Polymers

The Material of Choice

A **MAST** Module

Materials Science and Technology

1995

Acknowledgments

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Foreword

This module is intended as a curriculum supplement for high school science teachers who would like to introduce their students to concepts in Materials Science and Technology. Teachers are urged to use one, some, or all of the MAST modules. Some teachers may wish to implement this module in its entirety as a subject unit in a course. Others may wish to utilize only part of the module, perhaps a laboratory experiment. **We encourage teachers to reproduce and use these materials in their classrooms and to contact the workshop with any assessment, comments, or suggestions they may have.**

This is one in a series of MAST modules developed and revised during the Materials Technology Workshop held at the University of Illinois at Urbana-Champaign during 1993-'95.

A combination of university professors, high school science teachers, and undergraduates worked together to create and revise this module over a three year period.

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Introduction

Module Objective:

The objective of this module is to identify and characterize fundamental properties of polymers, and recognize the impact polymers have on our world today.

Key Concepts:

- Polymer, monomer, co-polymer, and macromolecule
- Addition and condensation polymerization
- Common plastics and their applications
- Thermoset and thermoplastic
- Crystalline and amorphous plastics
- Production of polymers

Prerequisites:

Some familiarity with the following concepts would be helpful in understanding the information in this module.

- covalent bonding
- laboratory technique and safety precautions
- fundamentals of organic chemistry

Placement in Curriculum:

This module could be used in either a high school chemistry or advanced chemistry class, or a physical science class.

What are Polymers?

Polymers are substances containing a large number of structural units joined by the same type of linkage. These substances often form into a chain-like structure. Polymers in the natural world have been around since the beginning of time. Starch, cellulose, and rubber all possess polymeric properties. Man-made polymers have been studied since 1832. Today, the polymer industry has grown to be larger than the aluminum, copper and steel industries combined.

Polymers already have a range of applications that far exceeds that of any other class of material available to man. Current applications extend from adhesives, coatings, foams, and packaging materials to textile and industrial fibers, **elastomers,** and structural plastics. Polymers are also used for most **composites**, electronic devices, biomedical devices, optical devices, and precursors for many newly developed high-tech ceramics.

Applications of Polymers:

<u>Agriculture and Agribusiness</u>

- Polymeric materials are used in and on soil to improve aeration, provide mulch, and promote plant growth and health.

<u>Medicine</u>

- Many biomaterials, especially heart valve replacements and blood vessels, are made of polymers like Dacron, Teflon and polyurethane.

<u>Consumer Science</u>

- Plastic containers of all shapes and sizes are light weight and economically less expensive than the more traditional containers. Clothing, floor coverings, garbage disposal bags, and packaging are other polymer applications.

<u>Industry</u>

- Automobile parts, windshields for fighter planes, pipes, tanks, packing materials, insulation, wood substitutes, adhesives, matrix for composites, and elastomers are all polymer applications used in the industrial market.

<u>Sports</u>

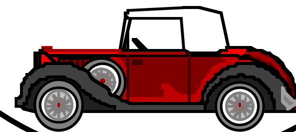
- Playground equipment, various balls, golf clubs, swimming pools, and protective helmets are often produced from polymers.

HISTORY OF POLYMERS

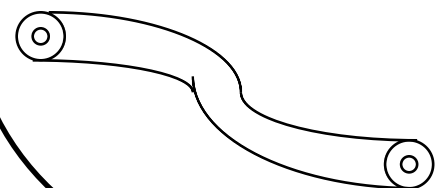
1500-PRESENT

1500's
British explorers discover the ancient Mayan civilization in Central America. The Mayans are assumed to be among the first to find an application for polymers; as their children were fond of playing with balls made from local **rubber** trees.

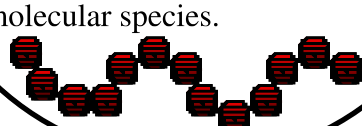
1839
Charles Goodyear discovers **vulcanization**, by combining natural rubber with sulfur and heating it to 270 degrees Fahrenheit. Vulcanized rubber is a polymeric substances that is much more durable than its natural counter part. Its most common use today is in automobile tires.



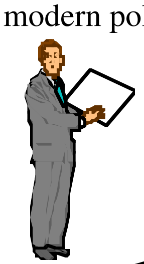
1907
The oldest recorded synthetic plastic is fabricated by Leo Bakeland. **Bakelite**'s hardness and high heat resistivity made it an excellent choice as an electrical insulator.



1917
X-ray crystallography is invented as a method of analyzing crystal structures. Eight years later, this method is used by M. Polanyi to discover the chemical structure of **cellulose**. This establishes the fact that polymer unit cells contain sections of long chain molecules rather than small molecular species.

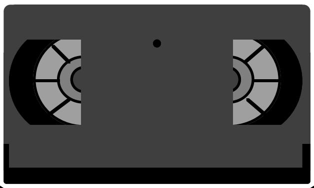


1920
Staudinger published his classic paper entitled "Uber **Polymerization.**" Publication of this paper heralded a decade of intense research and presented to the world the development of modern polymer theory.



1927
Large scale production of **vinyl-chloride** resins begins. This polymeric compound continues to be widely used today to make plumbing (PVC) pipe, Euttery tile, and bottles.

1930
Polystyrene is invented. This polymeric material is used in videocassettes and other packaging. Expanded polystyrene (commonly called Styrofoam) is used in cups, packaging, and thermally insulated containers.

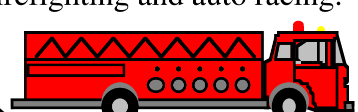


1938
Wallace Carothers of the Dupont company produces another well known polymeric product, nylon. **Nylon** is a common material used today for such applications as ropes and clothes.

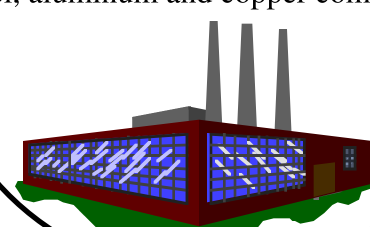
1941
Polyethylene is developed. Billions of pounds of both high and low density versions of this material are produced annually for everything from packaging film to piping to toys.

1970
James Economy develops one of the pioneer moldable high temperature polymers (**Ekono**l). This polymeric material paved the way for the development of liquid crystal polymers one year later. Ekonol's most common applications occur in electronic devices and aircraft engines.

1971
S. Kwolek, who has been awarded more than 37 patents in polymer science, develops **kevlar**. Kevlar is a high strength material that can withstand temperatures up to 300°C, and is used in applications such as bullet proof vests, and fire proof garments for firefighting and auto racing.



1976
The polymer/plastics industry outstripped steel as the nation's most widely used **material** per unit volume. We now use more plastic than steel, aluminum and copper combined.



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Future Trends

Just as nature has used biological polymers as the material of choice, mankind will chose polymeric materials as the choice material. Humans have progressed from the Stone Age, through the Bronze, Iron, and Steel Ages into its current age, the Age of Polymers. An age in which synthetic polymers are and will be the material of choice.

Polymeric materials have a vast potential for exciting new applications in the foreseeable future. Polymer uses are being developed in such diverse areas as: conduction and storage of electricity, heat and light, molecular based information storage and processing, molecular composites, unique separation membranes, revolutionary new forms of food processing and packaging, health, housing, and transportation. Indeed, polymers will play an increasingly important role in all aspects of your life.

The large number of current and future applications of polymeric materials has created a great national need for persons specifically trained to carry out research and development in polymer science and engineering. A person choosing a career in this field can expect to achieve both financial reward and personal fulfillment.

Scientific Principles

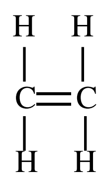
The field of polymers is so vast and the applications so varied, that it is important to understand how polymers are made and used. Since there are over 60,000 different plastics vying for a place in the market, knowledge of this important field can truly enrich our appreciation of this wonder material. Companies manufacture over 30 million tons of plastics each year, and spend large sums on research, development, and more efficient recycling methods. Below we learn some of the scientific principles involved in the production and processing of these fossil fuel derived materials known as polymers.

Polymerization Reactions

The chemical reaction in which high molecular mass molecules are formed from monomers is known as **polymerization.** There are two basic types of polymerization, chain-reaction (or **addition**) and step-reaction (or **condensation**) **polymerization**.

<u>Chain-Reaction Polymerization</u>

One of the most common types of polymer reactions is chain-reaction (addition) polymerization. This type of polymerization is a three step process involving two chemical entities. The first, known simply as a **monomer**, can be regarded as one link in a polymer chain. It initially exists as simple units. In nearly all cases, the monomers have at least one carbon-carbon double bond. Ethylene is one example of a monomer used to make a common polymer.



Ethylene

The other chemical reactant is a catalyst. In chain-reaction polymerization, the catalyst can be a **free-radical** peroxide added in relatively low concentrations. A free-radical is a chemical component that contains a free electron that forms a covalent bond with an electron on another molecule. The formation of a free radical from an organic peroxide is shown below:

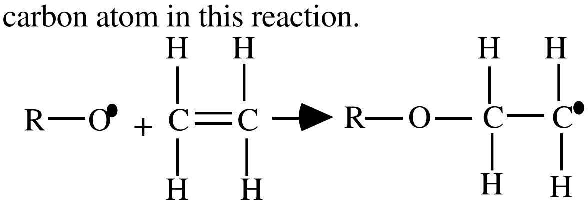
$$R-O-O-R \rightarrow R-O^{\bullet} + R-O^{\bullet}$$

with ($\bullet$) representing the free electron

In this chemical reaction, two free radicals have been formed from the one molecule of R_2O_2. Now that all the chemical components have been identified, we can begin to look at the polymerization process.

Step 1: **Initiation**

The first step in the chain-reaction polymerization process, initiation, occurs when the free-radical catalyst reacts with a double bonded carbon monomer, beginning the polymer chain. The double carbon bond breaks apart, the monomer bonds to the free radical, and the free electron is transferred to the outside carbon atom in this reaction.



Step 2: **Propagation**

The next step in the process, propagation, is a repetitive operation in which the physical chain of the polymer is formed. The double bond of successive monomers is opened up when the monomer is reacted to the reactive polymer chain. The free electron is successively passed down the line of the chain to the outside carbon atom.

$$\underbrace{R-O-CH_2-CH_2^{\bullet}}_{\text{Propagating Polymer chain}} + \underbrace{CH_2=CH_2}_{\text{Monomer}} \rightarrow R-\underbrace{O-CH_2-CH_2-CH_2-CH_2^{\bullet}}_{\text{New Polymer chain}}$$

This reaction is able to occur continuously because the energy in the chemical system is lowered as the chain grows. Thermodynamically speaking, the sum of the energies of the polymer is less than the sum of the energies of the individual monomers. Simply put, the single bounds in the polymeric chain are more stable than the double bonds of the monomer.

Step 3: **Termination**

Termination occurs when another free radical (R-O·), left over from the original splitting of the organic peroxide, meets the end of the growing chain. This free-radical terminates the chain by linking with the last CH_2· component of the polymer chain. This reaction produces a complete polymer chain. Termination can also occur when two unfinished chains bond together. Both termination types are diagrammed below. Other types of termination are also possible.

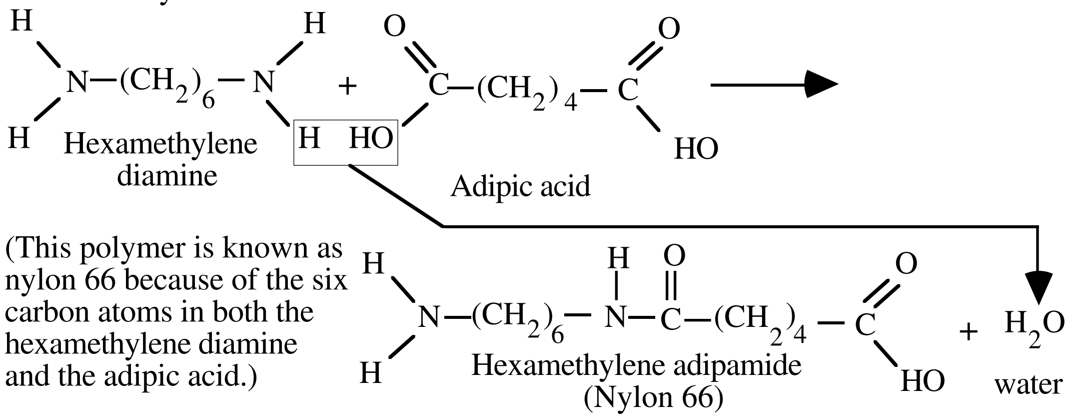
$$\underbrace{R-O-CH_2-CH_2-CH_2-CH_2^{\bullet}}_{\text{Propagating Polymer chain}} + \underset{\substack{\uparrow \\ \text{left over free-} \\ \text{radical}}}{R-O^{\bullet}} \rightarrow R-\underbrace{O-CH_2-CH_2-CH_2-CH_2-O}_{\text{Completed polymer chain}}-R$$

$$\underbrace{R-O-CH_2-CH_2^{\bullet} + R-O-CH_2-CH_2^{\bullet}}_{\text{Propagating Polymer chains}} \rightarrow R-\underbrace{O-CH_2-CH_2-CH_2-CH_2-O}_{\text{Completed polymer chain}}-R$$

This exothermic reaction occurs extremely fast, forming individual chains of polyethylene often in less than 0.1 second. The polymers created have relatively high molecular weights. It is not unusual for **branches** or **cross-links** with other chains to occur along the main chain.

