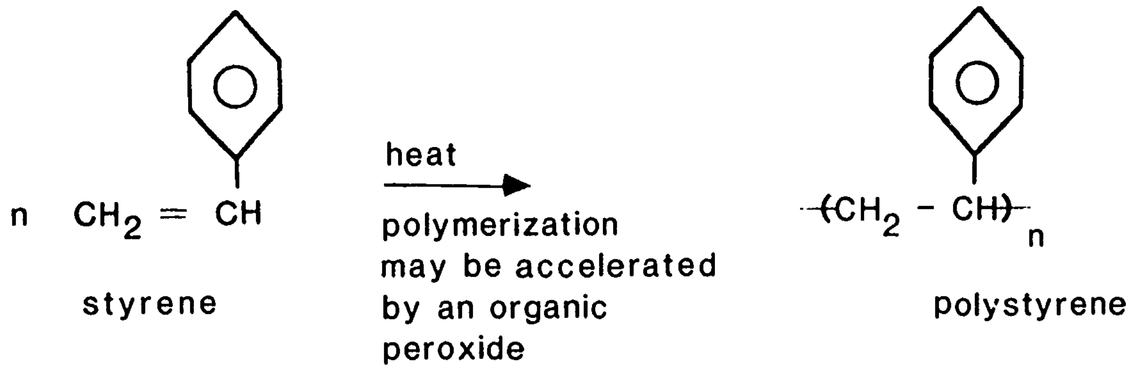
POLYMER



n≅ 6,000 to 20,000

SOME COMMON POLYMERS

Polystyrene



Polyvinylchloride

$$CH_2 = \underset{\displaystyle Cl}{\underset{|}{CH}} \qquad -CH_2-\underset{\displaystyle Cl}{\underset{|}{CH}}-\left(CH_2-\underset{\displaystyle Cl}{\underset{|}{CH}}\right)_{n-1}-$$

Monomer
Vinyl Chloride

Polyvinylchloride

III. Natural Polymers

All of life is based on the chemistry of building, decomposing and rebuilding organic polymers. Polymers comprise the structural, circulatory, transport and protective systems of all organisms. The wooden structures that shelter us, the fibers of cotton, wool and silk that clothe us and even our hair, skin, nails, and muscle are all natural polymers.

Carbohydrate metabolism provides most of the energy needed for life. Most carbohydrates exist as polysaccharides. They are stored in the form of starch in plants and as glycogen in animals. Starch and glucogen are homopolymers made of glucose.

The polysaccharide, cellulose, is the most abundant organic substance on earth. Cotton is almost pure cellulose. Wood cellulose is used in making paper, rayon, cellophane, paint lacquer and plastics. Cellulose is the structural material in plants and is a homopolymer of glucose.

Protein is an important polymer found in living things. Muscle tissue, skin, hair, silk, wool, nails, bone, teeth and horns are composed of proteins. Enzymes, hemoglobin, hormones, RNA and DNA are all composed of proteins. Proteins are copolymers of up to 20,different monomers.

Natural rubber comes from latex produced from gum rubber trees found mostly in southeast Asia. Natural rubber is an addition polymer, the only true hydrocarbon elastic polymer found in nature. Raw rubber is tacky, soft and of poor strength and elasticity.

ACTIVITY III-1. The Incredible Edible Polymer

Purpose: To acquaint the student with the abundance of polymers in food.

Procedure:

1) Research and bring to class sample of edible polymers

COMMON EDIBLE POLYMERS

Gummy Bears	Potatoes
Gum	Jello
Taffy	Jelly Beans
Caramel	Spaghetti
Celery	Licorice

ACTIVITY III-2. Peanut Brittle: Polyedible

Purpose: To prepare peanut brittle, an edible polymer.

Materials:

Sugar (sucrose)	250ml beaker
Dark corn syrup	400ml beaker
Butter or margarine	Burner
Salt (Nace)	Balance
Peanuts	Graduated cylinder
Baking Soda	Stirring rod
Vanilla	Wire gauze
Hot pot holder	Water

Procedure:

1) Add 75 grams of sucrose to a clean 400ml beaker.

2) Using the 250ml beaker, weigh out 62g of corn syrup and add this to the sugar in the 400ml beaker.

3) Add 10ml of water to the 250ml beaker to dissolve the remaining syrup. Add this to the mixture in the 400ml beaker. Repeat using 9ml of water.

4) Heat the mixture to boiling very slowly on a low flame, stirring constantly. Do not burn the mixture.

5) Add 9.5g of margarine to this mixture and continue to heat and stir.

6) When the temperature is 138 ^{o}C, add 0.3g of salt (nace) and 55g of peanuts.

7) Continue heating until the temperature is 154 ^{o}C. Remove from flame and add 3.7g of baking soda and 1.3ml of vanilla and stir vigorously.

8) When the beaker is nearly full to the top, pour the mixture on the aluminum foil and spread evenly.

9) Allow to cool and then enjoy.

NOTE: If this is performed as a classroom activity especially designated laboratory glassware should be set aside exclusively for this purpose.

Any peanut brittle recipe can be used and it could be made by the students or teacher at home and brought to class.

QUESTIONS:

1. Have students discuss the chemical names and formulas for some of the ingredients.

2. Compare the physical properties of:

    a.) The ingredients before and after cooking
    b.) The mixture before and after adding the baking soda
    c.) The peanut brittle before and after it cools.

ACTIVITY III-3. Natural and Synthetic Rubber

Purpose: To compare the properties of natural and synthetic rubber.

Materials:

Test tubes
Gum rubber (natural)
Neoprene (rubber stopper-synthetic)
Beaker
Burner

6ml of each of the following:

Dilute HCl
Dilute NaOH
Ethanol
Kerosene
Dilute H_2SO_4

Procedure:

1) Obtain samples of natural and synthetic rubber. Compare their elasticity, and their flexibility.

2) Drop a sample of each in boiling water for five minutes. How are they affected by heat.

3) Place samples in the refrigerator or freezer overnight and compare how each has been affected by the cold.

4) Put small samples of natural and synthetic rubber in each of 5 test tubes. Add 3ml of the following reagents to each test tube.

