

# Plastics and Polymers Science Fair Projects

Using Hair Gel, Soda Bottles, and Slimy Stuff



**Chemistry!**

**BEST**

**SCIENCE**

**PROJECTS**

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Madeline Goodstein

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**PROJECTS**

# Plastics and Polymers Science Fair Projects

*Using Hair Gel,  
Soda Bottles, and  
Slimy Stuff*

*Madeline Goodstein*

**E**

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# Plastics and Polymers Are All Around Us

**W**hat comes to mind when you think of plastics? How about wash-and-wear clothing that doesn't need ironing; bicycle and motorcycle helmets that save lives; thin, clear wrap to keep food moist and safe; automobile tires good for sixty thousand miles; bullet-proof vests; picnic cups that keep hot drinks hot and cold drinks cold; glue so "instant" that you have to be careful not to glue your fingers together; CDs and cassettes with your favorite music; carpets where food spills can be washed right off; and pot handles, quick-drying paints, chair and couch upholstery, airplane windows, tabletops and countertops, foam mattresses, patio chairs, boat hulls, vinyl floor tiles, dishes, toys, bathtub caulk, plumbing pipes, fences,



insulation, surgical gowns, computer chips, and much more. As you can see, plastics are used for many things in our lives.

How do you know when something is plastic? Often, you can tell that something is plastic when you lift it. This is because many plastics are lightweight. The feel of the plastic is often another way to tell. A chunk of plastic feels firm yet not as hard as metal. Plastic wraps have their own special properties. They are soft and flexible. A plastic wrap sticks to itself and can be stretched.

Weight, feel, and stretchability are all special characteristics of plastics that are unlike those of other materials. Why do plastics have these properties? The answers to this question will be explored in the experiments in this book.

### **WHAT ARE PLASTICS AND POLYMERS?**

What is a plastic? What makes it different from other materials?

The answer is a chemical one. All plastics are made of a special kind of chemical. This special kind of chemical is called a polymer. Plastics are all made principally of polymers.

What is a polymer?

A polymer is a very large molecule. A polymer molecule may be thousands or even millions of times larger than non-polymer molecules.

For any substance, the smallest bit of matter that can be identified as that substance is called a molecule. An example of a molecule that we all know is the water molecule,  $H_2O$ . The



tiny particles that together make up a cup or a pond or a lake of water are each made up of two hydrogen (H) atoms and one oxygen (O) atom. Each  $\text{H}_2\text{O}$  particle is a molecule, the smallest bit of water possible.

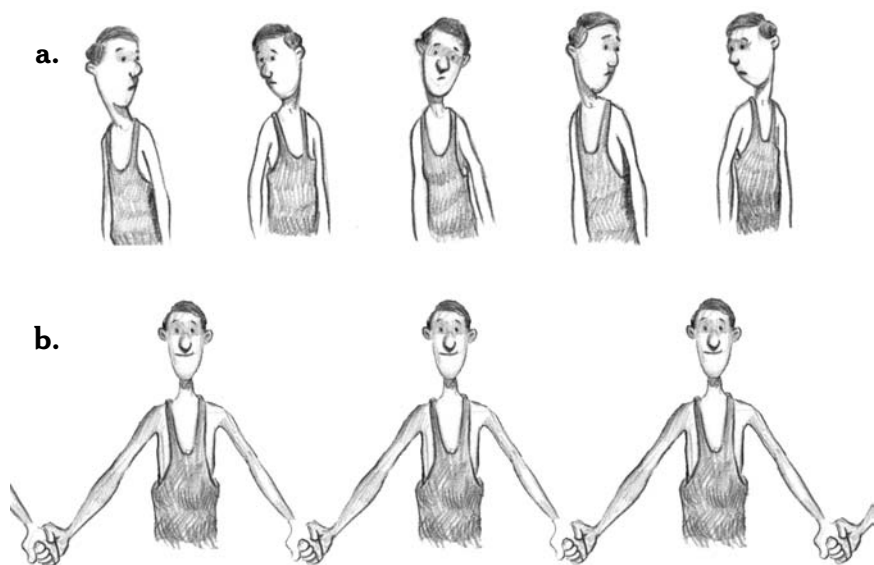
Until polymers were discovered, it was believed that all molecules were made up of small numbers of atoms. The discovery of polymers changed that belief. Now, we know that polymer molecules are made up of hundreds, thousands, or even hundreds of thousands of atoms in long chains or networks (chains connected to each other at various spots).

Does the extreme length of the polymer molecule give it properties very different from that of small molecules? The answer to that is a resounding *yes!* The length of a polymer molecule accounts for the distinctive behaviors of the plastics they make.

The long chains are formed from small molecules called monomers. Monomers combine end to end in a chemical reaction to form the polymer chain. Imagine a group of identical boys gathered in a school gymnasium (see Figure 1a). When a signal is given, the boys all have to join hands in a long chain as shown in Figure 1b. The long chain is the polymer. Each boy is a monomer. The process of polymer formation from monomers is called polymerization. Many chains may be formed at the same time, and the chains may even join together to form a network.

A polymer may also form from two different monomers. For example, the gymnasium might hold a large number of boys





*Figure 1.*

- a) In this model of a polymer, each boy represents a monomer.**  
**b) When the boys join hands, they form a polymer.**

and girls. At a signal, one boy is required to clasp a girl's hand. Holding on to the first boy, the girl clasps the hand of another boy with her other hand. Holding on, that boy clasps another girl's hand and so on until a long chain is formed. The boys and girls represent monomers that bond together to form the repeat segment. The chain of repeat segments is a polymer, as shown in Figure 2. Again, many chains may form, and they may join together to form a network.

All of the wonderful man-made plastic products that improve our lives today are based on polymers. Usually, plastics



contain more than just the polymer or polymers. Additives are introduced to make the polymer more flexible or more heat-resistant or to improve whatever special quality is needed to make it useful.

If all the plastics in the world suddenly disappeared, you might find yourself standing naked on a dirt floor. If all the natural polymers disappeared, you wouldn't exist because proteins, certain sugars, DNA, and RNA—all of which help to make up our bodies—are natural polymers. Plants would not exist either because the wall of a plant cell is built of cellulose, a natural polymer. The starch that helps to make up plants is also a natural polymer.