<u>Step-Reaction Polymerization</u>

Step-reaction (condensation) polymerization is another common type of polymerization. This polymerization method typically produces polymers of lower molecular weight than chain reactions and requires higher temperatures to occur. Unlike addition polymerization, step-wise reactions involve two different types of di-functional monomers or **end groups** that react with one another, forming a chain. Condensation polymerization also produces a small molecular by-product (water, HCl, etc.). Below is an example of the formation of Nylon 66, a common polymeric clothing material, involving one each of two monomers, hexamethylene diamine and adipic acid, reacting to form a **dimer** of Nylon 66.



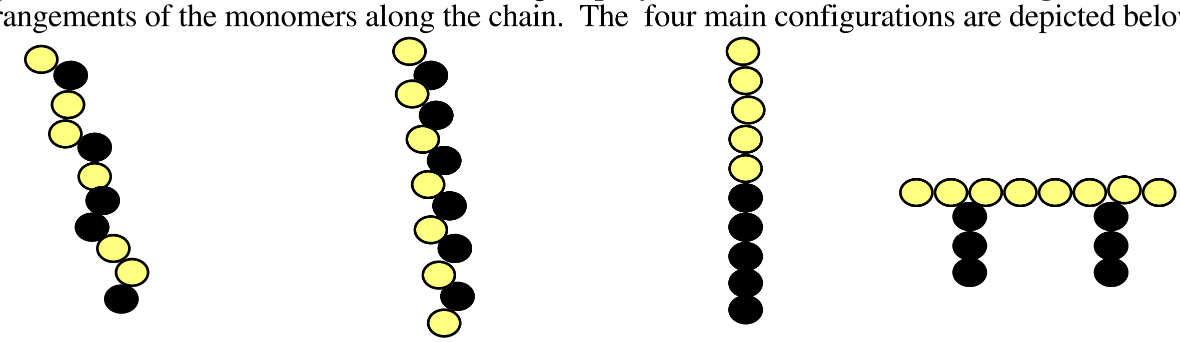
(This polymer is known as nylon 66 because of the six carbon atoms in both the hexamethylene diamine and the adipic acid.)

At this point, the polymer could grow in either direction by bonding to another molecule of hexamethylene diamine or adipic acid, or to another dimer. As the chain grows, the short chain molecules are called **oligomers**. This reaction process can, theoretically, continue until no further monomers and reactive end groups are available. The process, however, is relatively slow and can take up to several hours or days. Typically this process breeds linear chains that are strung out without any cross-linking or branching, unless a tri-functional monomer is added.

Polymer Chemical Structure

The monomers in a polymer can be arranged in a number of different ways. As indicated above, both addition and condensation polymers can be linear, branched, or cross-linked. **Linear** polymers are made up of one long continuous chain, without any excess appendages or attachments. **Branched** polymers have a chain structure that consists of one main chain of molecules with smaller molecular chains branching from it. A branched chain-structure tends to lower the degree of crystallinity and density of a polymer. **Cross-linking** in polymers occurs when primary valence bonds are formed between separate polymer chain molecules.

Chains with only one type of monomer are known as **homopolymers**. If two or more different type monomers are involved, the resulting **copolymer** can have several **configurations** or arrangements of the monomers along the chain. The four main configurations are depicted below:



Random Copolymers: Different monomers are randomly arranged within the polymer chains.

Alternating Copolymers: Different monomers show a definite ordered alternation.

Block Copolymers: Different monomers are arranged in long blocks of each monomer.

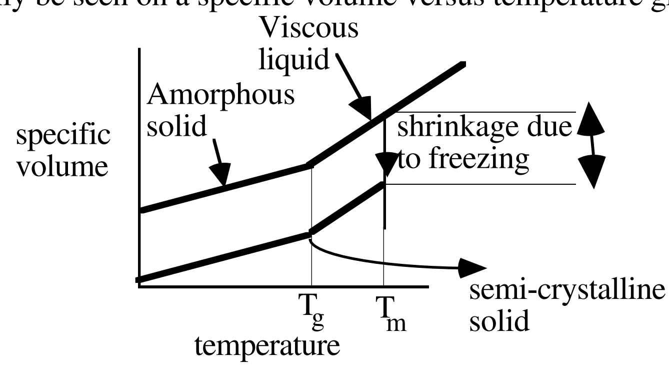
Graft Copolymers: Appendages of one type of monomer are grafted to a long chain of the other.

Figure 1: Copolymer configurations.

Polymer Physical Structure

Segments of polymer molecules can exist in two distinct physical structures. They can be found in either **crystalline** or **amorphous** forms. Crystalline polymers are only possible if there is a regular chemical structure (e.g., homopolymers or alternating copolymers), and the chains possess a highly ordered arrangement of their segments. Crystallinity in polymers is favored in symmetrical polymer chains, however, it is never 100%. These semi-crystalline polymers possess a rather typical liquefaction pathway, retaining their solid state until they reach their melting point at $\mathbf{T_m}$.

Amorphous polymers do not show order. The molecular segments in amorphous polymers or the amorphous **domains** of semi-crystalline polymers are randomly arranged and entangled. Amorphous polymers do not have a definable $\mathbf{T_m}$ due to their randomness. At low temperatures, below their glass transition temperature **($\mathbf{T_g}$)**, the segments are immobile and the sample is often brittle. As temperatures increase close to $\mathbf{T_g}$, the molecular segments can begin to move. Above $\mathbf{T_g}$, the mobility is sufficient (if no crystals are present) that the polymer can flow as a highly viscous liquid. The **viscosity** decreases with increasing temperature and decreasing molecular weight. There can also be an elastic response if the entanglements cannot align at the rate a force is applied (as in silly putty). This material is then described as visco-elastic. In a semi-crystalline polymer, molecular flow is prevented by the portions of the molecules in the crystals until the temperature is above $\mathbf{T_m}$. At this point a visco-elastic material forms. These effects can most easily be seen on a specific volume versus temperature graph.



In the are between Tg and Tm, the semi-crystalline polymer is a tough solid. The amorphous material changes to a viscous liquid after Tg. This is when the material can be easily deformed.

Figure 2: Specific Volume versus Temperature graph.

Members of the Polymer Family

Polymers can be separated into two different groups depending on their behavior when heated. Polymers with linear molecules are likely to be **thermoplastic**. These are substances that soften upon heating and can be remolded and recycled. They can be semi-crystalline or amorphous. The other group of polymers is known as **thermosets**. These are substances that do not soften under heat and pressure and cannot be remolded or recycled. They must be remachined, used as **fillers**, or incinerated to remove them from the environment.

Thermoplastics

Thermoplastics are generally carbon containing polymers synthesized by addition or condensation polymerization. This process forms strong covalent bonds within the chains and weaker secondary **Van der Waals** bonds between the chains. Usually, these secondary forces can be easily overcome by thermal energy, making thermoplastics moldable at high temperatures. Thermoplastics will also retain their newly reformed shape after cooling. A few common applications of thermoplastics include: parts for common household appliances, bottles, cable insulators, tape, blender and mixer bowls, medical syringes, mugs, textiles, packaging, and insulation.

Thermosets

Thermosets have the same Van der Waals bonds that thermoplastics do. They also have a stronger linkage to other chains. Strong covalent bonds chemically hold different chains together in a thermoset material. The chains may be directly bonded to each other or be bonded through other molecules. This "cross-linking" between the chains allows the material to resist softening upon heating. Thus, thermosets must be machined into a new shape if they are to be reused or they can serve as powdered fillers. Although thermosets are difficult to reform, they have many distinct advantages in engineering design applications including:

1. High thermal stability and insulating properties.
2. High rigidity and dimensional stability.
3. Resistance to **creep** and deformation under load.
4. Light-weight.

A few common applications for thermosets include epoxies (glues), automobile body parts, adhesives for plywood and particle board, and as a matrix for composites in boat hulls and tanks.

Polymer Processing

There are five basic processes to form polymer products or parts. These include; injection molding, compression molding, transfer molding, blow molding, and **extrusion**. Compression molding and transfer molding are used mainly for thermosetting plastics. Injection molding, extrusion and blow molding are used primarily with thermoplastics.

Injection Molding

This very common process for forming plastics involves four steps:

1. Powder or pelletized polymer is heated to the liquid state.
2. Under pressure, the liquid polymer is forced into a mold through an opening, called a sprue. Gates control the flow of material.
3. The pressurized material is held in the mold until it solidifies.
4. The mold is opened and the part removed by ejector pins.

Advantages of injection molding include rapid processing, little waste, and easy automation. Molded parts include combs, toothbrush bases, pails, pipe fittings, and model airplane parts.

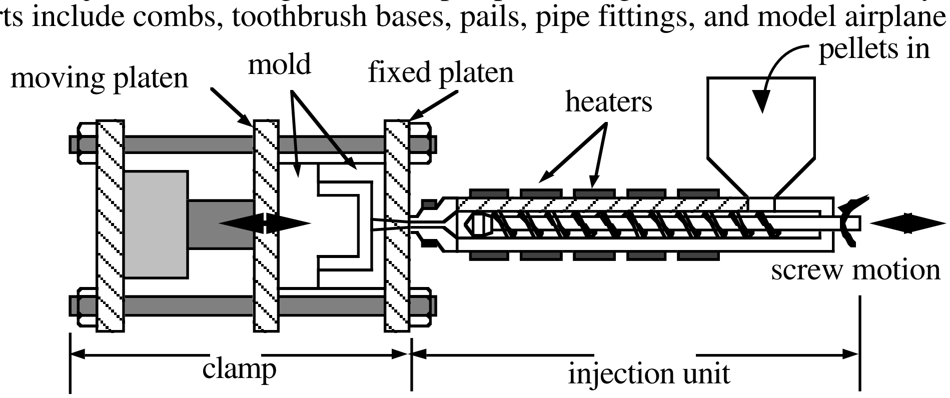


Figure 3: Diagram of injection molding.

Compression Molding

This type of molding was among the first to be used to form plastics. It involves four steps:

1. Pre-formed blanks, powders or pellets are placed in the bottom section of a heated mold or die.
2. The other half of the mold is lowered and is pressure applied.
3. The material softens under heat and pressure, flowing to fill the mold. Excess is squeezed from the mold. If a thermoset, cross-linking occurs in the mold.
4. The mold is opened and the part is removed.

For thermoplastics, the mold is cooled before removal so the part will not lose its shape. Thermosets may be ejected while they are hot and after curing is complete. This process is slow, but the material moves only a short distance to the mold, and does not flow through gates or runners. Only one part is made from each mold.

Transfer Molding

This process is a modification of compression molding. It is used primarily to produce thermosetting plastics. Its steps are:

1. A partially polymerized material is placed in a heated chamber.
2. A plunger forces the flowing material into molds.
3. The material flows through sprues, runners and gates.
4. The temperature and pressure inside the mold are higher than in the heated chamber, which induces cross-linking.
5. The plastic cures, is hardened, the mold opened, and the part removed.

Mold costs are expensive and much scrap material collects in the sprues and runners, but complex parts of varying thickness can be accurately produced.

Blow Molding

Blow molding produces bottles, globe light fixtures, tubs, automobile gasoline tanks, and drums. It involves:

1. A softened plastic tube is extruded
2. The tube is clamped at one end and inflated to fill a mold.
3. Solid shell plastics are removed from the mold.

This process is rapid and relatively inexpensive.

Extrusion

This process makes parts of constant cross section like pipes and rods. Molten polymer goes through a die to produce a final shape. It involves four steps:

1. Pellets of the polymer are mixed with coloring and additives.
2. The material is heated to its proper plasticity.
3. The material is forced through a die.
4. The material is cooled.

An extruder has a hopper to feed the polymer and additives, a barrel with a continuous feed screw, a heating element, and a die holder. An adapter at the end of an extruder blowing air through an orifice into the hot polymer extruded through a ring die produces plastic bags and films.

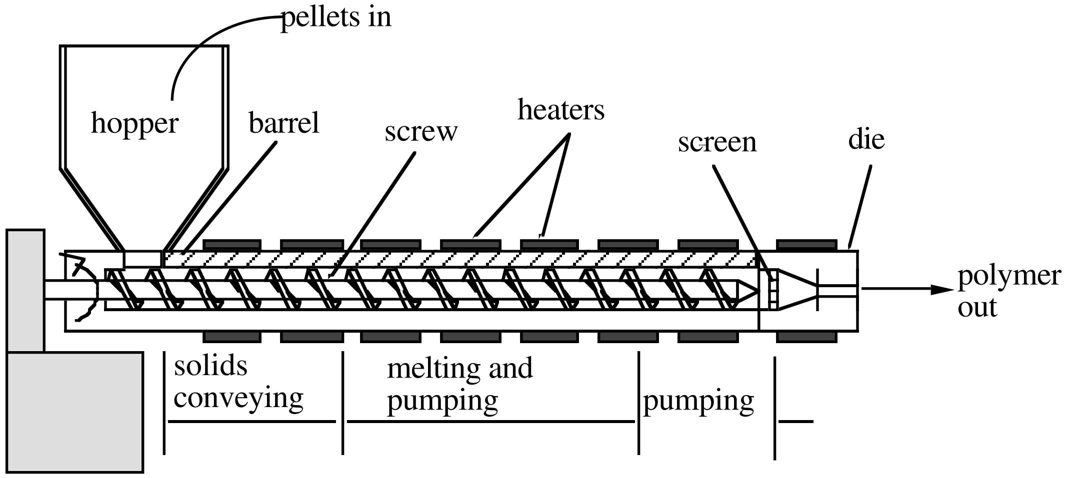


Figure 4: Diagram of an extruder.