   Dilute HCl
   Dilute NaOH
   Kerosene
   Water
   Dilute H_2SO_4

5) Observe for 15 minutes and record observations.

QUESTIONS:

1. Which type of rubber would be better to use in rubber bands and rubber gloves?

2. Which type would be better for stoppers for laboratory glassware?

3. Would you line the hose of gasoline pumps with natural or synthetic rubber? (Note: Gasoline may act like kerosene)

FURTHER RESEARCH:

1. How was natural rubber first discovered and what were its uses?

2. Study the development of synthetic rubber and compare the properties of natural and synthetic rubbers.

3. How and when was synthetic rubber first discovered? What is the significance of this?

4. What happens to old tires? Can they be recycled?

   Note: (Tires can be recycled by submerging in liquid nitrogen. This is related to the glass transition temperature of rubber).

   Note: (Methyl rubber was the first synthetic rubber discovered. Thickol was the 2nd synthetic rubber discovered).

CONCEPT IV. Thermosets and Thermoplastics

An important way of categorizing polymers is by their behavior upon being heated. Thermoplastics soften and melt when heated. Both addition and condensation polymers can behave in this manner. We have probably all experienced the melting of a polyethylene bag, or the fusing of polyester or nylon fabrics when a too-hot iron was used. The melting occurs because individual molecules are not chemically bonded to each other. Held together by van der Waals forces, polyethlyene melts in the 110-130°C range. Nylons melts at 265°C (It is held together by hydrogen bonds as well as by van der Waals forces).

Thermosets, just the opposite, maintain their original shape when heated. This is due to forming giant three-dimensional molecules, such as the bowling ball and billiard ball. They do not soften or melt upon heating.

ACTIVITY IV-1. Does It Set?

Purpose: To illustrate the difference between thermosets and thermoplastics.

Materials:

2	Eggs, uncooked
	Ice, crushed
100	Grams table salt (NaCl)
250ml	Beakers (2)
	Bunsen or alcohol burner
	Ring stand and ring
	Wire gauze
100ml	Water
	Stirring rod
	Test tube (plastic)

Procedure:

1) Boil an egg in a 250ml beaker for 10 minutes.

2) Peel the boiled egg and compare it to the uncooked egg. (The boiled egg is a model of a synthetic thermoset polymer which cannot be reformed after heating).

3) Mix 100g of NaCl with 100ml of water and stir. Add crushed ice to this mixture and stir to lower the temperature below 0°C.

4) Add 10ml of water to a test tube and submerge it in the salt-ice mixture until frozen. Remove the test tube and melt the ice in warm water. As in thermoplastics, this process can be done repeatedly.

ACTIVITY IV-2. Characteristics of Thermoplastics and Thermosets.

Purpose: To demonstrate to students the difference in properties of thermoplastic and thermoset plastics.

Materials: Materials for forming Bioplastic (hobby shop)
Stick of sealing wax
Heat source - burner or hot plate

Procedure:

1) Warm some sealing wax. Let a few drops fall on paper. Imprint the soft wax with a hard object like a ring. Make observations.

2) Prepare cold-setting bioplastic according to manufacturer's directions. Set some small object in the plastic before it hardens. After it hardens, make observations.

3) Select three or four plastic materials to test and classify. Immerse the object in boiling water for about 5 minutes. The objects that can be softened by heat and bent or molded while warm are thermoplastic.

Note: Following is a list of thermosets and thermoplastics to use with activity IV-2.

THERMOPLASTICS

Cellulose: Shoe heel covers, fabric coverings.

Cellulose Acetate: Vacuum cleaner parts, combs, toys, eyeglass frames, recording tapes, photo film, lamp shades.

Polyvinyl Chloride Plastics: Rain coats, door frames, inflatable water toys, garden hoses, floor coverings, shower curtains and wall coverings.

Acrylic: Airplanes and building windows, outdoor signs, car tail lights, salad bowls, surgical instruments, sky lights, costume jewelry.

Polyethylene: Ice cubes trays, moisture-proof freezer bags, rigid and flexible bottles, tumblers, candy bags.

Nylon: Gears, ropes, brush bristles, fishing line, faucet washers, clothing fabric.

Fluoro-Carbon Plastic: (Teflon) non-stick coating in cookware, long-lasting self-oiling piston rings, car bearings, ball joints, vein and artery replacements.

THERMOSETTING PLASTICS

Phenolics: (Bakelite) car distributor heads, washing machine agitator, cabinets, telephone cases.

Melamine: Unbreakable dinnerware, handles for kitchen utensils, buttons, hearing aid cases.

Epoxy resin: Coatings for ceramics, glass and plastics, bonding metals.

Polyurethane: Foam, insulation for homes, furniture, bedding.

CONCEPT V. Synthesis of Polymers

Polymers form, when substances with small molecular weight, join to form large molecular weight substances. The two primary methods of polymerization are addition polymerization and condensation polymerization.

In addition polymerization, monomers with carbon-carbon double bonds are usually converted to polymers. Under appropriate conditions, the electrons in the double bond form single bonds between monomers. Examples of polymers made by addition polymerization include polyethylene, polystyrene and polyvinyl chloride. If more than one kind of monomer is joined in this way, addition copolymers are formed.

In condensation polymerization, monomers containing different functional groups on each end of the molecule are linked. Functional groups such as -OH (alcohols), -C=O-OH (acids) or $-\overset{\overset{O}{\|}}{C}-NH_2$ (amides) are chemically active parts of molecules. These functional groups react and a molecule such as water is produced for each bond formed between monomers.

FUNCTIONAL GROUPS

NAME	STRUCTURAL FORMULA
ALCOHOL	-OH
ACIDS	$-\overset{\overset{O}{\|}}{C}-OH$
AMIDES	$-\overset{\overset{O}{\|}}{C}-NH_2$

ACTIVITY V-1. Condensation and Addition Polymerization: A Simulation

Purpose: To demonstrate the concept of polymer formation.