This book has many experiments designed to illustrate how the length and structure of a polymer chain causes it to have special properties. By doing these experiments, you can get



*Figure 2.*

**In this model of a polymer, each boy represents one specific monomer and each girl stands for a different monomer. The “monomers” join together in a chemical reaction to form a boy-girl sequence that repeats for the entire length of the “polymer” chain. A combination of boy-girl-girl would produce a different polymer.**



started learning about what causes gooey, bouncy, stretchy, rubbery, hard, flexible, or glassy plastics.

### ADVANTAGES OF PLASTICS

Why have polymers become so widely used? In less than a century, they have replaced wood, metal, marble, fabric, paint, caulking, glue, and other products in many places. A major reason for their popularity is that plastics are easy to shape. Polymers can be molded into desired forms, drawn into fibers (threads), stretched, and/or bent. Also, the raw materials that make them are easy to obtain and often inexpensive. Plastics are usually lightweight and not damaged by chemicals. Many polymers are waterproof. Some plastics are such good electrical insulators that they are used to coat electrical wiring. It is no wonder there are so many uses for plastics.

It was not until after World War II (1939–1945) that the plastics industry started to become important. That was when the name *plastic* first appeared. The name comes from a Greek word meaning “able to be molded.” Today, the production of plastics is the fourth largest manufacturing industry in the world. Millions of dollars are spent every year in research laboratories to develop new polymers for old uses and new polymers for uses never dreamed of before.



## EXPERIMENTS AND PROJECTS

This book contains lots of fun experiments about polymers and plastics. Many of the experiments are followed by a section called Science Project Ideas. The section contains great ideas for your own science fair projects.

All the materials needed for the experiments are available in the home, supermarket, hardware store, or drug store. The experiments are all easy to do and safe to carry out when the instructions are followed as given. Many experiments use only small quantities of materials. As a result, you may often be able to obtain them at no cost from people already using them. For example, you might ask a plumber for some epoxy putty or a painter for some solvents. Your school science teacher may occasionally be able to help you obtain some of the materials needed and may also be able to offer you guidance on projects.

There may be some words involving plastics in this book that are new and unfamiliar to you. The terms are included in the glossary.



### SCIENTIFIC PROCESS

A scientific experiment starts when someone wonders what would happen if a certain change were made. What if the temperature at which a certain polymerization took place is increased? A guess about what would happen is called the hypothesis. In this case, some possible hypotheses might be

1. The polymer formed will become stiffer
2. Less of the polymer will form
3. The polymer will turn dark

Let's say that your hypothesis is that less of the polymer will form as the temperature is increased.

A scientific experiment has only two variables in it, that is, only two things that can change. For this experiment, one variable is the temperature at which the polymerization takes place, and the other is the amount of the polymer formed. Nothing else is allowed to change, not the quantities of the reacting materials, or the time allowed for the reaction to take place, or even what the reaction container is made of. This is because if anything else besides the two variables were allowed to change, it would not be possible to tell what had caused the change in the quantity of polymer formed.

If the experiment was carried out and no change in the quantity of product was observed, it would not mean that the experiment was a failure. Even if your hypothesis turns out to be false, all results—positive or negative—provide important



information. The results can lead to further ideas that can be explored. In this book, you will be conducting scientific experiments. The results will lead to suggestions for projects that you can carry out for yourself.

Many great discoveries of science have taken a long time to become accepted. Science requires that theories be supported by experimental evidence. If any of the evidence contradicts the theory, then the theory must be discarded or changed. A theory can never be proven because it is always about things we cannot see or, as in the case of evolution, about things that happened in the past before there was anyone to record it. Scientists are, rightfully, cautious about accepting new theories until the evidence becomes convincing. That is the scientific process.

## **SAFETY**

Experimenting with chemicals can be dangerous unless proper precautions are taken. Although no harmful chemicals are used in the experiments in this book, some of them can be misused with possible serious consequences. It is your responsibility to use them only as directed in this book.

The precautions necessary to prevent accidents and to make the experiments safe and enjoyable are easy to follow.

- ✓ Wear safety goggles in experiments as directed. All chemists wear goggles for any work in the laboratory. Goggles can be purchased in any hardware store.



## Plastics and Polymers Science Fair Projects

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- ✓ Sometimes, you will need an adult to supervise your work or to do part of it. Make sure to follow this instruction.
- ✓ When using certain solvents, adequate ventilation is necessary, such as an exhaust fan or an open window.
- ✓ Some solvents are flammable and should not be used near a flame.
- ✓ Wear plastic gloves when handling the chemicals listed in the experiments. You can use the thin disposable gloves that may be used on either hand and are sold in packs of about one hundred in dollar stores or hardware stores.
- ✓ Some chemicals should not be flushed down the sink or thrown in the garbage. Instructions in the experiment will be given for disposal of such materials.

Consideration must always be given to safety when working with chemicals. Therefore, **all investigations and science fair projects should be approved by a responsible adult.** Where warranted, the experimentation should take place under adult supervision. If there are any questions about safety, the adult should be sure to obtain the approval of a science teacher before proceeding with any experiments.



## Experiment 1.1

# *Making a Polymer*

### *Materials*

- ✓ safety goggles
- ✓ 2 clean glass microscope slides or 2 flat dishes
- ✓ tube of extra-fast-drying glue (such as Krazy Glue)
- ✓ oil-based house paint or tube of artist's oil paint
- ✓ 2 wooden craft or popsicle sticks
- ✓ paper and pencil

Did you ever make a polymer? You probably have although you may not have recognized that you were doing it. Most industrial polymerizations are too hazardous to carry out at home. In this experiment, you will carry out two polymerizations that are safe for you to do. In fact, you may have already done them. This time, you will take a close look at what happens. The polymers that you will make in this experiment will be formed into plastic films. A film is a thin, flexible sheet like plastic wrap or photographic film.

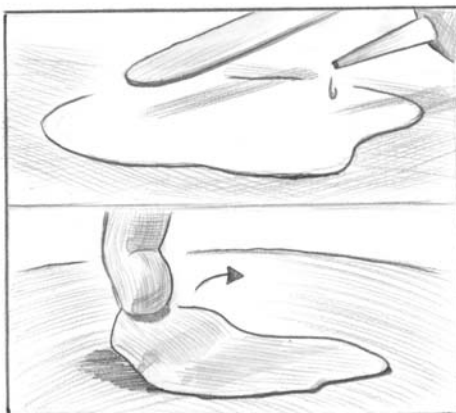
As discussed earlier, polymers are made of repeating parts. The reason that the parts repeat is that the polymers are made by combining small molecules end to end. Added all together, they make up the long polymer chain. The chains may be linked to each other to form a network polymer. The small molecules that form the polymer are called monomers. If a long





polymer is compared to a chain of paper clips, then each monomer is a single paper clip.