Table 1: Comparison of polymer processing techniques for thermoplastics and thermosets.

Process	Thermoplastic (TP) or Thermoset(TS)	Advantages	Disadvantages
Injection Molding	TP, TS	It has the most precise control of shape and dimensions, is a highly automatic process, has fast cycle time, and the widest choice of materials.	It has high capital cost, is only good for large numbers of parts, and has large pressures in mold (20,000 psi).
Compression Molding	TS	It has lower mold pressures (1000 psi), does minimum damage to reinforcing fibers (in composites), and large parts are possible.	It requires more labor, longer cycle than injection molding, has less shape flexibility than injection molding, and each charge is loaded by hand.
Transfer Molding	TS	It is good for encapsulating metal parts and electronic circuits.	There is some scrap with every part and each charge is loaded by hand.
Blow Molding	TP	It can make hollow parts (especially bottles), stretching action improves mechanical properties, has a fast cycle, and is low labor.	It has no direct control over wall thickness, cannot mold small details with high precision, and requires a polymer with high melt strength.
Extrusion	TP	It is used for films, wraps, or long continuos parts (ie. pipes).	It must be cooled below its glass transition temperature to maintain stability.

Recycling: Today's Challenge, Tomorrow's Reward

Overview

Consumer waste in the United States poses a challenge to everyone. Waste solid materials can be grouped into the following categories:

metals - aluminum, steel, etc.
glass - clear, colored, etc.
paper - newsprint, cardboard, etc.
natural polymers - leather, grass, leaves, cotton, etc.
synthetic polymers - synthetic rubbers, polyethylene terephthalate, polyvinyl chloride, etc.

Today, consumers are using more products and, therefore, producing more solid waste. As time goes by, we find ourselves with less space to put this waste. Eighty percent of all solid waste is buried in landfills. Today there are one third fewer landfills in operation than the 18,500 available a decade ago, making land-filling much more expensive.

Tipping fees, the charge to the waste hauler for dumping a load of solid waste, have been increasing regularly. Municipalities have imposed restrictions and/or have banned the startup of new landfills within their boundaries. As an example, 50% of New Jersey's solid waste is shipped out of state for landfill burial.

The amount which synthetic polymers contribute to the weight of solid waste will continue to go up as the use of plastics increases as projected below.

Table 2: America's plastic waste percentage by weight.

Year	Total Waste	Percentage Plastics
1960	76 million tons	2.7%
1984	133 million tons	7.2 %
1995	142 million tons	8.4 %
2000	159 million tons	9.8 % (projected)

Plastics constitute between 14 and 22% of the volume of solid waste. One possible answer to this problem is recycling. In 1990, 1 to 2% of plastics, 29% of aluminum, 25% of paper, 7% of glass, and 3% of rubber and steel as post consumer wastes were recycled. Obviously, increasing the amount of plastics recycled would appear to be the answer. However, a major handicap in the reuse of plastics is that reprocessing adds a heat history, degrades properties and makes repeat use for the same application difficult. For example, the 58 gram, 2-liter polyethylene terephthalate (PET) beverage bottle consists of 48 g of PET, the rest being a high density polyethylene (HDPE) cup base, paper label, adhesive, and molded polypropylene (PP) cap. The cup base, label, adhesive and cap are contaminants in the recycling of the PET.

In response to the contaminants issue in plastic recycling, plastic products are being designed "reuse-friendly". Products are being made with recyclability as a viable means for disposal. At least one company has designed a 2-liter beverage bottle made of all PET for cost effective recycling. Concerning the reuse of recycled plastics, many organizations are reevaluating the use of recycled plastics. As an example, plastic beads are being used to remove paint from aircraft employing a "sand blasting" type method. Previously, harsh, environmentally unfriendly chemical solvents were used. The use of recycled plastics is only limited by the imagination of the designers and end users of the plastics.

Another reason for not discarding plastics is the conservation of energy. The energy value of polyethylene (PE) is 100 % of an equivalent mass of # 2 heating oil. Polystyrene (PS) is 75%, while polyvinyl chloride (PVC) and PET are about 50%. With the energy value of a pound of #2 heating oil at 20,000 B.T.U., land filling plastics results in a waste of energy. Some countries, notably Japan, tap into the energy value of plastic and paper with waste-to-energy incinerators.

Another factor in the recycling equation is the economic trend of increasing tipping fees at landfills. In northeastern states, tipping fees have progressively increased, but in western states the fees have remained low due to the local government subsidies to landfills. As the cost of land filling of solid waste increases, so does the incentive to recycle. When the cost of land filling exceeds the cost of recycling, recycling will be a practical alternative to land filling.

These factors have led to certain recommendations by the United States Environmental Protection Agency. In order of highest to lowest, the EPA's recommendations are: source reduction, recycling, thermal reduction (incineration), and land filling. Each of these is not without its problems. Source reduction calls for the redesigning of packaging and/or the use of less, lighter, or more environmentally safe materials. The trade-off could mean reduced food packaging with the possibility of higher food spoilage rates. There would be fewer plastics, but more food in solid waste to be disposed. Whatever disposal method is chosen, the choice is complex. Whatever the costs, the consumer will bear them.

Recycling of Different Plastics

<u>PET (polyethylene terephthalate)</u>

In 1989, a billion pounds of virgin PET were used to make beverage bottles of which about 20% was recycled. Of the amount recycled, 50% was used for fiberfill and strapping. The reprocessors claim to make a high quality, 99% pure, granulated PET. It sells at 35 to 60% of virgin PET costs.

The major reuses of PET include sheet, fiber, film, and extrusions. When chemically treated, the recycled product can be converted into raw materials for the production of unsaturated **polyester** resins. If sufficient energy is used, the recycled product can be depolymerized to ethylene glycol and terephthalic acid and then repolymerized to virgin PET.

<u>HDPE (high density polyethylene)</u>

Of the plastics that have a potential for recycling, the rigid HDPE container is the one most likely to be found in a landfill. Less than 5% of HDPE containers are treated or processed in a manner that makes recycling easy. Virgin HDPE is used in opaque household and industrial containers used to package motor oil, detergent, milk, bleach, and agricultural chemicals.

There is a great potential for the use of recycled HDPE in base cups, drainage pipes, flower pots, plastic lumber, trash cans, automotive mud flaps, kitchen drain boards, beverage bottle crates, and pallets. Most recycled HDPE is a colored opaque material, that is available in a multitude of tints.

<u>LDPE (low density polyethylene)</u>

LDPE is recycled by giant resin suppliers and merchant processors either by burning it as a fuel for energy or reusing it in trash bags. Recycling trash bags is a big business. Their color is not critical, therefore, regrinds go into black, brown, and to some lesser extent, green and yellow bags.

PVC (polyvinyl chloride)

There is much controversy concerning the recycling and reuse of PVC due to health and safety issues. When PVC is burned, the effects on the incinerator and quality of the air are often questioned. The Federal Food and Drug Administration (FDA) has ordered its staff to prepare environmental impact statements covering PVC's role in landfills and incineration. The burning of PVC releases toxic dioxins, furans, and hydrogen chloride. These fumes are carcinogenic, mutagenic, and teratagenic. This is one of the reasons why PVC must be identified and removed from any plastic waste to be recycled.

Currently, PVC is used in food and alcoholic beverage containers with FDA approval. The future of PVC rests in the hands of the plastics industry to resolve the issue of the toxic effects of the incineration of PVC. It is of interest to note that PVC accounts for less than 1% of land fill waste. When PVC is properly recycled, the problems of toxic emissions are minimized. Various recyclers have been able to reclaim PVC without the health problems. Uses for recycled PVC include aquarium tubing, drainage pipe, pipe fittings, floor tile, and nonfood bottles. When PVC is combined with other plastic waste it has been used to produce plastic lumber.

PS (polystyrene)

PS and its manufacturers have been the target of environmentalists for several years. The manufacturers and recyclers are working hard to make recycling of PS as common as that of paper and metals. One company, Rubbermaid, is testing reclaimed PS in service trays and other utility items. Amoco, another large corporation, currently has a method that converts PS waste, including residual food, to an oil that can be re-refined.

The Future

Recycling is a viable alternative to all other means of dealing with consumer plastic waste. In response to the problem of mixed plastic waste, a coding system has been developed and adopted by the plastic industry. The code is a number and letter system. It applies to bottles exceeding 16 ounces and other containers exceeding 8 ounces. The number appears in the 3 bent arrow recycling symbol with the abbreviation of the plastic below the symbol.

Western European companies, especially the German firms Hoechst and Bayer, have entered the recyclable plastic market with success. With a high tech approach, they are devising new methods to separate and handle mixed plastics waste.

A potential use for recycled materials includes plastic lumber. The recycled plastic is mixed with wood fibers and processed into a replacement for lumber. The wood fibers would have become land fill if not reused. The end product is called Biopaste. This is expected to eventually become a multi-million dollar enterprise. Research and development continue to improve this product.

Recycling is a cost effective means of dealing with consumer plastic waste. Research to reduce the cost of recycling needs to continue. Recycling of plastics is not going to reach the level of the recycling programs of paper and some metals until lower cost, automatic methods of recycling are in place. Fortunately, the solutions to these problems are not beyond the scope of our technology or our minds. Below is a chart listing the different types of plastics and their uses before and after they are recycled.

Table 3: Major Plastic Resins and Their Uses

Resin Code	Resin Name	Common Uses	Examples of Recycled Products
1	Polyethylene Terephthalate (PET or PETE)	Soft drink bottles, peanut butter jars, salad dressing bottles, mouth wash jars	Liquid soap bottles, strapping, fiberfill for winter coats, surfboards, paint brushes, fuzz on tennis balls, soft drink bottles, film
2	High density Polyethylene (HDPE)	Milk, water, and juice containers, grocery bags, toys, liquid detergent bottles	Soft drink based cups, flower pots, drain pipes, signs, stadium seats, trash cans, re-cycling bins, traffic barrier cones, golf bag liners, toys
3	Polyvinyl Chloride or Vinyl (PVC-V)	Clear food packaging, shampoo bottles	Floor mats, pipes, hoses, mud flaps
4	Low density Polyethylene (LDPE)	Bread bags, frozen food bags, grocery bags	Garbage can liners, grocery bags, multi purpose bags
5	Polypropylene (PP)	Ketchup bottles, yogurt containers, margarine, tubs, medicine bottles	Manhole steps, paint buckets, videocassette storage cases, ice scrapers, fast food trays, lawn mower wheels, automobile battery parts.
6	Polystyrene (PS)	Video cassette cases, compact disk jackets, coffee cups, cutlery, cafeteria trays, grocery store meat trays, fast-food sandwich container	License plate holders, golf course and septic tank drainage systems, desk top accessories, hanging files, food service trays, flower pots, trash cans

References

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Handbook of Chemistry and Physics, 65th ed., CRC Press, Inc., Boca Raton, FL (1985).

Modern Plastics, Encyclopedia, Mid-October 1990 Issue, Volume 67, Number 11, McGraw Hill, Inc., Hightstown, NJ (1990).

Polymer Chemistry, American Chemical Society (1986).

Polymer Chemistry, National Science Teachers Association (1989).

Shakhashiri, B, Chemistry Experiments I, University of Wisconsin Press, Madison, WI (1983).

Smith, William F., Foundations of Materials Science and Engineering, McGraw Hill, NY (1993).

"Waste Solutions," Modern Plastics, April, (1990).

Polymer Resources

An excellent resource for this module is Polymer Chemistry, 1989. It includes applications, theory, and experiments/demonstrations. Also available with it is a computer program "An Introduction to Polymerization" for the APPLE II series. Both are available for $22.00 from:

NSTA Publications Department PL
1742 Connecticut Avenue NW
Washington, DC 20009-0002

Available on video cassette is a two part videotape. Part I is "Polymers" and part two is "Biochemistry". The cost in the current catalog is listed as $59.00. It is available from:

Wings for Learning/Sunburst Communication
1600 Green Hills Road
PO Box 660002
Scotts Valley, CA 95076-0002

Another video tape titled "Polymers" runs for approximately nine and one-half minutes and is available from:

Films for the Humanities and Sciences
PO BOX 2053
Princeton, NJ 08450

Useful in developing an understanding of the mechanism by which addition polymerization occurs is the game "Polymer Rummy - A Game for 2 - 4 Players" by Dr. Doug Halsted. It also emphasizes some of the many uses of polyethylene.

Any one or all the above materials are good and will help to bring to life the theory of polymers and the reactions by which they form. The video from WINGS for Learning also provides some information on processing and applications of polymers.

Recycling Resources

There are numerous not for profit and for profit organizations that can be contacted for recycling information. A few are listed below.