Materials: Dominos
Paper Clips
Overhead projector (if available)

Procedure:

1) Stand up dominos on the overhead projector so that on initiation (push one domino so that it falls into the next one) a linked "chain" will form. The dominos should be about 2cm apart and should stand on end. The number of dominos depends on the space (and dominos) available. This illustrates the formation of an addition polymer.

2) To simulate the formation of a condensation polymer, repeat the procedure but place a paper clip (functional group) on top of each domino. The paper clips should be placed on opposite ends of the standing dominos. The paper clips should fall away from the chain and represent the water molecules that generally form in this type of reaction.

ACTIVITY V-2. Preparation of an Addition Polymer

Purpose: To prepare an addition polymer from dental-grade self curing acrylic.

Materials:

- Gloves
- Disposable cup or beaker
- Stirring Rod
- 10ml Graduated cylinder
- Duz-all (Coralite Dental Products, Chicago, Illinois)

Procedure:

1) Put 5g of the solid component in the disposable cup.

2) Measure 3ml of the liquid component and mix with the solid in the cup.

3) Allow about 10 minutes for the mixture to set.

Alternate Procedure:

1) Obtain an auto body putty such as bondo. It consists of monomer composition containing a filler. When mixed with the catalyst a polymer which hardens will form.

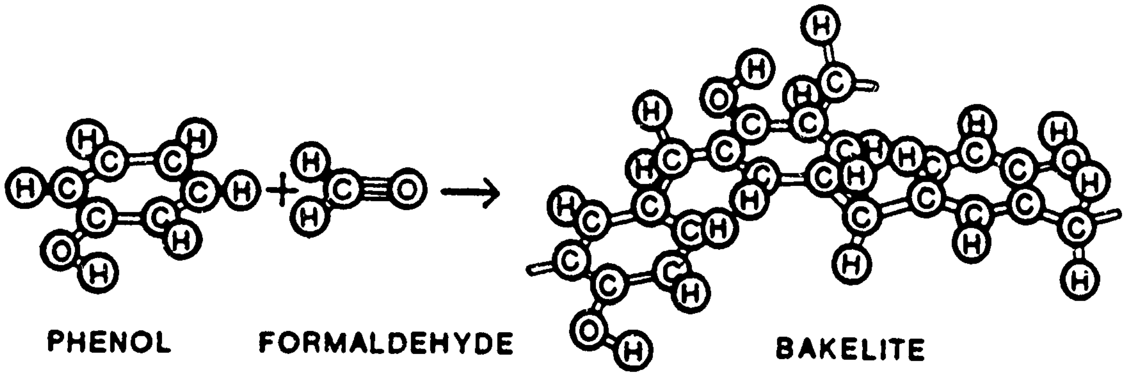
Note: For the formation of a condensation polymer refer to Activity II-3 Nylon Rope.

Note: To illustrate addition polymerization refer to Transparency II-6 some common addition polymers.

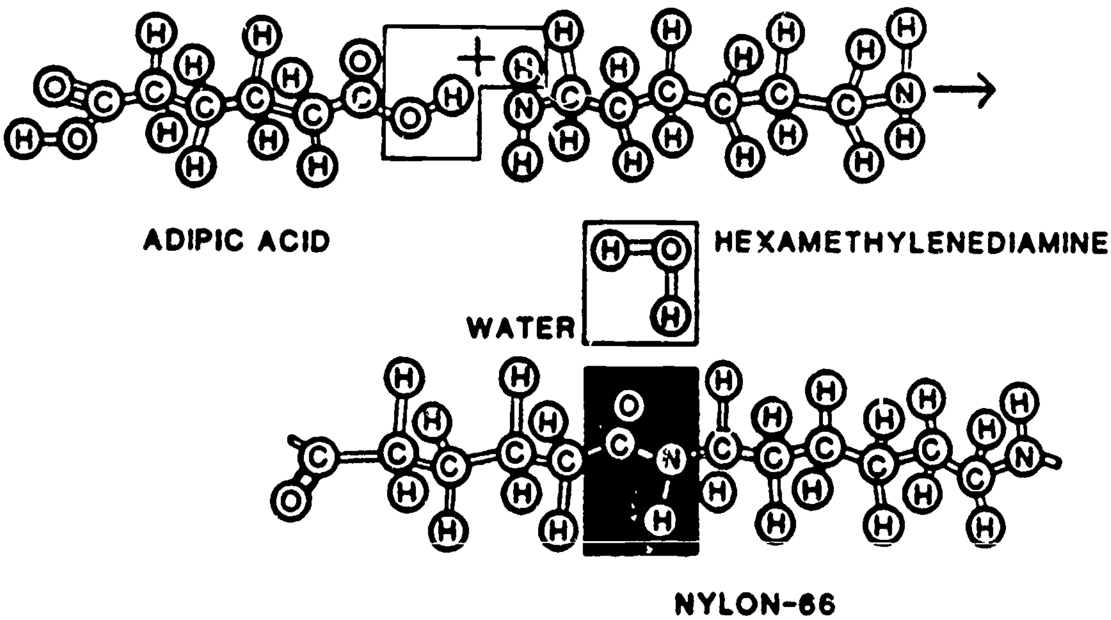
To illustrate condensation polymerization refer to Transparency V-3 polymerization.