In the first part of this experiment, the monomer that you use will be an extra-fast-drying glue. Obtain two clean glass microscope slides or two dishes with flat centers. These will act as supports upon which you will form small pieces of plastic film. Obtain a tube of the extra-fast-drying glue and read the directions for using it. Find out what to do if you get any on your skin. Put on your safety goggles. Open the tube and allow several drops to fall onto the glass slide or dish. With a wooden stick, quickly spread the glue into a thin layer, as shown in Figure 3. Remove the stick before it gets glued to the dish. Close



*Figure 3.*

**A film is formed from an extra-fast-drying glue by spreading several drops of the glue onto a glass slide. A popsicle stick is used, if needed, to shape the glue into a circle.**



the container of glue. Set the slide or dish aside and let the glue harden. Use the stick to check the glue after five minutes to see if it has hardened. If not, check it every five minutes and note how long it takes to become hard. Then discard the stick into a waste container. You may take off the safety goggles.

Slide your fingernail under the edge of the film and carefully peel it off the slide or dish. What does it feel like? How do you think it is able to act as a glue?

You should have a rather soft, flexible, transparent film. Once the film has formed, it can no longer act as a glue. The gluing takes place while the liquid is still polymerizing. At that stage, the liquid penetrates the surfaces around it. The film that forms glues the surfaces together.

Place the film onto a sheet of paper and label it. Store it away for a later experiment.

Next, you will make a polymer from oil paint. Apply a layer of any oil-based house paint or artist's oil paint to the second glass slide or dish. Set it aside to harden. Check the paint layer for hardness with a clean wooden stick once every hour. Find out how long it takes the paint to fully harden. When fully hardened, carefully peel off the film as before. How does this film feel? How does it compare to the other one?

The paint film may feel a little harder than the glue film. It becomes harder the longer it stands. Label and store this film for use in a later experiment.



Neither film actually forms by drying. Although there may be solvents in the fast-drying glue and in the oil paint that evaporate, the evaporation does not cause the glue or oil to become a film. What happens is that each polymerizes.

Oil paint contains monomers that connect to each other to form polymers in the presence of the oxygen in the air. Commercial paints contain compounds to speed up this process. The paint films are the polymerized oils. That explains why you should always store unused paint with the lid tightly on. Fast-drying glue polymerizes almost immediately. It is made up almost entirely of a very reactive monomer (either methyl-2-cyanoacrylate or ethyl-2-cyanoacrylate). When the monomer encounters moisture or certain impurities, it undergoes almost instant polymerization. Most surfaces, including the plate or slide used in this experiment, have a little moisture from the air or a bit of impurity on them. That is enough to cause the immediate polymerization.

Note that acrylic paints do not polymerize when painted onto a surface because they are already polymers. An acrylic paint mixture is made up of tiny globs of polymer in water. Once the paint is brushed on a surface, the water starts to evaporate. As the water evaporates, the globs move closer to each other and soon join together to form a film. They join each other just the way oil globules floating on water or fat globules in soup join when pushed together by a spoon.



## *Science Project Ideas*

- Auto body filler is made by a polymerization reaction that takes place fairly rapidly. A tiny amount of hardener (scientists call this the initiator) is added to the monomer. Then it is pressed into the space and shaped. Find out what the monomer is and show the reaction that takes place to form the polymer. Identify the initiator. Prepare a clay mold of a simple object such as a coin by first pressing clay around the coin and then carefully removing the clay. **With an adult**, bring the mold to an auto-body repair station. Explain your chemistry project about polymers and that you want to prepare a molded article using auto-body filler. Ask the shop operator to fill the clay mold for you. Be sure that none of the clay overlaps the filler because you need to be able to remove the mold when it is hard. Usually, the repair people are willing to help a student with a project. Observe the safety precautions that the operator takes while preparing the filler and using it. While the filler is hardening, carefully feel its temperature. Any warmth is a sign of a chemical reaction that is taking place. Allow the filler to become very hard. When cool and hard, carefully remove the mold. You have made your



own polymerized, molded article. Describe your project in a paper, show the reactions, and exhibit the final product. You can instead make the polymer yourself from an auto-body putty such as Bondo sold in stores. Be sure to follow the instructions for safe usage.

- Can you set up conditions where an instant glue cannot work? To do this, all impurities and moisture must be removed from the surfaces that you wish to glue together. The surfaces you select to glue should be hard and flat. They should be thoroughly washed and dried and then cleaned with solvents such as kerosene or other water-insoluble solvent. Be careful not to leave lint on the surfaces.

### Experiment 1.2

## *A Simple Model of a Polymer*

### *Materials*

- |  |                     |
|--|---------------------|
| ✓ small gumdrops (or clay balls or Styrofoam balls), at least 6 of one color and 12 of another color | ✓ box of toothpicks |
|  | ✓ tabletop          |
|  | ✓ paper and pencil  |

The chains of atoms that make up polymers are often thousands or even millions of atoms long. You can get an idea of



what a polymer looks like by constructing a simple model of a short segment of it. Then, you can imagine the polymer by picturing in your mind the segment repeating itself over and over again to make up the long chain. The segment model that you construct will show the atoms and their connections to other atoms. What the model will not show you is what an atom or molecule or polymer really looks like. In fact, you will make your model out of gumdrops and toothpicks.

The long chains of many polymers are built of linked carbon atoms. The carbon atoms form a backbone to which other atoms or groups of atoms are attached. You will start by constructing a segment of the carbon backbone of such a polymer. You will use small gumdrops all of the same color to represent carbon atoms. Instead of gumdrops, you may use any other soft candy that can be rounded, or you can make clay balls or use Styrofoam balls. Toothpicks will represent the chemical bonds that tie each atom to the next one. If the gumdrops are a little stale, it helps to reduce sticky fingers.

The model that you will be making in this experiment matches the way diagrams of polymer structures are shown in many chemistry books. The diagrams show all of the atoms as if they were all resting on a flat surface like a table. This will give you a two-dimensional (planar) model. In reality, polymer structures are three-dimensional; they stretch above and below as well as on the flat surface. We will get to that later.