DOW Plastics has a "Recycle This!" information package.
2040 Dow Center
Midland, MI 48674
1-800-441-4369

American Plastics Council
1275 K Street, NW.
Suite 400
Washington, DC 20005
202-371-5212 or 1-800-2-HELP-90

National Association of Recycling Industries
330 Madison Ave
New York, NY 10011

Center for Plastics Recycling Research
Rutgers University
Building 3529, Busch Campus
Piscataway, NJ 08855

National Recycling Coalition
45 Rockefeller Plaza
Room 2350
New York, NY 10011

National Soft Drink Association
1101 16th Street, NW.
Washington, DC 20036
202-463-6770

National Polystyrene Recycling Company
1700 W 119th Street
Chicago, IL 60643
708-945-2139

also,
4 Kildeer Court
Bridgeport , NJ 08014
609-467-9377

also,
720 South Temescal Street
Corona, CA 91719
909-736-7040

Polymer Demonstrations Materials Grid

Materials	Demo 1	Demo 2	Demo 3
Methyl Acrylate	LE		
Potassium Bromate	LE		
Sodium Bisulfite	LE		
Sodium Chloride	LE/GS		
Acetone	LE/PH		
Pop beads (3 colors)		LE/DS	
Leaf bag (1 layer)		GS/DS	
Leaf bag (2 layer)		GS/DS	
Newspaper		GS	
Cellophane tape		GS/DS	
Iridescent plastic film		LE	
2 Polarizing lenses		LE	
Hexamethylene-diamine			LE
Sodium Hydroxide			LE/DS
Sebacoyl Chloride			LE
Hexane			LE
Erlenmeyer flask	LE		
Beaker	LE		
Stirring rods	LE		LE
Polyethylene sheets	LE		
Gloves			LE
250 ml beaker			LE
Forceps			LE
Food coloring			GS
Phenolphthalein			LE

Key:
DS = DISCOUNT STORE
LE = LAB EQUIPMENT/SCIENTIFIC CATALOG
GS = GROCERY STORE
PH = PHARMACY

Demonstration 1

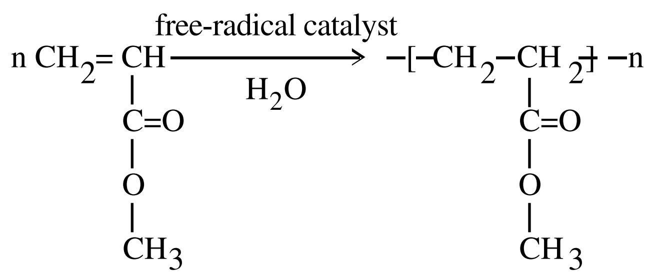
Let's Make an Addition Polymer

The Polymerization of Polymethylacrylate from a Methyl Acrylate Monomer

Objective: The objective of this demonstration is to produce an addition polymer using a free radical initiator.

Review of Scientific Principles:

Poly (methyl acrylate) is an addition polymer. The reaction can be represented as:



Because the high rate and heat of polymerization of acrylates make control of bulk polymerization impractical, the most important method of preparation is by emulsion polymerization. Water serves as a moderator and a solvent for the catalyst system. The catalyst is produced by the reaction of bromate ions and hydrogen sulfite ions and is known to produce hydroxyl radicals (OH•) and hydrogen bisulfite radicals (HSO_3•). Other water soluble catalysts such as ammonium peroxydisulfate or potassium peroxydisulfate (often called persulfate), may be used, but the mixture must be heated to generate free radicals.

In this demonstration, methyl acrylate in an aqueous emulsion polymerizes in the presence of a free-radical catalyst. The polymer is coagulated in a concentrated solution of sodium chloride to yield a white product. An acetone solution can be used to produce a film.

Time: 20 -25 minutes are required

Materials and Supplies:

- 300 ml of 0.6 M (5%) methyl acrylate, $CH_2 = CHCOOCH_3$ (To prepare: mix 16 ml of methyl acrylate with 284 ml of water.)
- 5 ml of 0.1 M potassium bromate, $KBrO_3$, (To prepare: dissolve 0.4 g $KBrO_3$ in water and dilute to 25 ml. This will be enough for 5 demonstrations.)
- 5 ml of 0.45 M sodium hydrogen sulfite, $NaHSO_3$ (freshly prepared) (To prepare: dissolve 0.47 g $NaHSO_3$ in water and dilute to 10 ml. This will be enough for 2 demonstrations.)
- 300 ml 5 M NaCl (To prepare: dissolve 88 g of NaCl in water and dilute to 300 ml)
- 10 ml acetone, CH_3COCH_3
- 1 Liter Erlenmeyer flask
- 50 ml beaker
- 2 stirring rods
- polyethylene sheet, 15 cm x 15 cm
- gloves, plastic or rubber

General Safety Guidelines:

- Perform this demonstration in a hood and wear plastic or rubber gloves.
- Methyl acrylate has an acrid odor and is a lachrymator. The monomer is highly irritating to eyes, skin, and mucous membranes.
- If large concentrations of the vapor are inhaled, lethargy and convulsions may result.
- Since methyl acrylate and acetone are extremely flammable, this demonstration should be performed away from flames or other sources of heat.

Procedure:

1. Perform this demonstration in a hood and wear gloves.
2. Place 300 ml of 5% methyl acrylate in a 1-Liter Erlenmeyer flask.
3. Add 5 ml of 0.1 M potassium bromate solution and 5 ml of 0.45 M sodium hydrogen sulfite solution.
4. Swirl the flask to mix the contents thoroughly and allow the reaction to proceed for about 15 minutes, shaking the flask occasionally during this time. As the particles grow, the mixture quickly takes on a milky appearance.
5. Pour the emulsion into 300 ml of 5 M sodium chloride solution to coagulate the polymer.
6. Remove the polymer mass with tweezers.
7. Wash it thoroughly and knead it under water to remove salt and any unreacted monomer.
8. Repeat once or twice with additional fresh water.
9. Prepare a film by tearing or cutting the white poly (methyl acrylate) into small pieces and dissolving it in acetone (about 1 g/10 ml).
10. Stir the mixture with a glass rod. The resulting liquid should be thick and viscous.
11. Pour this liquid onto a piece of polyethylene film and allow it to dry for several hours.
12. The film can be peeled from the polyethylene surface.

Disposal:

The washed polymer can be discarded in a waste container.

Teacher Notes:

- This should be conducted only as a "DEMONSTRATION." Adequate hood facilities are generally not available for each member of the class to run this as a qualitative lab and student exposure is definitely a consideration. Special note should be made to the safety section of this lab.

- Addition polymerization can also be shown more expeditiously by the use of the following:
  a) Squirt string (polystyrene) from an aerosol can. This can be purchased from a number of discount stores.
  b) Aerosol foam insulation which is used in homes to seal electrical boxes. This can be purchased at most hardware stores.
  c) <u>Mounting in Minutes</u> is a product which is used in model railroading. This two can mix may be purchased from most hobby shops.

Demonstration 2

Intro. to the New Chain Gang

An Introduction to the Physical Properties of Polymeric Chains

Objective: The objective of this demonstration is to present the characteristics and properties of polymer chains.

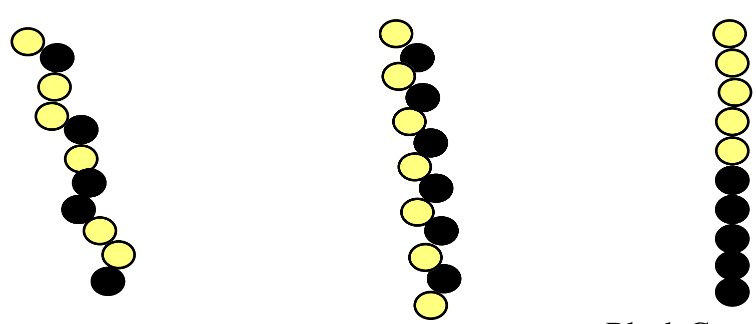
Materials and Supplies:

3 different colored sets of pop-beads
1 single-layer leaf bag
1 double-layer leaf bag
1 newspaper
Cellophane tape
Iridescent plastic film
2 Polarizing lenses

Procedure:

1. Identify a polymer chain as being similar to a string of pop beads 100 to 200 in number. Each bead represents a monomer. Simply pour these out of a beaker. This models their linkage to each other. Normal polymer chains will have from 100 to 1000 times the number of monomers.

2. Show some of the common physical structures of copolymers (polymers with more than one monomer). Separate the chain types into three classes using colored beads to represent each of the monomers (note you will need at least two different colors of beads). Connect the beads before class.



Random Copolymers: Different monomers are randomly arranged within the polymer chains.

Alternating Copolymers: Different monomers show a definite ordered alternation.

Block Copolymers: Different monomers in the chain are arranged in relatively long blocks of each monomer.

3. Model tearing along the chain versus across the chain of the polymer.
   a) Use a series of 4-5 short chains of beads (20-30 each strand) held parallel to each other. Insert a pencil between the chains and move it up and down showing the ease of the separation of the chains.
   b) Use an inexpensive 1 layer plastic leaf bag. This will allow easy penetration and will rip up the side of the bag (between the chains).
   c) Another model that is a natural polymer is a newspaper. No chemical reaction has occurred in pressing the fibers of paper together. Instead, it is a physical pressing out of excess water. Tearing the newspaper vertically gives a neat, clean, straight tear (between the fibers). Tearing across the newspaper gives a ragged tear (across the fibers).
   d) Take the 5 strands of pop beads from part A, hold them at their ends, and pull apart. Notice they do not all break in the same position (ragged) and that it is more difficult than simply separating the strands.
   e) Tear cellophane tape along the length and width. Observe how cellophane tape tears smoothly and easily along the length of the tape (between the chains). Notice how it is very difficult to tear across the chains (a sharp edge is usually needed to cut the tape).

4. Show how cross-linked polymers tend to be much stronger than non cross-linked polymers. Use a two ply garbage bag. Try to stick your finger through the side of the bag. Its strength is the result of at least two layers of polymers in which the chains are oriented at right angles to each other. Using 2 sets of the 5 chains of pop beads used before, hold at right angles to each other and repeat the above (d) procedure.

5. Examine some of the optical properties of polymers.
   a) Iridescent films are available for exhibiting the effect of multilayers of polymers that have different indices of optical refraction. A rock sample of mica is a perfect model for representing the polymer layering.
   b) Optical rotation properties of polymers.
      i) Adequate background on how polarizing lenses work is provided in "Chem Matters," April 1984, page 9. An overhead will work very well making a transparency of the pictures shown.
      ii) Set up and demonstrate that no light passes through when two of the polarizing lenses are held at 90 degrees to each other. Set the two filters with formed plastic pieces <u>between</u> the two filters. The plastic pieces will rotate the polarized light due to the presence of the polymer chains. This property is used to identify stress points on shape plastics that are pressed out or extruded. Numerous strips of cellophane tape criss-crossed randomly over a piece of overhead transparency will also give an array of colors. The cellophane tape rotates the plane of polarized light.

Demonstration 3

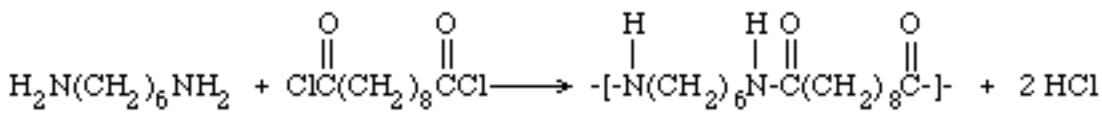
The Formation of the Wonder Polymer

The Condensation Polymerization Reaction Used in the Creation of Nylon 6-10

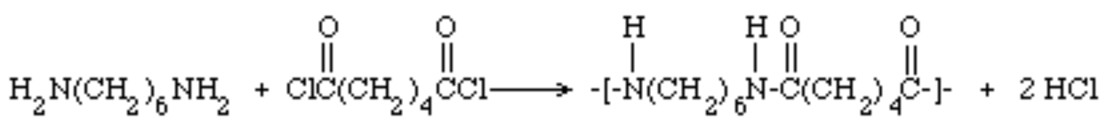
Objective: The objective of this demonstration is to show the formation of a condensation polymer.

Review of Scientific Principles:

The word "nylon" is used to represent synthetic polyamides. The various nylons are described by a numbering system that indicates the number of carbon atoms in the monomer chains. Nylons from diamines and dicarboxylic acids are designated by two numbers, the first representing the diamine and the second the dicarboxylic acid. Thus nylon 6-10 is formed by the reaction of hexamethylenediamine and sebacic acid. In this demonstration the acid chloride, sebacyl (or Sebacoyl) chloride, is used instead of sebacic acid. The equation is:



Many diamines and diacids (or diacid chlorides) can be reacted to make other condensation products that are described by the generic name "nylon." One such product is an important commercial polyamide, nylon 6-6, which can be prepared by substituting adipoyl chloride for Sebacoyl chloride in the procedure described here. The equation is:



Time: About 20-30 minutes of class time.

Materials and Supplies:

50 ml 0.50 M hexamethylenediamine (1,6-diaminohexane), $H_2N(CH_2)_6NH_2$, in 0.5 M sodium hydroxide, NaOH (To prepare: dissolve 3.0 g of $H_2N(CH_2)_6NH_2$ plus 1.0 g NaOH in 50 ml distilled water. Hexamethylenediamine can be dispensed by placing the reagent bottle in hot water until sufficient solid has melted and can be decanted. The melting point is 39-40^o C.)
50 ml 0.2 M Sebacoyl chloride, $ClCO(CH_2)_8COCl$, in hexane (To prepare: dissolve 1.5 ml to 2.0 ml Sebacoyl chloride in 50 ml hexane.) gloves, plastic or rubber (ones that will not dissolve in hexane)
250 ml beaker or crystallizing dish
forceps
2 stirring rods or a small windlass
food-coloring dye (optional)
phenolphthalein (optional)

General Safety Guidelines:

- Hexamethylenediamine is irritating to the skin, eyes, and respiratory system.
- Sodium hydroxide is extremely caustic and can cause severe burns. Contact with the skin and eyes must be prevented.
- Sebacoyl chloride is corrosive and irritating to the skin, eyes, and respiratory system.
- Hexane is extremely flammable. Hexane vapor can irritate the respiratory tract and, in high concentrations, be narcotic.