POLYMERIZATION

BAKELITE: A CONDENSATION POLYMER



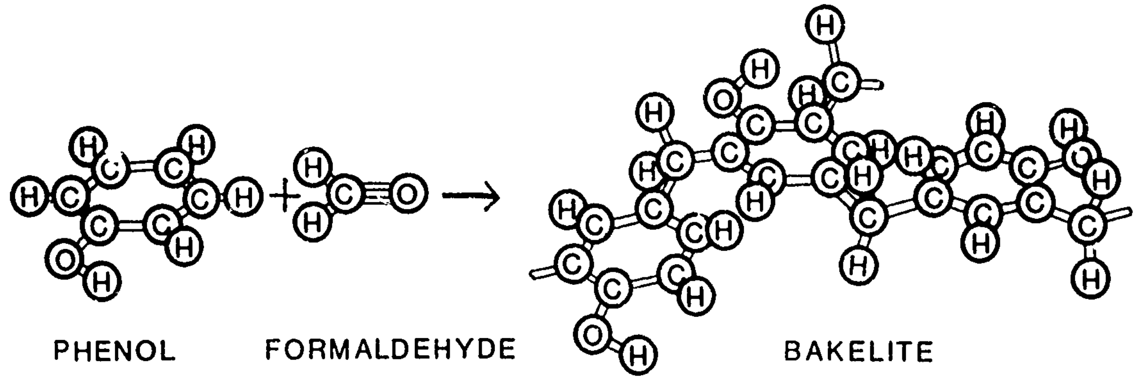
NYLON: A Condensation Polymer



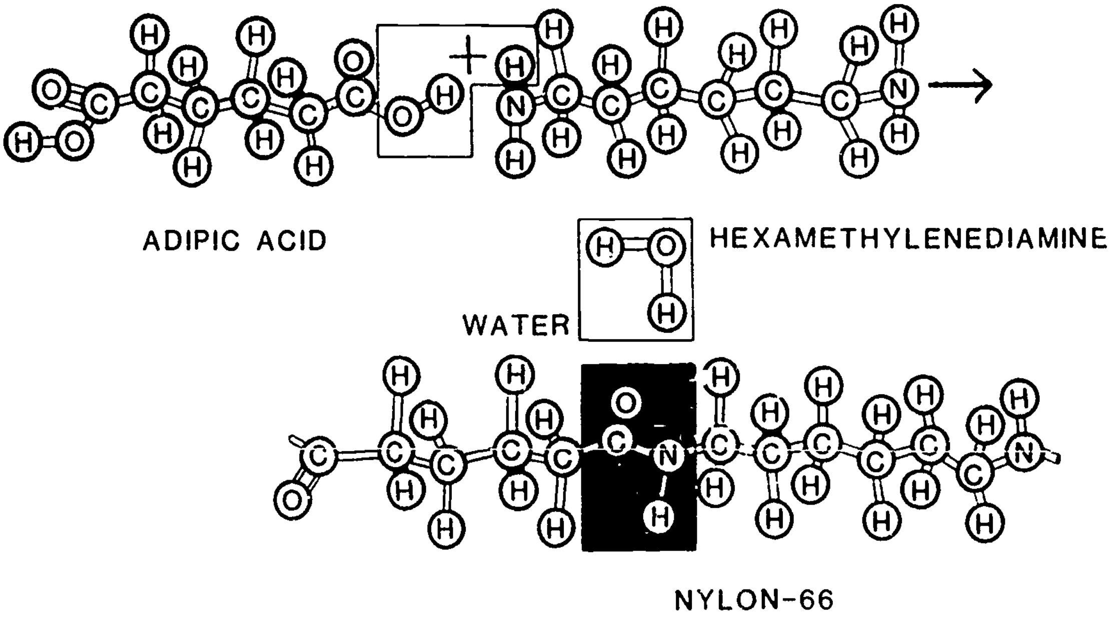
*Drawings adapted from Giant Molecules: Life Science Library, Time, Inc. N.Y.

POLYMERIZATION

BAKELITE: An Addition Polymer



NYLON: A Condensation Polymer



CONCEPT VI. Polymer Structure

Today's polymer chemist is a molecular engineer who uses his knowledge of molecular structure and chemical principles to design specific products. In order to build his made-to-order materials, he must consider three key factors: the chemical make-up of his building blocks, the shapes of the polymer chain they can produce, and the arrangement of these chains within the final product.

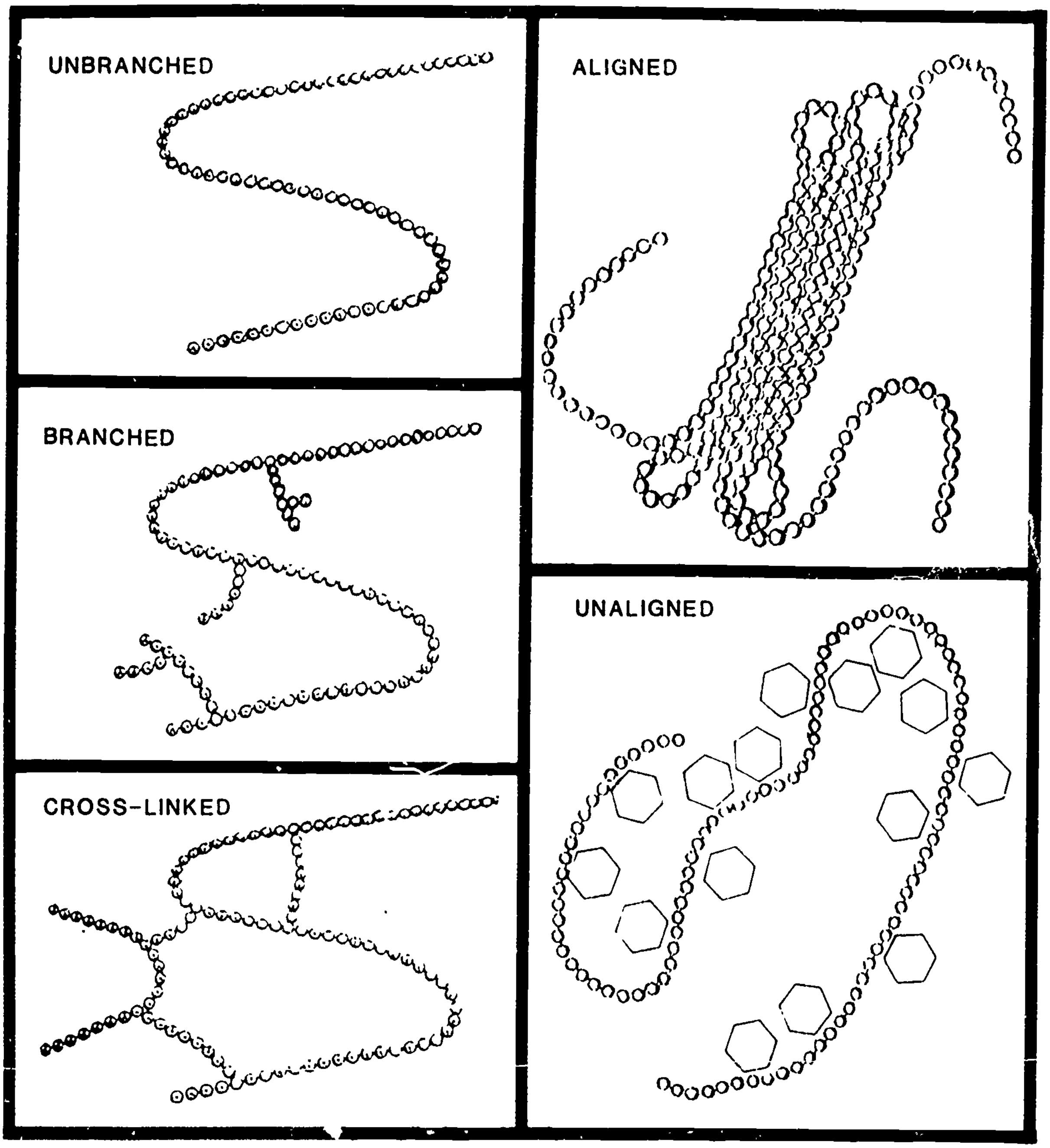
Polymer molecules can have a linear, branched or cross-linked structure. Linear or unbranched chains can be crowded close together to give the material a rigid, tough quality. Branched chains produce a softer and more flexible product, but they are not as heat resistant as linear polymers. When the chains are cross-linked, the polymer is at its strongest and resists melting up to 165°C.