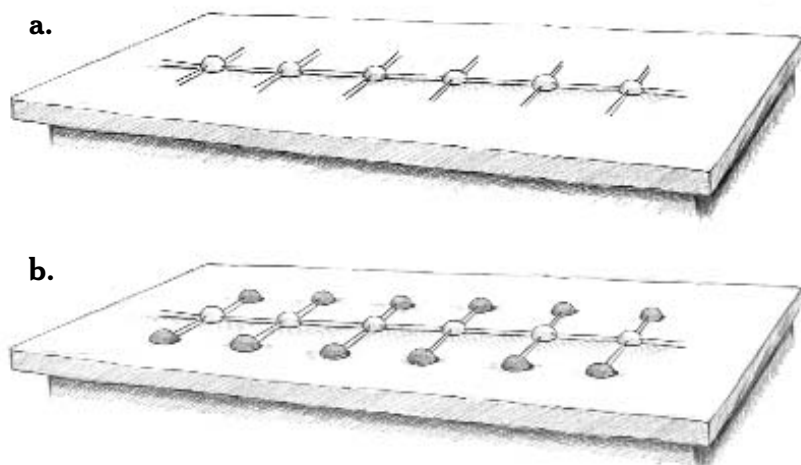
## Plastics and Polymers Science Fair Projects

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Put one bond (toothpick) partway into a carbon atom (gumdrop). Insert the other end of the toothpick bond partway into another carbon atom (another gumdrop of the same color). Use a second toothpick to bond one of the two carbon atoms to a third one. Continue until you have made a chain that is six carbon atoms long. A carbon atom is stable when it forms four bonds to atoms. Insert additional toothpicks into each gumdrop until all have four bonds to which other atoms can be attached. Remember to keep all the atoms resting on the table top. Place each toothpick as far from the others as you can. How many toothpicks did you use? How many bonds does your model have? See Figure 4a.

Your model should have nineteen toothpicks representing nineteen bonds. Of these, five bonds are used to connect the six carbon atoms to each other in a line. The other fourteen bonds each have one free end that is available to link to other atoms. So far, you have formed a segment with a six-carbon backbone.

The simplest atom that can be connected to the carbon atoms is hydrogen. Molecules that contain only carbon and hydrogen are called hydrocarbons. Let's see what the simplest hydrocarbon polymer looks like. To represent hydrogen atoms, use gumdrops of a different color from that used for carbon atoms. Place one hydrogen atom (gumdrop of different color) onto the free end of one of the bonds on each carbon atom. Repeat for a second bond. The two end carbon atoms will



*Figure 4.*

a) This is a model of the carbon backbone of a six-carbon segment of a polymer chain. The gumdrops represent carbon atoms, and the toothpicks are chemical bonds.

b) This is a hydrocarbon model of a six-carbon segment of a polymer chain. Two hydrogen atoms represented by darkened gumdrops are bonded to each carbon atom. The two end toothpicks are extended to be attached to another segment at each end. The model represents the simplest hydrocarbon polymer.

each have one bond left with a free end. Leave these empty. How many hydrogen atoms did you attach to your six-carbon backbone?

Your model (see Figure 4b) now represents a segment of a hydrocarbon polymer. It should show a backbone of six carbon atoms with two hydrogen atoms connected to each. There should be a total of twelve hydrogen atoms. The





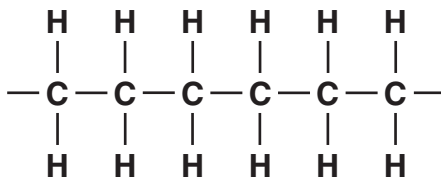
two end carbon atoms should each have one bond with a free end. They represent the links to the next segments of the polymer chain.

Chemistry books often show the arrangement of atoms in a polymer by what is called a structural formula. A structural formula looks very much like your model except that chemical symbols for the atoms are used instead of gumdrops and a bond is shown by a single line. Figure 5 shows the structural formula of the six-carbon segment that you have constructed.

Imagine how your model would look with another such hydrocarbon segment attached to each end of your polymer segment. Next, imagine additional segments attached to each end, on and on, until your chain has several thousand carbon atoms. You now have a mental picture of the simplest hydrocarbon polymer chain. The name of this polymer is polyethylene. Polyethylene is used to make food wraps, stiff or flexible plastic containers, telephone and power cable, toys, and trash bags.

*Figure 5.*

**In this structural formula of a six-carbon segment of a polymer chain, each atom is identified by its symbol. Each bond holding two atoms together is shown by a straight line.**





Hydrogen atoms are not the only atoms that can be attached to carbon atoms. Chlorine atoms, oxygen atoms, nitrogen atoms, carbon atoms, and many others can be substituted for the hydrogen atoms. Many of the substituted atoms can have various atoms attached to them in more than one kind of arrangement. Moreover, there are polymers that do not have a carbon backbone. Silly Putty has a silicon backbone. All of this contributes to the tremendous variety of polymers that can be made.

On a piece of paper, write the structural formula of a segment of a polymer with a six-carbon backbone and with all of the hydrogen atoms replaced by fluorine atoms. This structural formula is shown in Figure 6. Its common name is Teflon.

### Experiment 1.3

## ***Arrangement of Carbon Bonds in Space***

### ***Materials***

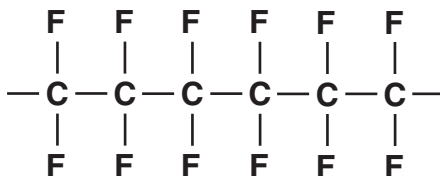
- ✓ small gumdrops, at least 6 of one color and 12 of another color
- ✓ Styrofoam board, at least 25 cm x 15 cm (10 in x 6 in)
- ✓ box of toothpicks

The directions for making the model in Experiment 1.2 stated that the bonds should be as far apart as possible. Because you