Procedure:

1. Wearing gloves, place the hexamethylenediamine solution in a 250-ml beaker or crystallizing dish.
2. Slowly pour the Sebacoyl chloride solution as a second layer on top of the diamine solution, taking care to minimize agitation at the interface.
3. With forceps, grasp the polymer film that forms at the interface of the two solutions and pull it carefully from the center of the beaker.
4. Wind the polymer thread on a stirring rod or a small windlass.
5. Wash the polymer thoroughly with water or ethanol before handling.

Food coloring dyes or phenolphthalein can be added to the lower (aqueous) phase to enhance the visibility of the liquid interface. The upper phase can also be colored with dyes such as azobenzene, but observation of the polymer film at the interface is somewhat obscured. Some of the dye will be taken up with the polymer, but can be removed by washing with water.

Disposal:

1. Any remaining reactants should be mixed thoroughly to produce nylon. The solid nylon should be washed before being discarded in a solid waste container.
2. Any remaining liquid should be discarded in a solvent waste container or should be neutralized with either sodium bisulfate (if basic) or sodium carbonate (if acidic) and flushed down the drain with water.

Polymer Laboratories Materials Grid

Materials used	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5
Tooth picks	GS				
cheezeballs	GS				
cheeze puffs	GS				
cheetos	GS				
polyvinyl alcohol		LE			
Borax		GS/LE	GS/LE		
Styrofoam cups		GS	GS	GS	
Tongue depressors		PH			
latex gloves		PH/DS			
Food Dye		GS	GS		
Zip Lock Bags		GS	GS		
Elmer's White Glue			GS/DS		
250 ml beaker				LE	
Acetone				PH/LE	
Calcium Chloride					LE/DS (deicer)
Ethanol					LE/PH
Plastic "PET"					GS/DS
" HDPE					GS/DS
" LDPE					GS/DS
" PS rigid					GS/DS
" PS foam					GS/DS
" PP					GS/DS
" PVC rigid					GS/DS
" PVC flex					GS/DS

Key:
DS = DISCOUNT STORE
LE = LAB EQUIPMENT/SCIENTIFIC CATALOG
GS = GROCERY STORE
PH = PHARMACY

Experiment 1

Crunch and Munch Lab

Desk Top Building of Polymer Chain Components

Objective: The objective of this lab is to introduce the concepts and vocabulary of "polymers" with simple models.

Review of Scientific Principles:

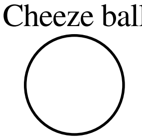
Polymers (Greek-POLY...many and MEROS...parts) have existed since the beginning of life. Both "natural" and "synthetic" polymers are an integral part of our life. Most of the natural and synthetic materials with which we come in contact are wholly or partly polymeric in nature.

Polymers (plastics) are large molecules (**macromolecules**) made up of repeating units called "mers" or more correctly "monomers". These "units" are chemical molecules. To introduce the common terms used in polymers, we will use the models shown in this desktop experiment.

Time: This laboratory experiment requires about 40 minutes.

Materials and Supplies:

Cheeze balls



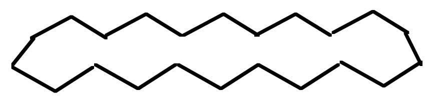
Initiators

30 half toothpicks

Cheeze Puffs

Monomers

Cheto Crunchies



Crosslinkers

Procedure:

1. Remove the initiators from the bag that you were given. Record your bag number. Add a toothpick and than a monomer to each initiator. Continue to add toothpicks and monomers to chain until all the monomers have been used. (Don't eat the experiment.)

Different polymers have different types, shapes, and numbers of monomers. The initiators are used only in addition polymerization reactions like those we are modeling in this experiment (there are also condensation types of polymerization). The initiators which start the polymerization reaction are a group of chemicals called "free radicals". These chemically unstable groups are formed by tearing apart a normally stable molecule so that there is an unpaired electron (pairing produces stability) in some part of the chemical segment.

2. Using toothpicks, connect the partial chains together at the ends which do not have "initiators" located on them. Continue the connection until all the partial chains have been used.

3. Using the ends of the crosslinker with the attached toothpick, connect the chains together (cross-link). The connection of chains together along their body is called cross-linking. The synthetic process has an origin as far back as "vulcanization" in which sulfur was used to cross-link natural rubber in making and patching tires. In later experiments, we will be using borax as a cross-linking agent.

Questions:

1. Describe (define) a polymer in your own words.

2. Draw your polymer and the polymers of two other people who have different numbers on their bags. It should be noted here that normal polymers have literally tens to hundreds of thousands of monomers making up a chain instead of the sparingly few that you have been given to use.

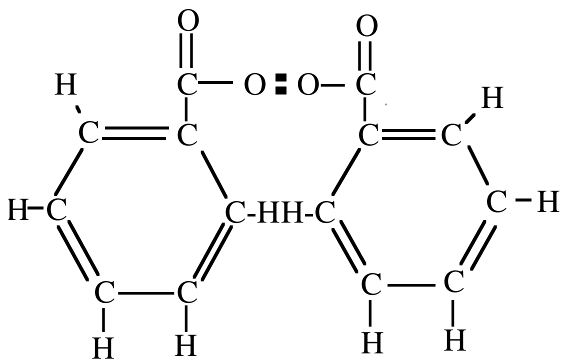
3. As the number (concentration) of initiators increase, what happens to the length of the chains? (Note: You will have to compare the above structure to those of other students.)

4. How (predict) do the "strength" and "flexibility" of the polymers change as the number (concentration) of cross-linkers increases.

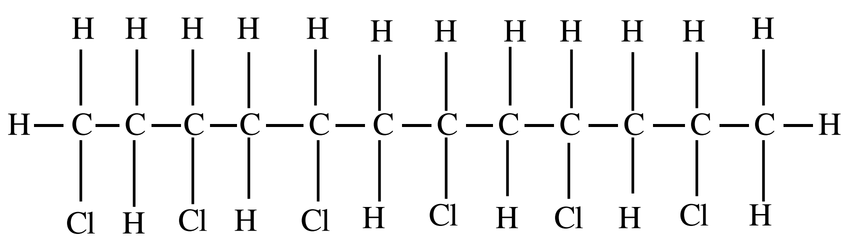
5. a) A "branched polymer" is formed when one chain is attached along the body of another chain. A branched polymer resembles the branches of a tree. Redraw your structure so that it shows branching.

   b) What did you have to do with one of the terminal ends in order to create the branching requested for your polymer?

6. Below is the structure of benzoyl peroxide (used in acne medicines). Separate the molecule to show two identical free radicals.



7. Below is the polymer of PVC, Poly(Vinyl) Chloride. Circle the repeat unit of this if is was made from ethylene.



Teacher Notes:

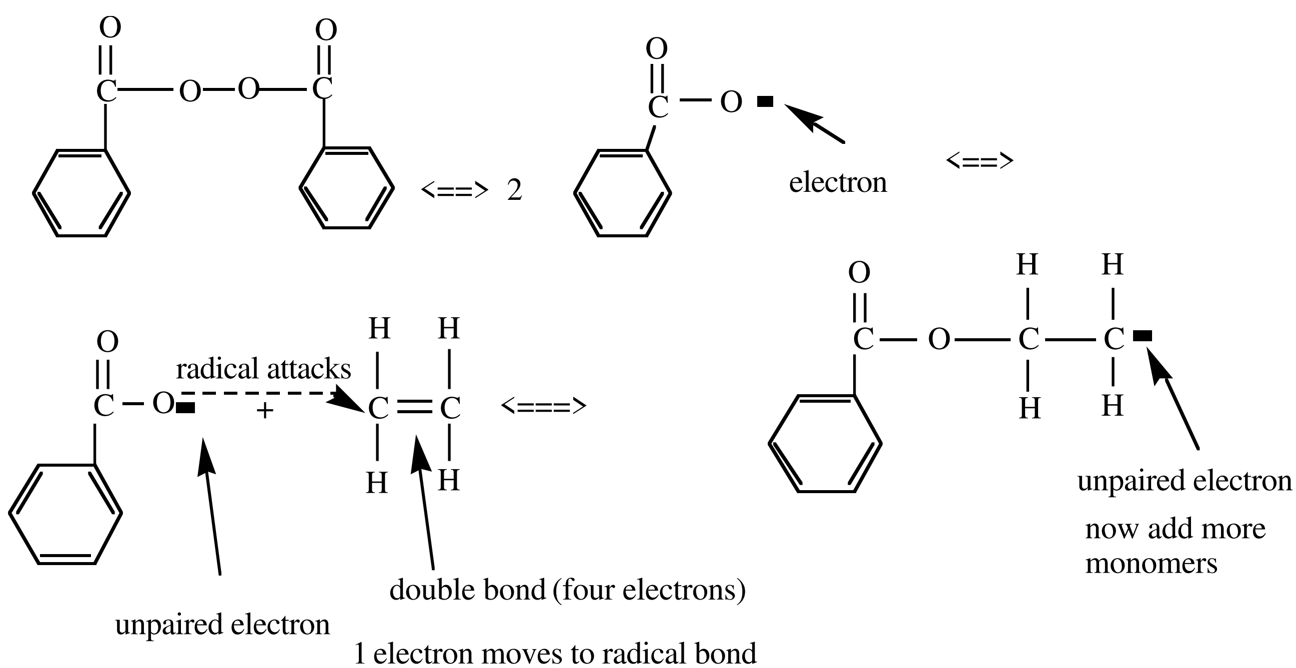
Objective: The objective of this laboratory is to learn the vocabulary of polymer synthesis through the making of models. This is a very simplistic modeling lab. The terms used will have meaning and purpose as a result of this desk top lab.

Review of Scientific Principles:

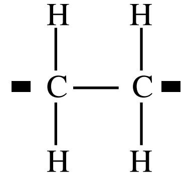
We will be using cheeze snack foods to present models in addition polymerization and cross-linking of the polymer chains. All of these materials may be obtained from a grocery or discount store. Starch or Styrofoam peanuts may be used instead of food products if the maturity of the class is in question.

Students at this point have no background for condensation polymerization and it is suggested that nothing but its existence be noted at this time. A more "in-depth" presentation will be made later in the module.

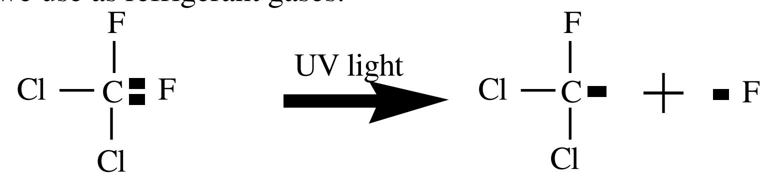
Free radicals are introduced as initiators to the polymerization process. The formation of a sample radical and its action on a monomer may be described as:



In the presence of UV light or other high energy sources, a monomer may also form a radical. In this section the cross-linker and monomer were considered as totally different. This self initiating and/or self cross-linking of the monomer should <u>not</u> be presented to the student at this time. The ethylene above can alter the double bond forming the unstable radical (shown bellow) as it is struck by UV light.



A popular example of a harmful radical is one formed by the types of Chloro-Fluoro-Carbons that we use as refrigerant gases.



chloro-fluoro carbon (freon) radical radical

note: only bonding electrons are shown

Of course, the very reactive ozone of the ozone layer of the atmosphere may cause the same reaction, also forming the unstable radicals.

Time: The preparation time for this lab is about 30 minutes.

Procedure:

Three classes of bags should be filled and numbered as follows:

Bag #	Cheeze balls	Cheeze Puffs	Cheeto Crunchies
1	4	20	2
2	7	20	4
3	10	20	7

Answers to Questions:

1. A high molecular weight macromolecule made up of multiple repeating units.

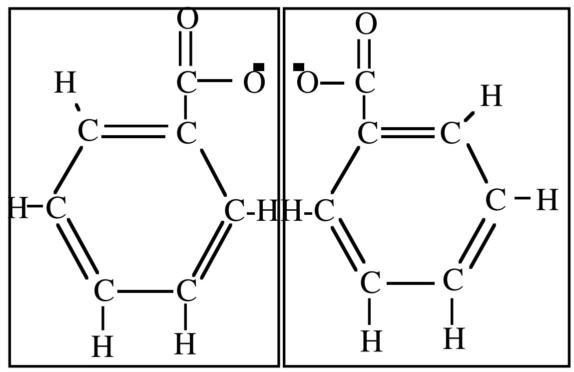
2. Students should have only one attachment on each initiator.

3. The greater the number of initiators or concentration of initiators, the shorter will be the length of the straight chain of the polymer.