In designing a material to be used in automobile tires, for example, certain qualities are desirable. The material must be tough; it must be rigid enough to hold tire treads and shape. At the same time, it must be flexible enough to resist bumps and curb-pounding, and must be able to withstand relatively high temperatures produced by road friction and stretching.

In the rubber material designed for auto tires, the molecules are cross-linked for toughness, but are unaligned for flexibility. A combination of these two molecular designs produces the desired characteristic in this product.

The alignment to polymers within a substance has a direct bearing on the density of a substance. Chains which can align themselves closely produce stiff heat resistant synthetics. Unaligned chains result in a less dense, more flexible plastic.

POLYMER STRUCTURE



ACTIVITY VI-2. Hands-On Polymers

Purpose: To demonstrate to the students the molecular structures of polymers and the properties which result from varying structures.

Materials: No materials are needed. Students will be the "monomers" in this simulation.

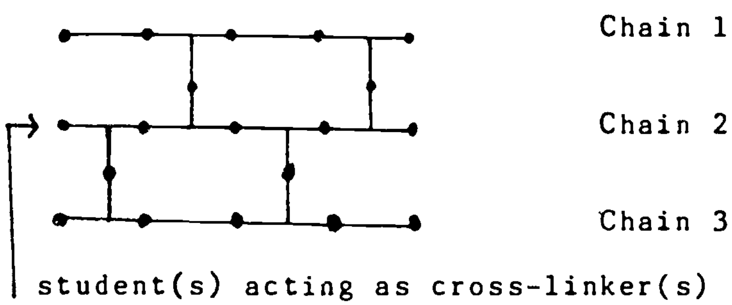
Procedure:

1) Ask five students volunteers to come up and stand in the front of the classroom. Each student is a monomer. How many monomers do we have?

2) The teacher moves between each pair of students (monomers) and joins their hands. Each of these links is a chemical bond. (Tell the class to imagine that the chain continues to grow. When the number is significantly large, the molecule is called a polymer.
This is a linear polymer. X - X - X - X - X
By itself, it is very flexible.

3) Repeat the procedure with ten more students to form second and third chain. Have the groups move to the front of the room and form parallel lines. Note that the movement of one chain is independent of the movement of the second chain.

4) The effect of the addition of a cross-linker to the chains can be illustrated by having four to five students grasp parallel chains forming a bridge between them.



Note that the flexibility of the chains is reduced with the addition of a cross-linker.

5) Questions for discussion:

A. Is the crosslinked polymer as mobile as before? (No)
B. Is it flexible at all? (Yes)
C. What would happen if more cross-linkers were added? (Flexibility would be diminished even more).

ACTIVITY VI-3. Creepy Crawly Slime: A Cross-Linked Polymer

Purpose: To have students actually synthesize a cross-linked polymer and observe its properties.

Materials: (Per student or student team):

20ml 4% (by weight) polyvinyl alcohol (dissolve in H_2O with moderate heating - do not overheat) - order from Flinn Chemical

6ml 4% (by weight) sodium borate solution disposable cup, plastic or wooden spoon for stirring.

Procedure:

1) Add 20ml of 4% polyvinyl alcohol solution to cup.

2) Mix 6ml of 4% sodium borate solution with the alcohol and immediately begin to stir vigorously until a gel-like substance forms. (The sodium borate is the cross-linking agent).

3) Once the gel has formed, the "slime" should be removed from the cup and kneaded to firm it to the desired consistency.

4) Play with your slime: Allow it to flow, tear it apart, roll it in a ball and place on the desk, make a ball and bounce it, let it "creep" off the edge of the desk, be creative! (Try to keep your slime clean and off the floor).

*Slime lasts between 2 days and 2 weeks depending on the amount of handling it gets and how clean the hands are. It usually molds and should be discarded at this point.

Note: Polyvinyl alcohol may be obtained from Flinn Chemical. Dissolve in water with moderate heating - do not overheat!

CONCEPT VII. Common Polymers: Their Use and Properties

Synthetic polymers are an integral part of modern life. They are found in almost every conceivable form in the products we come in contact with everyday. These "designer polymers" are possible because of the relationship between science and technology.

The multitude of materials produced by the polymer industry has a wide variety of properties in terms of strength, flexibility, chemical resistance and thermal stability. These properties depend on their molecular weight, mix of crystalline and amorphous properties, forces between molecules, glass transition temperature and their structure.