**Figure 6.**

**This is the structural formula of a 6-carbon segment of Teflon.**



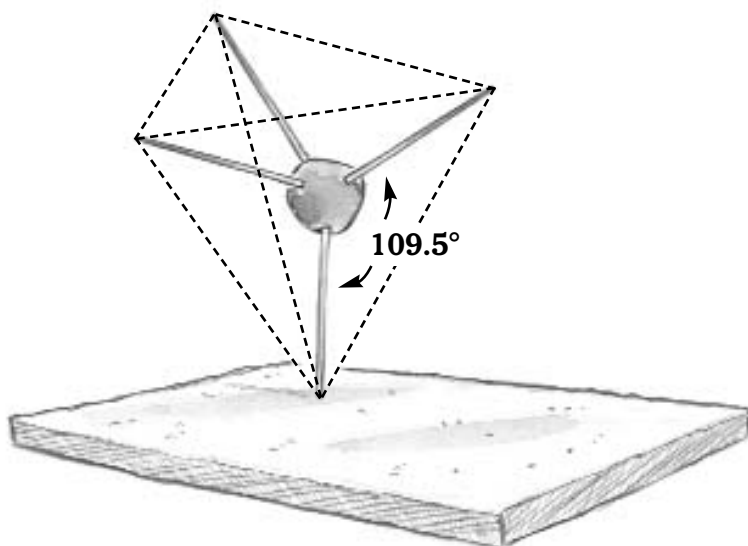
laid out a two-dimensional (flat) model, the farthest apart the four bonds could be was when directed to the four corners of a square. However, atoms and molecules exist in three-dimensional space. When atoms bonded to a central carbon atom can spread out in any direction, there is another arrangement that allows the bonds to get even farther apart. This is the arrangement that the bonds coming from the carbon atom would have if they were pointing to the four corners of a tetrahedron. Figure 7 shows this arrangement. This experiment will look at a model constructed with the tetrahedral arrangement, the one found in nature rather than in the pages of a book.

To construct a model of a carbon backbone with bonds in the tetrahedral formation around each carbon atom, start as before with toothpicks and gumdrops. Place four toothpicks into one carbon atom, setting the toothpicks as far from each other as you can. Keep Figure 7 in mind. Turn your carbon atom in various directions to check that the bonds are spaced as far from each other as they can get. If you spaced the four bonds of the carbon atom perfectly, each would form an angle of 109.5 degrees with any of the other bonds. An approximation will do for this experiment.



Hold your carbon atom by one toothpick and insert that toothpick vertically into a Styrofoam board. Make up another carbon atom with toothpicks spaced in the tetrahedral arrangement. Stick that one into the board. Make four more such carbons atoms, each with its four tetrahedral bonds.

The carbon atoms are now ready to be assembled into one segment. Remove one of the bonds on one carbon atom. Attach a second carbon atom by one of its bonds to the first by replacing the bond that was removed. You now have a



*Figure 7.*

The tetrahedral arrangement of single bonds around a central carbon atom is shown. The dotted lines show the tetrahedral shape. Each bond is at an angle of 109.5 degrees to the others.

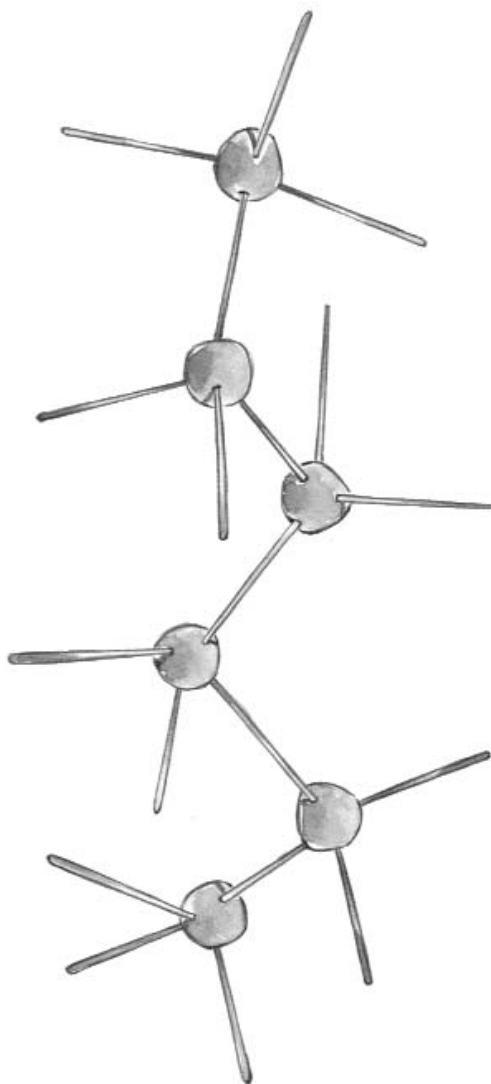


two-carbon segment. In the same way, attach to the chain each of the other four carbon atoms that you have prepared. Each time, one of the bonds replaces the one that is removed.

Do the carbon atoms lie in a straight line? Save your model for Experiment 1.5. Figure 8 shows a model that was constructed using the above instructions. In this model, the six-carbon atoms do not lie in a straight line. Rather, they have a jagged arrangement due to the tetrahedral arrangement of bonds. The arrangement that you get in your model depends in part on how each carbon atom was turned when joined to the next one. As a result, there are other possible arrangements besides the one in Figure 8. Different strands of the same polymer may have different shapes.

### *Science Project Idea*

If you have a four-carbon backbone of a chain, there are two different ways that carbon atoms can be connected. The four atoms can be attached one to the next, or three carbon atoms can be attached to one central atom. Construct permanent tetrahedral models that can be displayed to show both arrangements. Include the bonded hydrogen atoms. How does this add variety to the polymeric hydrocarbons that can be produced?



*Figure 8.*

A toothpick/gumdrop model of the six-carbon backbone segment of a polymer chain shows the tetrahedral arrangement of bonds around each carbon atom.