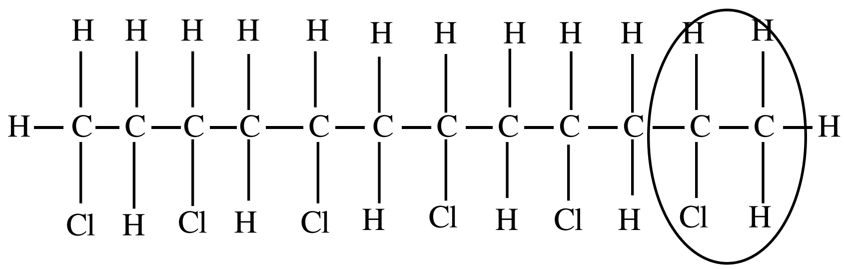
4. As the concentration of cross-linkers increase, the flexibility/fluidity of the polymers will decrease. This explanation can be likened to the fact that as the number of steps on a ladder increase, so will the stability of the ladder.

5. Those students having an odd # of initiators will already have a branched polymer in this model. In the normal polymerization "branching" will occur as part of the normal process regardless of the number of initiators. Students that had an even number of initiators could do one of two things:
   a) they could remove one of the initiators from one of chains to make the connection.
   b) they could break one of the chains making a branch with each segment.

6.



7.



Experiment 2

Slime Away

Cross-Linking Poly (vinyl alcohol) with Sodium Borate

Objective: The objective of this experiment is to explore the change in physical properties of a polymer as a result of cross-linking. The result of adding more cross-linking agents to a polymer is considered and another model of cross-linking is viewed.

Applications:

There are a number of uses of the PVA polymer we are studying:

1. They may be used in sheets to make bags to act as containers for pre-measured soap you simply throw into a washing machine.
2. The PVA sheets may be made into larger bags to be used by hospitals as containers for the cotton cloth used in the operating rooms or to hold the bed linen or clothing of infected patients.

Time: This experiment will require approximately 15-20 minutes to run and clean up.

Materials and Supplies:

100 ml/group of poly (vinyl alcohol) 4%
10 ml of sodium borate 4%
Styrofoam cups and wooden stir sticks (tongue depressors)
Zip lock bags or latex gloves (surgical)

General Safety Guidelines:

- Laboratory aprons and goggles should be worn in this experiment as in all procedures.

- Both the borax and the PVA will burn the eyes. Hands should be washed at the end of the experiment.

Procedure:

The polyvinyl alcohol and sodium borate are mixed together in approximately a 10 to 1 ratio.

1. 100 ml of the 4% poly (vinyl alcohol) is added to a Styrofoam cup .

2. Food coloring can be added to the PVA in the cups to make different colors. Simple food coloring is recommended. This coloring should be added before any of the borax solution has been added, or it can be added directly to the borax solution.

3. Add 10 ml of the 4% cross-linker (sodium borate) to each cup. Begin stirring the mixture immediately with your wooden tongue depressor.

4. Make observations as to what is occurring as the reaction proceeds.

5. Within a couple of minutes the slime will be formed. Lift some of it out with the tongue depressor and make your observations. Record your observations on your data sheet.

6. Take some in your hand and stretch the slime slowly. Record your observations on your data sheet.

7. Repeat the stretching exercise only this time do it rapidly**.** Record your observations on your data sheet. Compare the results of the two tests. The slime is non toxic and is safe to handle, so you can put it in a Zip-lock bag (or latex glove) and seal it to take home.

8. Follow good laboratory procedure and wash your hands with soap and water. It is recommended that this procedure be followed whenever handling this material. Keep it in the glove or bag until it is discarded. The sodium borate or PVA could burn your eyes.

9. Place a small amount of the PVA on a paper towel and set it off to the side to dry until tomorrow. Upon returning to class the next day, record in the data section your observation of the slime.

Data and Analysis:

Observation of the PVA before the sodium borate is added:

Observation of the PVA after the sodium borate is added:

Observation of stretching the cross-linked PVA slowly**:**

Observation of stretching the cross-linked PVA rapidly**:**

Observation of the cross-linked PVA left out in the air overnight:

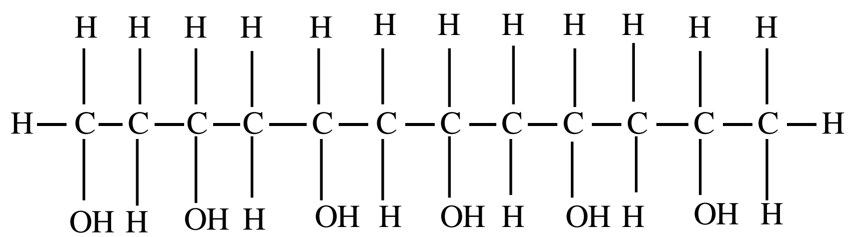
Questions:

1. What are the physical properties that change as a result of the addition of sodium borate to the poly (vinyl alcohol).

2. What would be the effect of adding more sodium borate to your cup (your thoughts only)?

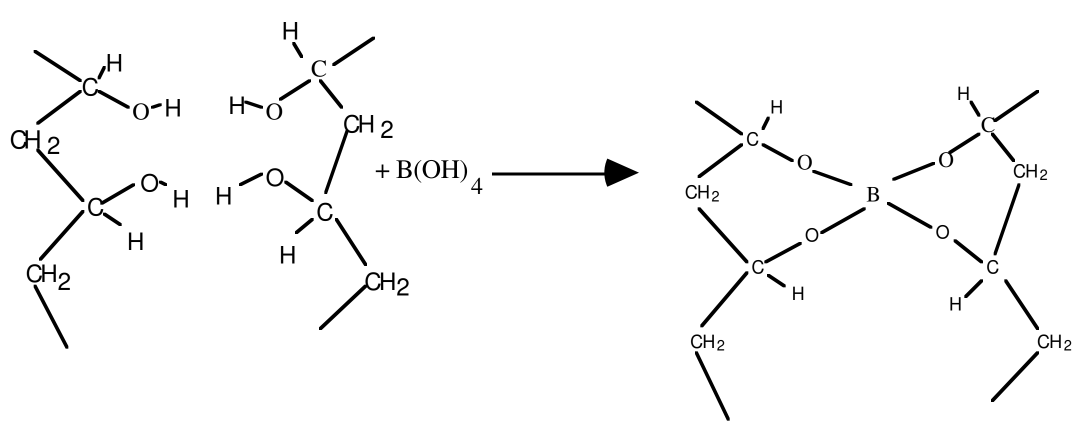
3. After making the observations on the dried PVA, how does the water affect the elasticity of the polymer? What is elasticity?

4. Find and circle the repeat unit in the polymer molecule below?



5. What is the formula of the poly (vinyl alcohol) monomer circled above? (Your teacher may want to show you how to alter this slightly after you have drawn the structure.)

6. In the picture below, circle the borax cross-linking agent.



Teacher Notes:

Objective: The objective of this experiment is to explore the change in physical properties as a result of cross-linking polymers. The results of the addition of more cross-linking agents are considered and another model of cross-linking is viewed. Students also have an opportunity for monomer identification.

Experimental:

1. The Polyvinyl Alcohol as a solid is mixed in water to make a 4% solution. That is 40.0 grams of PVA per 960 grams (milliliters) of water. The best results are obtained by heating the water to about 80^oC on a hot plate with magnetic stirrer. Sprinkle the PVA powder in very gently and slowly on the top of the solution while stirring so as not to cause the mixture to clump together. Temperatures above 90^oC may result in decomposition of the PVA and perhaps the creation of an odor to the solution. Continue to sprinkle the PVA into the hot solution while it is stirring. After all of the PVA has been added to the water, place a top on the vessel. If the water evaporates off, a skin of PVA will form. This PVA sheet might also be a nice item to lift off and show the students. Continue stirring until the mixture is uniform (note also that it will be somewhat viscous). Allow the solution to cool, and the resulting solution will be ready for the students to use.

2. If students are adding a dye to their PVA, make sure they do this before the addition of borax.

3. The borax (sodium borate) can be obtained from your grocery store as "Twenty Mule Team Borax," a laundry bleaching agent. The borax is mixed at a 4% concentration in water. To do this measure out 4 grams of borax and dissolve in 96 grams (milliliters) of water (note: Water has a density of 1 g/mL).

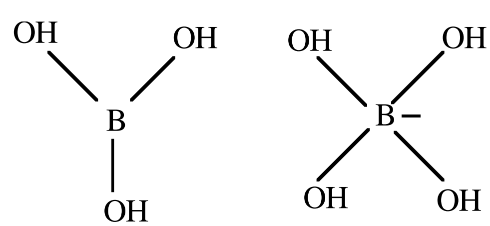
4. The material becomes more viscous as we mix the PVA and the borax. It will reach a maximum level of viscosity and will not thicken further without more cross-linking agent. The addition of a higher ratio of Borax will result in a very viscous polymer (like Jell-O).

Theoretical:

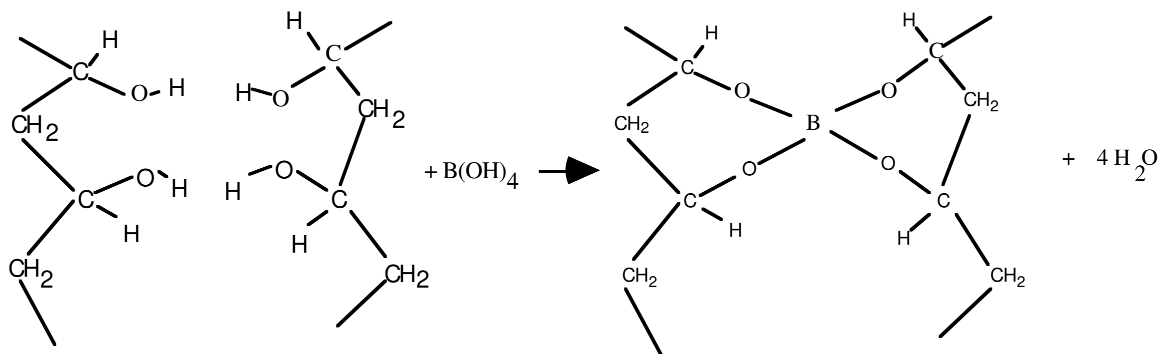
The polymer used is "poly (vinyl alcohol)". The monomer has a formula of:

- Borax is sodium borate, Na_3BO_3. The borax actually dissolves to form boric acid, H_3BO_3. This boric acid-borate solution is a buffer with a pH of about 9 (basic). Boric acid will accept a hydroxide OH^- from water as indicated on the next page.

$$B(OH)_3 \quad + \quad 2H_2O \quad \Longleftrightarrow \quad B(OH)_4^- \quad + \quad H_30^+ \qquad pH= 9.2$$



The hydrolyzed molecule will then act in a condensation reaction with PVA as indicated in the last question on the student laboratory.



- In the above illustration, two PVA molecules are shown being cross-linked by a hydrated borax molecule. Four molecules of water are also produced.

- The resulting material is about 95% water. It is the water that gives the polymer flexibility. Note that as the polymer dries it returns to its solid phase now as a sheet that is rigid and almost transparent.

- The PVA does not dissolve easily in water. Prepare the PVA solution at least one day in advance.

- Guar Gum dissolves in water much more easily than PVA, but seems to "jell" at a much more unpredictable rate than the PVA mixture does. For this reason, PVA is preferred.

Additional reading for more in depth information can be found in:
Journal of Chemical Education, Jan. 1986, #63, pp. 57-60.

Sample Data and Analysis:

Observation of the PVA before the sodium borate is added:
The solution is fluid.

Observation of the PVA after the sodium borate is added:
The mixture becomes more viscous (thicker).

Observation of stretching the cross-linked PVA slowly**:**
The slime flows and stretches.

Observation of stretching the cross-linked PVA rapidly**:**
The slime breaks.

Observation of the cross-linked PVA left out in the air overnight:
It became a dry film.

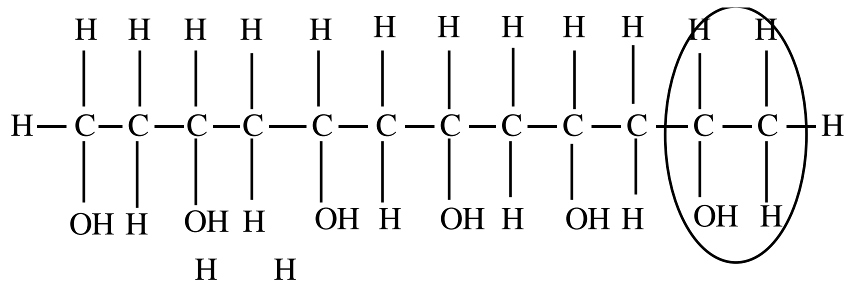
Answers to Questions:

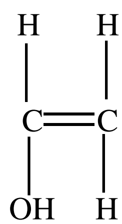
1. The mixture becomes more viscous (thicker).

2. The mixture would jell.

3. The ability of the cross-linked polymer to stretch decreases. The polymer becomes more brittle and will break.

4.



actually: 

5. C_2H_3OH

6. The hydrated borax, minus the four hydrogens are shown on the previous page bonding two chains of the PVA polymer together.

Experiment 3

A Silly Polymer

Cross-Linking a Polymer to Create Everyone's Favorite Childhood Toy, Silly Putty

Objective: The objective of this experiment is to cross-link a polymer and observe the changes in the physical properties as a result of this cross-linking. The changes in physical properties of a cross-linked polymer are also studied as the temperature is varied.