ACTIVITY VII-1. LAB. Identification of Polymers

Introduction: Polymers are high-molecular weight organic molecules made up of repeating units called monomers. This activity will compare the properties of samples of 3 commonly used polymers. Properties of other samples may vary because of the addition of coloring matter, extenders, or plasticizers; the use of blowing agents to make expanded polymers; or treatments to cause cross-linkages between the long polymer molecules.

Problem: What are the properties of 3 common polymers?

Materials:

Samples of polypropylene, polyvinyl chloride, and polystyrene
Acetone
Aluminum foil square
3 100ml beakers
Forceps
Salt solution (density 1.20 g/cm^3)

Procedures: (Note: Enter results on data table which follows.)

1) Make visual observations: Clear? Opaque? Color?

2) Perform flex and feel tests: Flexible? Brittle? Waxy? Slippery? Tears?

3) Attempt to stretch.

4) Observe sound when dropped.

5) Add 5ml acetone to each of 3 beakers. Test solubility of one sample in each beaker. Discard used acetone in labeled waste containers.

6) Heat copper wire in Bunsen burner flame and touch the polymer. Then reintroduce hot wire in flame. Observe melting and flame color.

7) Flame test. Hold a small sample with forceps over the aluminum foil square. Hold sample in Bunsen burner flame until it ignites; remove from flame and observe. Blow out any remaining flame, let most of smoke dissipate, and carefully smell sample. Record results. Perform test under a good, working hood.

8) Flotation test. Put 20ml water in one beaker and 20ml salt solution in a second beaker. Place clean samples of each polymer in each beaker [note: Use unexpanded (clear) polystyrene]. Observe and record.

Data Table: (Separate page)

Conclusion: Write a short paragraph describing each polymer tested. Include the approximate density of each.

LAB: IDENTIFICATION OF POLYMERS NAME:____________________

Data Table:

	POLYPROPYLENE	POLYVINYL CHLORIDE	POLYSTYRENE
MONOMER:			
1. Clear			
Opaque			
Color			
2. Flexible			
Brittle			
Waxy			
Slippery			
Tears readily			
3. Stretches readily			
with difficulty			
In one direction only			
Can't stretch			
4. Dull sound			
Ringing sound			
5. Soluble in acetone			
Slightly soluble			
insoluble			
6. Melted by hot wire			
Green flame when wire reintroduced to flame			
7. Burned clean			
Black soot			
Drip while burning burns when removed from flame			
Color of base of flame			
Odor after burning			

8. Floats on water	______	______	______
Floats on salt water	______	______	______

<u>CONCLUSION:</u>

SOURCES FOR EACH OF THE POLYMERS

1. Polypropylene: Clear drinking straws
   2 liter soft drink container
   (clear portion)

2. Polyvinyl chloride: Saran Wrap
   Tygon Tubing
   Shower Curtain
   Credit Card

3. Polystyrene: White foam coffee cups
   Meat trays
   Egg cartons

PROPERTIES OF THE POLYMERS

1. Polypropylene

   A. Translucent but not clear
   B. Odor: Acrid when burned; sweet when melted
   C. Blue flame with yellow tip
   D. Floats in water
   E. Insoluble in acetone
   F. Melting point 165-171 ^{o}C

2. Polyvinyl chloride

   A. Clear or opaque
   B. Burns with a yellow flame, may have green spurts
   C. Odor-Hydrochloric acid smell on burning
   D. Positive copper wire test (green flash or steady glow)
   E. Difficult to ignite, burns only in flame
   F. Soluble in acetone

3. Polystyrene

   A. Clear or opaque
   B. Burns with a yellow flame, may have green near base
   C. Emits clouds of dense, black smoke when burned; does not drip flaming drops
   D. Very soluble in acetone
   E. Rings when dropped if unmodified

FLOTATION TEST

Place samples of polystyrene, polyvinyl chloride and polypropylene in distilled water (density = $1.0 g/cm^3$) and in salt water (density = $1.20 g/cm^3$)

Expected Results:

A. In distilled water:

1. samples sink
   polystyrene (density = $1.04 g/cm^3$)
   polyvinyl chloride (density = $1.30 g/cm^3$)

2. samples float
   polypropylene (density = $0.90 g/cm^3$)

B. In salt water:

1. samples sink
   polyvinyl chloride (density = $1.30 g/cm^3$)

2. samples float
   polystyrene (density = $1.04 g/cm^3$)
   polypropylene (density = $0.90 g/cm^3$)

ACTIVITY VII-2. Topics and Projects for Student Research

1. Report on the three types of polymers: eastomers, fibers and plastics.

2. From a list or collection of common polymers, classify and name them.

3. Develop a polymer museum from collected samples.

4. What are some innovations due to polymer chemistry in the following fields?

   Transportation
   Communication
   Health Care
   Textiles
   Photography

5. How are polymers processed to make fibers, pipes, bottles, balls, toys, foamed plastic; etc.?

ACTIVITY VII-3. How Long Can It Last?

Purpose: To investigate the biodegradable properties of polymers.

NOTE: This is a long-term investigation.

Procedure:

1) Select a sample of a polymer and measure it. (mass and dimensions) The members of the class should select from a wide variety of polymers.

2) Bury the polymer and place a marker over the "grave".