Experiment 1.4

## ***Making Slime: Cross-Linking***

### *Materials*

- |  |                                      |
|--|--------------------------------------|
| ✓ safety goggles   | ✓ measuring spoons                   |
| ✓ small glass jar  | ✓ wooden craft or<br>popsicle sticks |
| ✓ paper cup  | ✓ coin                               |
| ✓ borax (20 Mule Team<br>Borax or other source)                          | ✓ page from a newspaper              |
| ✓ plastic gloves (thin, loose-<br>fitting, discardable after<br>one use) | ✓ thin plastic wrap                  |
| ✓ Elmer's Glue-All or<br>White Glue                                      | ✓ pen with washable ink              |
| ✓ water  | ✓ refrigerator                       |
|  | ✓ plastic garbage bag<br>and tie     |
|  | ✓ table                              |

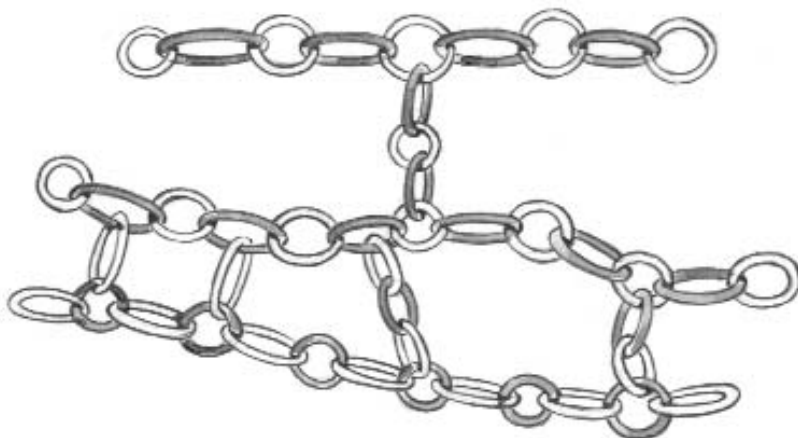
In this experiment, you will carry out a chemical reaction. In a chemical reaction, substances are changed into different substances by reorganizing which atoms are connected.

The reaction in this experiment will cause a link (chemical bond) to form between one polymer chain and another one near to it. You will start with long chains separate from each other and finish with chains that are linked together. One chain may become connected to one, two, three, or even more different



chains, depending on how the reaction is carried out. In fact, multiple links between chains can form all over the solution. This process is called cross-linking (see Figure 9). The more the cross-linking, the stiffer and more solid the product becomes. If all the chains were to be linked together in many places, the product would be a solid. Chemists are usually able to vary the quantities of ingredients to control the amount of cross-linking that takes place.

The product of this particular experiment will be a partly cross-linked polymer. The product will be very much like Slime



*Figure 9.*

**Each link in the diagram represents a group of atoms in a segment of cross-linked polymer chains. The cross-links may be made up of the same links or of links made of a different atom or group of atoms.**





or Silly Putty. The polymer that will be cross-linked is called polyvinyl acetate. It is the glue ingredient in Elmer's Glue-All or Elmer's White Glue. Borax will form the bridges (cross-links) between one chain and the next.

**Safety:** *Handle the dry borax with a spoon, not your fingers. Wear plastic gloves since some people are allergic to dry borax. Be careful not to inhale the dry borax. Wash your hands after handling any chemicals and after the experiment is finished. Do not allow small children to play with your product since they may try to put it their mouths. Do not put the product that you make on top of any fabric such as a cloth or your clothing; you may not get it out.*

Put on your safety goggles and plastic gloves. Mix together 1 tablespoon of white glue and 1 tablespoon of water in a small glass jar. In a paper cup, place about  $\frac{1}{8}$  teaspoon of borax into 1 tablespoon of water. Stir with a wood stick until all the borax is dissolved. While stirring the glue mixture in the jar, add the borax solution to it. A slime will form leaving a little water behind in the jar. Pour this water back into the paper cup. Pour a little water over your slime to cleanse it and add that water to the paper cup.

Now you can play with your slime. Remove your gloves and knead the slime with your hands. When you break the slime in half, can it be kneaded back into a whole? Shape it into a ball. Does the ball bounce? What happens when you press the ball downward gently? What happens when you place the ball on a



table and give it a hard slap? Press a coin into the slime. Does it hold the shape of the coin? What happens when you tear or cut the slime? Can it lift print from a newspaper? Draw on a thin film of plastic with washable ink. Can you get your slime to lift off the ink? Compare how the slime behaves when pulled apart slowly and carefully and when pulled apart rapidly. What happens to it if you stick a piece on the outside wall of the refrigerator?

When you have completed the experiment, place the wooden stick and the paper cup with the water in it into a sealed plastic bag and discard the bag in the garbage. Do not discard any of it down the drain because there may still be some glue in it. You can store your slime in a sealed plastic bag. Keep it in the refrigerator to prevent mold. Should you have to discard the slime, throw it in the garbage can, not down the drain. You may remove the safety goggles.

At the start, the glue has in it millions of extremely long chains of the polymer, polyvinyl acetate. The addition of borax causes links to form between the chains. Many of the chains become tied together by one or more links. The amount of cross-linking depends on the proportions of the reactants. A little more of the borax will make the product almost solid, while less of the borax will make the product more like a gel. The slime can be stretched slowly but will break with sharp edges when pulled rapidly. A ball of slime bounces when dropped. Your slime was probably depressed by the coin, although the carving did not show. The slime does not lift off the print from newspaper (commercial



Slime lifts colored print), but it does remove the color of the washable ink from the plastic. The parts can be kneaded together. When placed on the side of the refrigerator, the slime stays there.

Now that you have observed some of the properties of the slime that you made, you can investigate how changes in the recipe affect the properties. Vary the proportions of the glue, water, and borax to observe the differences. Make a chart of the proportions, your hypotheses, and the results.

Slime, Silly Putty, Gak, Ooze, and other such products are called non-Newtonian liquids because they do not flow the way ordinary liquids do. The differences that you saw are due to the entangling of chains and the cross-links that pull the chains back in place when they start to flow a little. As you can see, the long length of the polymer chains causes them to have certain properties different from that of ordinary molecules.

### *Science Project Ideas*

- Compare the properties of commercial Slime and Silly Putty to the slime that you made. How do they behave when stretched slowly or quickly? Do they bounce? How well? When placed on a vertical surface, do they flow? How long does a dent made in them last? Do they pick



up ink from a surface? Do they have other properties that your slime did not have? The Slime sold in stores is made with guar gum and borax. Silly Putty is prepared from borax and silicone oil. Other such products are made with polyvinyl alcohol and borax.

- Many other slime-type materials can be made. What is the effect of separately adding each of the following to the mixture you used in Experiment 1.4: a few drops of glycerin, some talcum powder, some ground-up chalk (you may have to adjust the basic ingredients by adding more water)? Try some other additives to see their effect.
- Look for products containing polymers that might form cross-links with borax. These include water-soluble polymers that have alcohol or acetate groups on them. Polyvinyl alcohol (PVA) is known to cross-link with borax. Try searching the supermarket and drugstore shelves for water-containing products such as hair styling gels that list PVA or a copolymer of PVA as an ingredient. Test the products to see if there is evidence of cross-linking when combined with a borax solution. Thickening or stiffening is evidence of cross-linking. Note that ingredients on labels are listed in order of their weight so that the PVA needs to be one of the first products listed. Also, look for food products that use natural gums (such as guar gums) as thickeners in water. Test these products to see if they are cross-linked by borax.