Review of Scientific Principles:

If a substance springs back to its original shape after being twisted, pulled, or compressed, it is most likely a type of polymer called an **elastomer**. The elastomer has elastic properties (i.e., it will recover its original size and shape after being deformed). An example of an elastomer is a rubber band or a car tire.

The liquid latex (Elmer's glue) which you use contains small globules of hydrocarbons suspended in water. The silly putty is formed by joining the globules using sodium borate (a cross-linker). The silly putty is held together by very weak intermolecular bonds that provide flexibility around the bond and rotation about the chain of the cross-linked polymer. If the cross-linked bonds in a polymer are permanent, it is a thermosetting plastic, even if above the glass-transition temperature (T_g). If the bonds are non-permanent, it can be considered either thermoplastic or an elastomer.

Time: A 20-25 minute period is required to perform the mixing/making of the silly putty.

Materials and Supplies:

55 % Elmer's glue solution in water
4 % borax solution (sodium borate)
Styrofoam cups
zip lock bags
food colors

General Safety Guidelines:

- Since borax solid (a bleaching agent) and solution will burn the eyes, goggles and aprons should be worn.
- Hands should always be washed after kneading the silly putty and finishing the experiment.

Procedure:

1. Wear goggles and lab aprons.
2. Pour 20 ml of the Elmer's glue solution into a Styrofoam cup.
3. Add 10 ml of the cross-linker (borax solution) to each cup.
4. Immediately begin stirring the solutions together using the wooden stick.

5. After a couple of minutes of mixing, the silly putty should be taken out of the cup and kneaded in the hands. Don't worry about the material sticking to your gloves as these pieces will soon mix with the larger quantity with which you are working. Continue to knead until the desired consistency is reached.

6. Using a ruler to measure, drop the ball from a height of 30 centimeters. To what height does it rebound?

7. Stretch the silly putty slowly from each side.

8. Compress the silly putty back into a ball.

9. Pull the silly putty quickly from each side and compare the results.

10. Place the silly putty on some regular news print and press down firmly.

11. Remove the silly putty from the news print and make observations.

12. Repeat the same procedure on a comic section of the newspaper. The silly putty is non-toxic and safe to handle so you can put it in a zip-lock bag and take it home.

13. Follow good laboratory procedure and wash your hands with soap and water when you have finished the experiment.

Data and Analysis:

Height of the rebound _________ cm.
Observations of pulling the silly putty slowly:

Observations of pulling the silly putty quickly:

Observations of the silly putty on newsprint:

Observations of the silly putty on the comic's section of the newspaper:

Questions:

1. How do the physical properties of the glue, water mixture change as a result of adding the sodium borate?

2. What would be the effect (your thoughts) of adding more sodium borate solution?

3. What is the ratio of the height of the drop to that of the rebound distance?

4. Who in the class had the ball with the most elasticity?

5. How did you come to the conclusion of whose ball was most elastic?

At Home:

-Place your ball in the refrigerator for 10 minutes. Recheck the bouncing portion of this experiment.

6. What are your observations?

7. Why do you think this was observed?

-Now place your ball about 6 inches from a light bulb for about 5 minutes and again recheck the bouncing portion of this experiment.

8. What are your observations?

9. Why do you think this happened?

Explain the Following:

1. Why does a car tire appear to be flat in the summer even though the gas inside is hotter than in the winter.

2. Why does a basketball bounce differently inside a gym than it does outside on a cold wintry day.

3. Why will a tire sometimes bump during the winter as a car is moving, only to smooth out its ride after the car has been traveling for a distance.

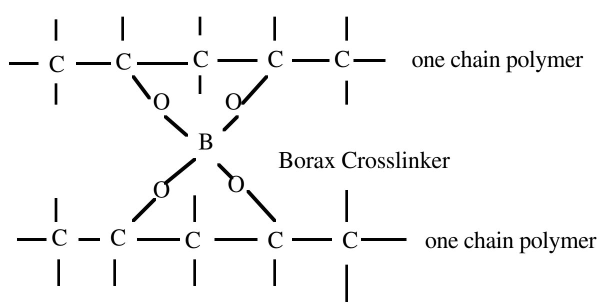
Teacher Notes:

Objective: The objective of this experiment is to investigate cross-linking using a similar technique as was used in the making of slime. The same parameters are worked again with a formal and a quantitative measurement used to describe elasticity. The added home investigation of the effect of temperature on the elasticity also includes concepts of molecular motion and intermolecular bond strength.

Review of Scientific Principles:

If a substance springs back to its original shape after being twisted, pulled, or compressed it is a type of polymer called an elastomer. The elastomer has elastic properties. It will recover its original size and shape after being deformed.

The liquid latex used contains small globules of hydrocarbons suspended in water. Joining these globules forms the mass with which the students will be working. The covalent bonds along the chain are strong, but the bonds between chains are normally weak. However, additives such as borax allow the formation of strong "cross-links" between chains, such as C-B-C. As the number of cross-links increases, the material becomes more rigid and strong.



crosslinker with two chains of polymer

If the rigidity of a polymer is noticed to decrease when a critical temperature is reached, the polymer is called a thermoplastic. If the bonds between polymer molecules are very strong, the material decomposes before any softening occurs. Such a material is called a thermoset plastic.

Natural sources of this liquid latex are milkweed, rubber trees, pine trees, aloe plants, and many desert plants. This latex is used to quickly mend and repair any damage to the outer covering of the plant.

General Safety Guidelines:

- The materials used in this experiment are all non toxic. It is a good idea always to exhibit good laboratory technique when working with the students. Make sure the laboratory.

Experimental:

There are many variations of this experiment.

1. The original silly putty was prepared using sodium silicate and mixing this with borax.

2. A variation also exists using laundry starch and mixing it with borax.

3. Similar variations also exist by sprinkling the borax evenly and gently over the solution of latex then working it with the hands. This does not require as much kneading to dehydrate the sample.

Time: - About 15 minutes are required to ready solutions, cups and tongue depressors.
10-15 minutes will be required in lab for testing and clean up.
The students will require 10-15 minutes of work at home in order to finish all of the experimental work on this laboratory and the write up.

Answers to Questions:

1. The liquid type of starting material should jell and become more viscous as cross-linking occurs.

2. The material will become more solid or rigid.

3. Student answer. This is only a method of measuring elasticity of the polymer. Stretching gives a similar means of comparison.

4. Student answer.

5. Greatest rebound to drop height ratio.

6. Here the student will be studying the effect of temperature variation on elasticity. Students are sometimes surprised if they place their sample into a freezer rather than a refrigerator. The results are that the ball will shatter rather than bounce.

7. The ball should be more elastic.

8. Contrary to what some students will predict, should the ball become too warm, the resulting ball will deform rather than continue to increase in elasticity.

9. The ball deformed rather than rebounding.

-All of the answers to the questions in the EXPLAIN THE FOLLOWING section involve the use of principles previously presented in this laboratory.

Experiment 4

Don't Throw it in the Garbage

Investigating the Classification and Processing of Recycled Products

Objective: The objective of this desk-top laboratory procedure is to increase awareness of recycling polymers through the use of the "three arrow numbering system". Classes of polymers, uses, and physical properties of some thermoplastics will be investigated.

Review of Scientific Principles:

Thermosetting plastics are types of polymers that will characteristically decompose before they will melt. Thermoplastics are polymers are remoldable when heated. These thermoplastics are the ones that we like to recycle. Refer to the "Scientific Principles Section" of this module to obtain a more complete discussion and explanation as to why these two classes of polymers act as they do.

Time: Around 40-45 minutes are required for this experiment and the demonstration at the completion of the experiment.

Materials and Supplies:

Bring two (2) <u>different</u> polymers to class. If these are containers or wrapping material, make sure they are clean and empty. The polymers are identified by the 3-arrow number system placed somewhere on the container. Identify the type of polymer and its use before class.

General Safety Guidelines:

- The acetone used in the demonstration portion of this lab is extremely flammable and should be disposed of by mixing it with water and pouring the mixture into the sink.

Procedure:

1. Answer question #1 below concerning your own polymer.

2. As the collection box is passed around, identify orally to the class the type of polymer you acquired, its number, and its use.

3. Place your polymer into the box for a future experiment. The excess will be recycled.

Data and Analysis:

1. What are the recycling numbers, names, and uses of the two polymers which you brought in?

Number	Name	Uses

2. What are the recycling numbers, names, and uses of four (4) different polymers which other students contributed?

Number	Name	Uses	Student Names

Questions:

3. Your plastics (polymers) will melt or soften at the following temperatures:
HDPE: about 130°C
LDPE: about 110°C
PET: 250 to 260°C
PP: 160 to 170°C
PS: (in solid or foam forms) 70 to 115°C
PVC: 75 to 90°C

Identify each of the polymers that you have listed above (in questions #1 and #2) and note its melting point.

Which of the polymers would melt in the liquids held at the temperature that has been listed below?

a) Which would melt in boiling water (100°C)?

b) Which would melt in boiling antifreeze (ethylene glycol) (190°C)?

c) Which would melt in glycerin held at 290°C? <u>Danger: Glycerin would begin decomposing before you reached this boiling temperature.</u>

4. What properties should a polymer possess to be used in each case on the list below? Name two properties for each usage.

Bag

Ice cream container

Water and Snow skis

Basketball

Tire

Post Lab Demonstration 4

What Happened to the Polymer?

Procedure:

1. Place a Styrofoam cup inside a 400 ml beaker.
2. Place 20 ml of acetone (this is flammable-keep from flames) into the cup which is inside the beaker.
3. Use a glass stirring rod and stir.
4. Record your observations below.
5. Remove the mass from the beaker using the stirring rod and blot dry with a paper towel. Caution: Acetone will remove paint from surfaces.
6. Make your observations of the mass blotted dry on the paper towel.
7. Dispose of the excess acetone in the sink mixing it with water from the faucet.

Data and Analysis:

Observation of mass in the beaker.

Observation of the mass after it has been blotted dry on the paper towel.

Questions:

5. When would this ever be a desirable property?

Teacher Notes:

Objective: The objective of this experiment is to allow students to identify polymers using the recycling codes, state uses of the polymers, and use melting points in a hypothetical experiment as a means of comparing physical properties of polymers.

Review of Scientific Principles:

Students will be bringing in samples of polymers and identifying them using the recycling codes. The code/name/abbreviation are all listed on the chart at the end of the RECYCLING section of the scientific principles portion of this module.

The code number is found in the 3 bent arrow recycling symbol on the polymer.

One of the main public concerns in America now is dealing with waste. Read the section of this module dealing with recycling techniques, products, and economics.

We will begin a two lab series investigating the physical properties of polymers. Note that the question dealing with the heating of the liquids is strictly hypothetical. This is <u>not</u> to be performed as there is <u>danger</u> with ethylene glycol vapors and with the glycerin decomposing much before the temperatures stated in the question.

Time: This lab is expected to take 60 minutes.

Materials and Supplies:

a large box to contain samples of polymers
Styrofoam cup
250 ml beaker
30 ml acetone
students supply polymers

General Safety Guidelines:

- The acetone is extremely flammable and should be kept away from flames.

Procedure:

1. As a prelab exercise, students are to bring two samples of polymers from home. The polymers should be clean and empty.

2. Students are to answer question #1 before coming to class.

3. Students are to hold up and orally identify the polymer's name, use, and recycling number.

4. Students should place the polymer in the large recycling box after the polymer has been identified.

5. As students orally respond around the room, they can answer question #2.

6. When students are finished responding, students should answer question #3. These are <u>hypothetical</u> questions and are <u>NOT</u> to be performed as a lab.

Demonstration:

7. A Styrofoam cup is placed into a 250 ml beaker and 30 ml of acetone are poured into the cup. The cup will collapse upon itself. Note that the acetone will remove paint from surfaces.

8. Stir with a stirring rod until the whole cup has collapsed.

9. Use the stirring rod to remove the clump of polystyrene and place it onto a paper towel.

10. Blot the polystyrene dry.

11. The acetone is to be poured down the sink flushing it with copious quantities of water.

12. The clump of polystyrene can be disposed of in the trash can after the experiment.

13. Students are to answer the observations and answer the question as you perform this experiment.

Suggestions:

- The experiment with boiling liquids is hypothetical and not meant to be performed. There are problems with ethylene glycol vapor and glycerin decomposing.

- This is an excellent lab to do before the investigation of "physical properties of polymers."

- After the collection of the polymers, the samples collected can be used for testing in the next laboratory investigation.

- Have a large box available for the collection of the empty containers brought by the student. (e.g., a towel box)

- Have each student identify his polymer, its number and its use.

- After the students identify their polymer, it may be deposited in the box.

Answers to Questions:

1. Student chart.
2. Student chart.
3. Student answer

3a PVC--Sometimes Polyethylene wrap will be noted to soften in practice.

3b HDPE, LDPE, PP, PS and the one listed above

3c PET and the ones listed above

4. The terms <u>elasticity</u> and <u>strength</u> could surely be used for each of the two answers. Discussion of elasticity and strength at different temperatures is appropriate at this point.

Sample Data and Analysis:

Observation of mass in the beaker.
Gooey polystyrene mass.

Observation of the mass after it has been blotted dry on the paper towel.
It is sticky.

5. As an adhesive

Experiment 5

Plastics the Second Time Around

Physical Properties of Polymers

Objective: The objective of this experiment is to test and compare the physical properties of thermoplastic polymers.