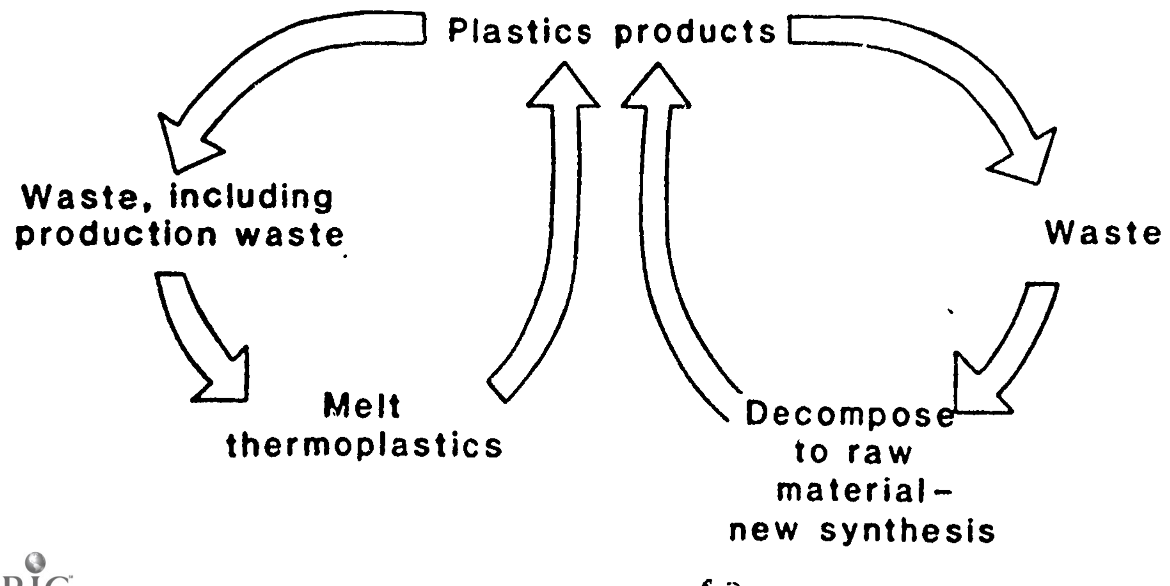
3) Record all data in a "Doomsday Book". (mass, dimensions, polymer, date of burial).

4) Dig up the sample after a month. Record evidence of deterioration and measurements in the "Doomsday Book". Rebury the sample and replace the marker.

5) Continue the observation process periodically.

Suggestion: In some cases it may be possible to bury a synthetic polymer along side a natural substance used for the same purpose. For example silk and nylon; or a wooden and a plastic popsicle stick could be used. Comparisons could then be made of the properties of the two substances with the passage of time.

RECYCLING METHODS



ACTIVITY VII-4. What Makes It Gummy?

Purpose: To illustrate the difference in properties of a polymer above and below the glass transition temperature.

Introduction: The glass transition temperature (Tg) is a fundamental characteristic of polymers. Below Tg the polymer is hard and glassy. Above Tg it is a flexible polymer.

Materials:
Chewing gum
Ice
Hot drink (coffee, cocoa)

Procedure:

1) Remove gum from the wrapper and chew it. (The Tg of the material in chewing gum is near body temperature - ($37^{\circ}C$, $98.6^{\circ}F$). Note it is soft and rubbery.

2) Put ice in the mouth along with the gum. The gum will become stiff and hard.

3) A hot drink consumed while the gum is in the mouth will cause the gum to become soft and sticky.

CONCEPT VIII. Polymers: Their Impact On Modern Life

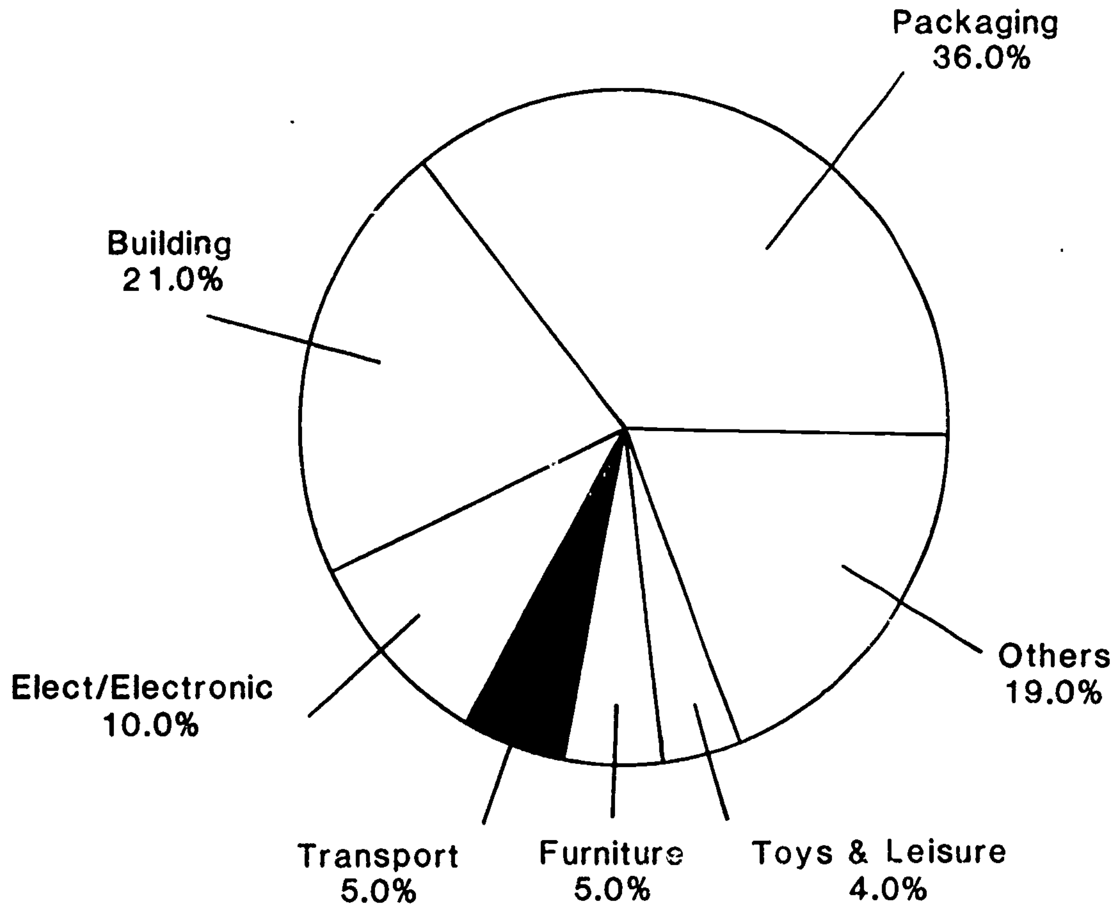
People have always tried to supplement natural materials with others that are more suitable for their purposes. Today we cannot imagine the domestic scene or our daily environment without polymers. Household equipment, furniture, toiletries, textiles, toys, office equipment, for sport, for camping, and for leisure, generally are all made with synthetic polymers.