Experiment 1.5

## *A Model Problem*

### *Materials*

- ✓ model of a polymer segment from Experiment 1.3
- ✓ centimeter ruler

In Experiment 1.3, you constructed a six-carbon segment of a polymer called polyethylene. Suppose you wanted to make a model of a polyethylene strand with a backbone of 1,000 atoms. How long would this model be?

Measure the distance between the centers of two carbon atoms in the model that you constructed in Experiment 1.3. Use this measurement to calculate the length of a model that is 1,000 atoms long.

Here is one solution to the above problem. Let us say that the measured distance between the centers of the two carbon atoms in the model is 5.0 cm. There are 999 bonds between 1,000 atoms. To simplify calculations, we'll say that there are 1,000 bonds. The length of the polymer model from carbon atom to carbon atom will be:

$$1,000 \text{ atoms} \times \frac{5.0 \text{ cm}}{\text{atom}} = 5,000 \text{ cm or } 50 \text{ m (over } 50 \text{ yards)}$$

This model has a problem! It is too long.





See Appendix A for uses of some hydrocarbon polymers.

As pointed out earlier, the hydrogen atoms on a polymeric carbon chain may be replaced by many other atoms or groups. Each of these replacements changes the characteristics of the polymer and adds to the possible uses. Even the arrangement of the replacement groups, whether all on one side of the chain or staggered or random, affects the properties of polymers. Variations such as these make it possible to produce over sixty thousand different polymers each year.



## *Science Project Ideas*

- Construct a two-carbon model of a polymer segment that has one chlorine atom substituted for each hydrogen atom. Draw the corresponding structural formula.
- Make a series of drawings (or a series of models) of different configurations of a three-carbon segment of a hydrocarbon polymer chain. All three carbon atoms may rotate separately around its bond to the next carbon atom.
- Show with a series of drawings how the arrangement of carbon atoms in the carbon backbone of several adjacent polymer chains can cause the chains to become entangled.
- Draw the structural formulas of a six-carbon segment of a polymer where two of the hydrogen atoms have been replaced by chlorine. How many different such polymers can be constructed? Explain.



## Chapter 2

# Some Properties of Polymers

**A**lthough we can never see inside molecules or atoms with our eyes, scientists have developed all kinds of tools to help us find out what is there. These bits of information are something like the information obtained when six blind men examined an elephant, as told in a fable in India many years ago.

The first blind man approached the elephant and fell against it. He decided that an elephant is like a wall.

The second blind man felt the tusk and concluded that an elephant is like a spear.

The third grasped the trunk and thought that an elephant is like a snake.



The fourth felt the elephant about its knee and said that an elephant is like a tree.

The fifth touched the elephant's ear and thought it obvious that an elephant is like a fan.

The sixth grabbed the elephant's swinging tail and concluded that an elephant is like a rope.

The six blind men debated loudly, each sure that only he was right. They never found out what an elephant is really like.

Like the six blind men, chemists also find out little bits and pieces in their experiments, but there is a big difference in how the chemists share this information. Chemists are part of an international community of scientists who present their newly gained knowledge as quickly as possible via meetings, publications in journals, and on the Internet. Based on the collected information, chemists have been able to build up, bit by bit, detailed pictures of the parts of matter, pictures of what is too small to ever see. They know what the "elephant" is like. In a real way, they are today's wizards. They are able to see inside of matter in ways that would have been considered magical before our time. And chemists have used this knowledge to build materials that have never existed before on our earth or even, perhaps, in our universe.

In this chapter, the experiments will examine some polymers and how their properties are related to their extreme length.



Experiment 2.1

## *Polymers That Melt, Polymers That Burn*

### *Materials*

- ✓ glue stick that melts at low temperature or glue gun with glue stick
- ✓ stove with burners
- ✓ pot of water
- ✓ sink
- ✓ metal tongs
- ✓ metal pot lid
- ✓ goggles
- ✓ **an adult**

Some solid polymers melt when heated. Polymers that can melt are called thermoplastic. When melted, thermoplastic polymers can be poured into molds where they harden to form desirable products. Thermoplastic polymers can also be extruded (pushed through a narrow opening) to form fibers (thin or thick threads). Furthermore, the solidified products can be remelted.

Other solid polymers are called thermosets. They do not melt at all when heated. Instead, they end up scorched or even burned. As a result, thermosets can only be molded into a desired shape as they are formed.

All solid polymers are either thermoplastic or thermosetting. Which type do you think is likely to be produced the most? See Table 1 for the answer.



*Table 1.*

**PROPERTIES OF THERMOSETS COMPARED TO  
THERMOPLASTIC POLYMERS**

<b>Type of Solid Polymer</b>	<b>What Happens When Heated</b>	<b>How They Are Shaped</b>	<b>Percent of Total Plastics Used Today</b>
Thermoplastic	Melts	By molding or extruding	85
Thermosetting	Scorches and eventually burns	As formed	15

Thermosets cannot melt to a liquid because they are made of chains with enough cross-links between them so that the chains cannot slip past each other. In the liquid state, particles are able to move around each other. Since extensively cross-linked polymer chains cannot move past each other, they cannot be melted and will burn if the temperature gets high enough.

Thermoplastic polymers can be compared to water that is frozen into a block of ice and is then melted to liquid water again. The process can be repeated again and again. Thermosetting polymers are more like the white of an egg. If you boil an egg for ten minutes and then examine the white, you will find that it is a white solid. There is no way that you can return it back to the liquid egg white. If you keep increasing the heat, the egg white will burn.