Review of Scientific Principles:

Plastics are long chain molecules. Depending upon the monomers, the plastic will have different physical and chemical properties. Chemical properties are difficult to test for and usually call for the destruction of the plastic through incineration. Burning plastics can give off toxic fumes. This is one of the reasons firemen wear a self contained breathing apparatus when entering a burning building.

It is easier and safer to check the physical properties. Different plastics look, feel, and behave differently. Some are clear and colorless, while others are opaque. Some feel soft, while others feel slimy, slippery, or tacky. Some are more rigid than others. Each plastic has a unique density. Each plastic has a temperature at which it softens and/or melts as we saw in the last laboratory experiment.
The densities (in g/ml) of the plastics you will be checking are:

HDPE 0.952 to 0.965
LDPE 0.917 to 0.940
PET 1.29 to 1.4
PP 0.900 to 0.910
PS (in solid form) 1.04 to 1.05
PS (in foam form) variable but always less than 1
PVC (rigid) 1.30 to 1.58
PVC (flexible) 1.16 to 1.35

The melting or softening point we discussed in the last investigation is important when recycling, because when a plastic is softened or melted, it will adhere (stick) to itself. Generally when two or more plastics are softened or melted, the plastics will not adhere to one another. This is one of the reasons why recycled plastics must be sorted. This is an expensive process that adds to the costs of recycling.

Time: To perform this experiment and answer the questions will require 35-40 minutes.

General Safety Guidelines:

- Care should be taken in minimizing contact with the solutions used in the buoyancy portion of this experiment.

- Aprons and goggles should be worn during the experiment.

- The ethanol solutions and calcium chloride solutions are to be returned to the container provided by your instructor.

- Hands should be washed after the experiment has been completed.

Materials and Supplies:

Samples of the following plastics:
HDPE (high density polyethylene),
LDPE (low density polyethylene),
PET (polyethylene terephthalate),
PP (polypropylene),
PS [in solid form] (polystyrene),
PS [in foam form], and
PVC (polyvinyl chloride);

ethanol/water solutions of various concentrations:
52% ethanol (density = 0.911),
38% ethanol (density = 0.9408), and
24% ethanol (density = 0.9549)

calcium chloride/water solutions of various concentrations:
6% $CaCl_2$ (density = 1.0505),
32% $CaCl_2$ (density = 1.3059), and
40% $CaCl_2$ (density = 1.3982)

250 ml beaker

Procedure:

1. Obtain a sample of each type of plastic, noting the letter on each piece. The letters are used to reference each sample.

2. Examine each sample and write a visual description in the proper location in the data table.
   a) Is the sample clear? Is the sample opaque? Does it have color?
   b) In the data table describe how the sample feels. Is the sample smooth or rough? Does it have a pattern?
   c) Flex each sample through an angle of 10^o to 30^o. Note in the data table how easy it was to flex the sample. Is it flexible or rigid? You might want to compare the various samples.

3. Pour 50 ml of the 40% $CaCl_2$ solution into a 150 ml beaker. Place each of the plastic samples in the solution. Note which samples sink (S) or float (F) in the DATA TABLE.

4. Return the solution to the appropriate container and dry out the beaker.

5. Dry off your samples.

6. Repeat Step #3-5 with:
   32% calcium chloride,
   6% calcium chloride,
   24% ethanol,
   38% ethanol, and
   52% ethanol

7. Return all plastics to the recycling box after usage.

Data Table:

Test	A	B	C	D	E	F	G
Visual Descrip-tion							
Surface Appear-ance							
Rigidity							
Float/ Sink Ethanol mix 52%							
38%							
24%							
Float/ Sink $CaCl_2$ mix 6%							
32%							
40%							

Questions:

1. From the data given in the REVIEW OF SCIENTIFIC PRINCIPLES section identify each of the plastics by proper recycling number and proper name.

Sample A

Sample B

Sample C

Sample D

Sample E

Sample F

Sample G

2. When testing for the density of the plastic samples, why did some of the samples stick out of the solution more than other samples?

3. If you were given two plastic samples, how would you identify them?

4. Which of the polymer (plastics) would be used as a material in making each of the following?
Use letters and names to identify each polymer.

   i) A covering to go around a sandwich?

   ii) A replacement for a picture window ?

   iii) As a covering for a plastic bowl?

   iv) As a replacement for the lead sinkers used in fishing?

   v) As a clip board to write on?

5. Which polymer was most flexible?

6. Which polymer was most transparent?

Teacher Notes:

Time : This lab is expected to take 40 minutes.

Materials and Supplies:

Samples of the following plastics:
HDPE (high density polyethylene)
LDPE (low density polyethylene)
PET (polyethylene terephthalate)
PP (polypropylene)
PS [in solid form] (polystyrene)
PS [in foam form]
PVC (polyvinyl chloride)

Three different ethanol solutions of various concentrations are used. 50 ml of each solution is needed for every group.
52% (density = 0.911) - to 619.1 ml of 95% ethanol add distilled water to make 1000.0 ml
38% (density = 0.941) - to 467.2 ml of 95% ethanol add distilled water to make 1000.0 ml
24% (density = 0.965) - to 302.7 ml of 95% ethanol add distilled water to make 1000.0 ml

Three different calcium chloride solutions of various concentrations are used. 50 ml of each solution is needed for every group.
Caution: The hydration of $CaCl_2$ is an exothermic reaction. The solutions should be made ahead of time to allow the solution to cool. One day in advance is recommended.

6% (density = 1.0505) - 6 g of $CaCl_2$ (anhyd.) plus 94 ml distilled water <u>or</u> 7.95 g of $CaCl_2•2\ H_2O$ plus 92.05 ml of distilled water.
32% (density = 1.306) - 32 g of $CaCl_2$ (anhyd.) plus 68 ml of distilled water <u>or</u> 42.39 g of $CaCl_2•2\ H_2O$ plus 58.61 ml of distilled water.
40% (density = 1.398) - 40 g of $CaCl_2$ (anhyd.) plus 60 ml of distilled water <u>or</u> 52.99 g of $CaCl_2•2\ H_2O$ plus 47.06 ml of distilled water.

250 ml beaker

General Safety Guidelines:

- Students should wear lab aprons and goggles at all times during this experiment.
- Students should wash their hands after the lab has been completed.

Procedure:

1. Prepare the solutions given above and ask the students to return them to the original containers after use. An alternative procedure might be to provide a number of beakers each containing one solution. Identify the beakers so the students can simply take these beakers to their desk for usage and exchange beakers among lab groups after their use.

2. Using the polymers brought by the students in the previous lab, cut the polymers into 2 cm by 4 cm pieces. With an indelible marker, write a letter A-G on each type of polymer. These letters provide a technique for identifying and talking about the polymers used. A polymer can be identified using the recycling code on the bottom of the plastic. The recycling codes are: 1 = PET, 2 = HDPE, 3 = PVC, 4 = LDPE, 5 = PP, and 6 = PS. Students should be familiar with the code numbers found in the 3 bent arrow recycling symbol. At this time you should not identify any of the polymers used in this experiment nor their recycling numbers.

3. Students should get one sample of each type of polymer to use in this experiment. Should the indelible ink be leached from a polymer, a fresh identification marking should be reapplied.

4. When the experiment is finished, students are to place their polymers in the recycling box.

- Students will obtain good results with the densities except for the PET and PVC samples. These two polymers are hard to distinguish using their densities.

- Students will be able to identify Styrofoam from its appearance. After the lab, ask the class about the appearance, color, feel, and rigidity of the samples. These are extrinsic, physical properties. Density, melting, and softening point are intrinsic physical properties. Depending upon the placement of this lab in the school year, these terms might be new or a review for the students.

- Review the manufacturer's recycling code for the plastics with the students.

Answers to Questions:

1. Student answers.

2. Differences in density.

3. Using density or physical appearance.

4i) HDPE and/or LDPE

4ii) PP and/or PS rigid

4iii) PET, HDPE, and/or LDPE

4iv) PVC

4v) PS (rigid), PP, and/or PVC

5. LDPE and/or PET

6. PP, PS (rigid), and/or PET

Name ____________________

Polymer Quiz

1 & 2. Many polymers occur in nature. Name any two naturally occurring polymers.

____________ and ____________

3 & 4. What will happen when we begin heating each of the polymers below?

a) A thermosetting (polymer).

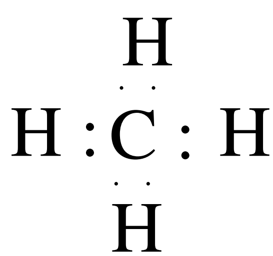
b) A thermoplastic (polymer).

5 & 6. Name any two properties that you may look for in describing a polymer.

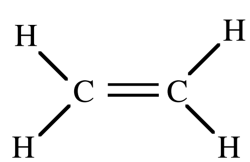
____________________ and ____________________

7. Describe what is meant by the term "polymer".

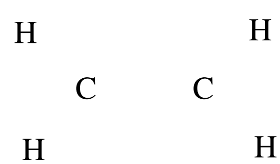
8. Look at the molecule below and make it a radical.



9. Below is ethylene, the basic monomer of a common polymer. Write its "Electron Dot" (Lewis) Structure.

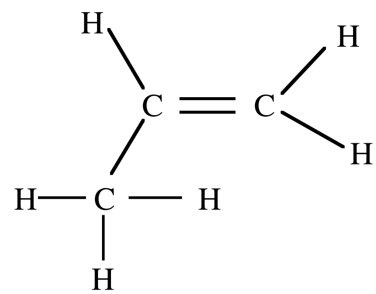


Ethylene



Lewis Structure

10. Below is the monomer, "propylene". Show three monomers, united together to form the polymer polypropylene.



Propylene

11. "Initiators" begin and may end a polymer chain. As the number of initiators increase in a polymerization, the length of a straight chain will _________ (increase/decrease).

12. "Cross-linkers" are atoms or groups of atoms that will bind chains of polymers together. Name a property of a polymer that will be altered as a result of altering the number of cross-linkers. ____________________

13. As the number of cross-linkers used with any polymer increases, describe how the property from #12 above will be altered.

14. What is meant by the elasticity of a polymer.

15. A rubber band is used around a newspaper. What would be the effect of using this rubber band in the snow in the winter?

16. List two properties you may look for to make either a fishing line or a head band (circle the one to which you are responding).

a. _________________ and b. ____________

Glossary

Abbreviations:
HDPE: high density polyethylene
LDPE: low density polyethylene
PET: polyethylene terephthalate
PP: polypropylene
PS: polystyrene
PVA: polyvinyl alcohol
PVC: polyvinyl chloride

addition polymerization: a chemical reaction in which simple molecules are linked together to form long chain molecules.
amorphous: non-crystalline polymer or non-crystalline areas in a polymer.
Bakelite: a polymer produced by the condensation of phenol and formaldehyde.
branched polymer: polymer having smaller chains attached to the polymer backbone.
cellulose: a natural polymer found in wood and other plant material.
composite polymer: a filled or reinforced plastic.
condensation polymer: one in which two or more molecules combine resulting in elimination of water or other simple molecules, with the process being repeated to form a long chain molecule.
configuration: related chemical structure produced by the making and breaking of primary valence bonds.
copolymer: a macromolecule consisting of more than one type of building unit.
creep: cold flow of a polymer.
cross-linking: occurs when primary valence bonds are formed between separate polymer chain molecules.
crystalline polymer: polymer with a regular order or pattern of molecular arrangement and a sharp melting point.
dimer: a polymer containing two monomers.
domains: sequences or regions in block copolymers.
elastomer: a type of polymer that exhibits rubber-like qualities.
Ekonol: a moldable, high temperature polymer.
end group: functional group at the end of a chain in polymers, e.g. carboxylic group.
extrusion: a fabrication process in which a heat-softened polymer is forced continually by a screw through a die.
filler: a relatively inert material used as the discontinuous phase of a polymer composite.
free radical: A chemical component that contains a free electron which covalently bonds with a free electron on another molecule.
homopolymer: a macromolecule consisting of only one type of building unit.
initiation: the start of a chain reaction with a source such as free radicals, peroxides, etc.
kevlar: a high strength polymer which can withstand high temperatures.
linear: polymers made up of one long continuous chain, without any excess appendages or attachments.
macromolecule: a polymer.
material: a substance useful for structural purposes.
monomer: smallest repeating unit of a polymer.
nylon: a polymer used commonly in the textiles industry.
oligomer: a low molecular weight polymer in which the number of repeating units is approximately between two and ten.
polyethylene: the most extensively produced polymer.
polyester: a polymer with a COOR repeating unit.
polymer: a high molecular weight macromolecule made up of multiple repeating units.

polymerization: the chemical reaction in which high molecular mass molecules are formed from monomers.
polystyrene: a polymer commonly used in packaging.
propagation: the continuous successive chain extension in a polymer chain reaction.
T_g: glass transition temperature below which a polymer is a hard glassy material.
thermoplastic: a polymer which may be softened by heat and hardened by cooling in a reversible physical process.
thermoset: a network polymer obtained by cross-linking a linear polymer to make it infusible or insoluble.
T_m: melting temperature.
Van der Waals forces: intermolecular attractions.
viscosity: the resistance to flow as applied to a solution or a molten solid.
vinyl chloride: the monomer used in PVC production.
vulcanization: cross-linking with heat and sulfur to toughen a polymer.

Source: Seymour and Carraher POLYMER CHEMISTRY Dekker 1993