The reason for the success of polymers in the replacement of traditional materials is largely because of their unique properties, which are (a) they can be produced from raw materials which are inexpensive and plentiful, (b) they are light in weight, (c) they can be cheaply fabricated, and they can be produced with nearly desired characteristics.

It is easy to see why the total consumption of plastics for 1985 was 2.25×10^{10} kg billion pounds. Note: The following graph should be used to enrich the summary.

CONSUMPTION BY END-USE MARKET 1984/85

PERCENTAGE OF TONNAGE CONSUMPTION



Others include:	Housewares	2.5%
	Agriculture	2.0%
	Clothing & footware	1.0%
	Medical products	1.0%

ACTIVITY VIII-3. Graphing Stat ics On Polymers for the Years of 1985, 1984, and 1983.

Purpose: The student will demonstrate a knowledge of graphing and will be able to readily identify areas of increased and decreased production.

Directions: Arrange the following information on a bar graph.

TYPES OF POLYMERS	THOUSANDS OF METRIC TONS
1985	
Plastics	
A. Thermosetting resins	2560
B. Thermosplastic resins	14330
Synthetic Fibers	
A. Cellulosics	270
B. Noncellulosics	3430
Synthetic Rubber	4
1984	
Plastics	
A. Thermosetting resins	2520
B. Thermosplastic resins	13650
Synthetic Fibers	
A. Celluiosics	270
B. Noncellulosics	4280
Synthetic Rubber	5

1983

Plastics

A.	Thermosetting resins	2390
B.	Thermosplastic resins	12640

Synthetic Fibers

A.	Cellulosics	270
B.	Noncellulosics	3960

Synthetic Rubber........................ 2

Source: Society for the Plastics Industry Textile, and Economics Bureau, Rubber Manufacturers Association.

QUESTIONS:

1. Which division of polymers experienced the largest decrease in production?

2. Which kind of polymer experienced the greatest increase?

3. Why do you think that the synthetic rubber industry decreased in production in 1985?

4. How do oil embargos affect the plastic industry?

ACTIVITY VIII-4. Research on the Impact of Polymers on Modern Life

Purpose: To reinforce the concepts taught in this lesson.

1) What careers are available in the field of polymer chemistry?

2) What are some innovations in health care related to polymer chemistry?

3) How does the polymer industry affect the economy?

4) Is recycling the answer?

5) Debate the pros and cons of polymers on modern life.

6) Visit a polymer plant as an enrichment activity.

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3. MULTIMEDIA MATERIALS AVAILABLE

Mark, Herman. "The Father of U.S. Polymer/Science". Dimensions in Science Series. (audio cassette)

"Polymers". (An inexpensive ($5) computer program for Apple computers which simulates the processes of polymerization. Order apple disk #705. For an additional $5.00 you can receive "Polymer Chemistry in the General Chemistry Classroom" Document #IT006) order from:

Project Seraphim/Chem Matters
Joan Moore
Dept. of Chemistry
Eastern Michigan University
Ypsilante, Michigan 48197

Polymers. (A very good film on structure and use of polymers available to members of American Chemical Society only.)

ACS High School Film Library
RHR Filmedia, Inc.
9 East 39th Street
New York, N.Y. 10016

4. USEFUL MATERIALS TO ORDER

Duz-All Coralite Dental Products, Chicago, Illinois (polymeth,i methacrylate).

Heat Shrinkable Tubing (shows effect of radiation on polymers)

Ray Chem Corporation
300 Constitution Drive
Menlo Park, CA 94025

Jumping Rubber Kit

Organometallics, Inc.
Route 111, East Hampstead
New Hampshire

(poly butadiene)

Super Foam

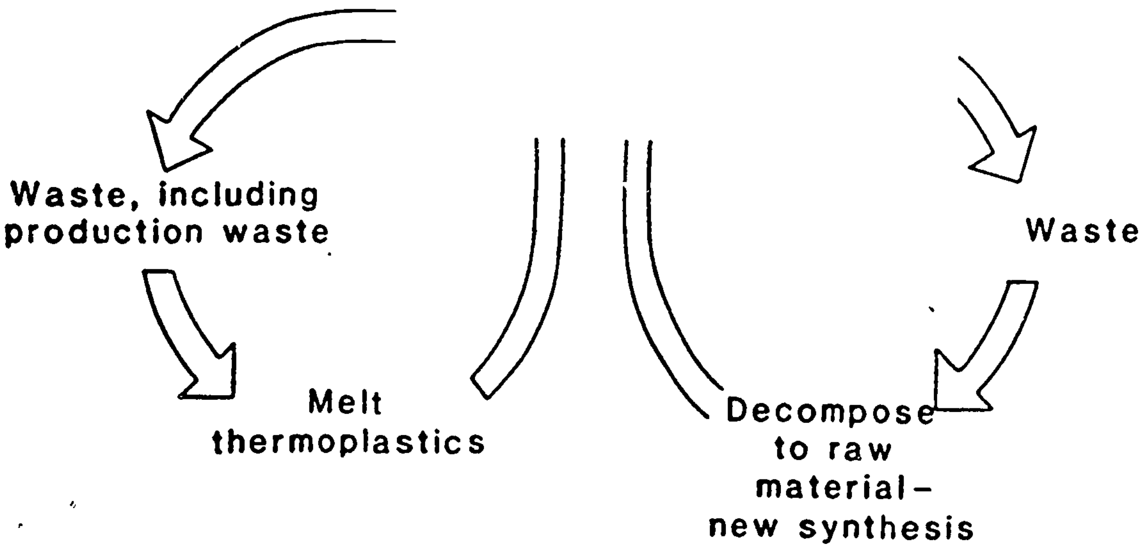
Edmund Scientific Co.
101 E. Gloucester Pike
Barrington, N.J. 08007

(polymethane)

"Superslurper"

Grain Processing Corp.
Muscatine Town

(polymeric highly absorbent material)


Waste, including production waste
Waste
Melt thermoplastics
Decompose to raw material– new synthesis