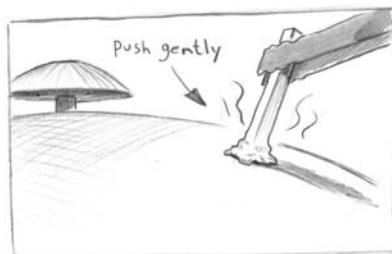
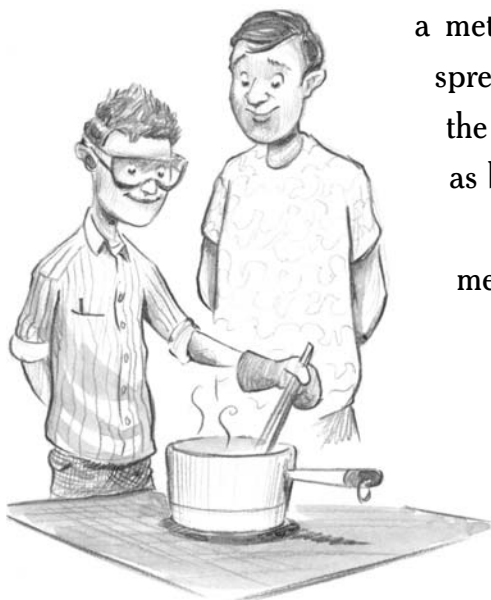
The following experiment illustrates one of these two types of solid polymers.

In a craft store, look through the assortment of glue sticks available. Find one whose label says that it melts below the temperature of boiling water. See later instructions if you can only find glue sticks for glue guns.

Put your goggles on. **Under the supervision of an adult**, boil a pan of water. Use tongs to hold the low-melting glue stick at its top. Lower the glue stick halfway into the boiling water. Does the glue stick melt? Raise it and, with the

tongs, quickly press the hot stick onto a metal pot cover. Does the stick spread out a bit? Put the end of the glue stick back in the water as before. Does it melt again?

If you cannot obtain a low-melting glue stick, **have an**



*Figure 11.*

**The hot end of the glue stick is lowered into boiling water and then pressed onto the top of a pot cover.**



**adult** use a glue gun to melt a glue stick. Allow some of the melt to drip onto a solid metal surface such as the pot lid (see Figure 11). Then, **the adult** should touch the solidified melt with the hot tip of the glue gun. Does the solid melt again? Pour the water into the sink. The plastic can be wedged off the metal and thrown into the garbage.

Was the glue stick thermoplastic or thermosetting?

### Experiment 2.2

## ***Making and Shaping Thermosetting Plastic***

### *Materials*

- ✓ safety goggles
- ✓ disposable plastic gloves
- ✓ epoxy putty (can be obtained in hardware stores)
- ✓ plastic knife
- ✓ candle and matches
- ✓ tongs
- ✓ **an adult**

The following experiment will enable you to make a thermosetting plastic and then to test its thermosetting properties. Put on goggles and a pair of disposable plastic gloves. Obtain a roll of plumber's epoxy putty. With a plastic knife, gently cut two slices about 1 cm ( $\frac{1}{3}$  in) from the end of the roll. You can probably see the different colors of the two ingredients. Gently put one of the slices aside. Knead and twist the other slice until



it is all one color. As you knead it, do you feel any temperature change? A temperature change indicates that a chemical reaction may have taken place. Feel the unkneaded putty to find out if its temperature has also changed. Shape the kneaded putty, now all one color, into a disk. Punch in two eyes, a nose, and a mouth; see Figure 12. Place it on a countertop. After one minute, feel its temperature. Feel the temperature of the unkneaded putty, too. Were there any changes? Discard the plastic gloves and remove the goggles. Let the two pieces of putty stand for about twenty minutes without touching them. Then, note any changes. Being careful not to press or squeeze



*Figure 12.*

**After you have shaped the kneaded putty into a disk, punch in two eyes, a nose, and a mouth.**



the unkneaded putty, leave both pieces until the next day in a cool, safe place where no one will touch them.

The next day, compare both pieces. Gently press each piece to check hardness. Use tongs to pick up the small piece of putty that you kneaded and shaped. Carry out the next step outdoors or under an exhaust fan that vents to the outside. **Ask an adult** to light a candle. With tongs, hold the small piece of shaped putty in the flame. Does it melt? Does it burn? After cooling, it may be safely discarded in the trash.

When epoxy putty is kneaded, a heat-producing reaction takes place. The two parts of the putty combine with each other to form a polymer. Is a thermosetting or thermoplastic polymer formed? Did cross-linking occur? How do you know?

What happened to the unkneaded putty? Did it change in any way?

You can expect to find no change in the unkneaded putty. When the two parts needed to make the polymer are not inter-mixed, no polymerization can occur. It is not safe to test this piece to see if it melts or burns. You need to get rid of it. To do this safely, knead this piece as you did the other, taking the same precautions as before. Let it harden and then discard it.





# Science Project Ideas

***I**n any experiment that uses heat, be sure to wear your safety goggles and to do your work **with adult supervision**. Handle hot solids with tongs.*

- Is the product of an instant glue a thermosetting or a thermoplastic polymer? **Under adult supervision**, investigate using the polymer film that you made in Experiment 1.3. Find this out also for the dried oil paint and for the slime that you made. Explain the results.
- Make a film out of Elmer's Glue-all or Elmer's White Glue. **Under adult supervision**, find out if it is a thermosetting or a thermoplastic polymer. How does it compare to the slime that you made from the glue?
- Obtain a glue stick that melts below the boiling point of water. Repeatedly, melt a piece of it and allow it to harden again. What changes, if any, do you observe in the plastic?



Experiment 2.3

## *Some Polymers Like Water*

### *Materials*

- ✓ safety goggles
- ✓ 1 medium-sized disposable baby diaper
- ✓ scissors
- ✓ white sheet of paper
- ✓ stapler
- ✓ measuring cup
- ✓ tap water
- ✓ colorless, wide-mouth, quart-sized glass jar
- ✓ glass-marking pen
- ✓ small cup
- ✓ teaspoon
- ✓ table salt
- ✓ sink

Most polymers are insoluble in water. This means that if you add a teaspoonful of an insoluble polymer to water and stir it up, the polymer will simply remain unchanged in the water. This is unlike salt, which is quite soluble in water and will disappear into water upon stirring.

There are a few polymer solids that water can penetrate. Such polymers may swell in water, form gels, or even dissolve. These polymers are hydrophilic; they “like” water (from the Greek words *hydro* meaning “water” and *philos* for “dear” or “loving”). When polymers like water, they can be used to absorb water. Such polymers may be found in diapers and in some packets enclosed in packages of fresh meat to help



absorb fluids. How effective is the polymer in a diaper in absorbing water?

Put on safety goggles. The moisture-absorbing material to be used in this experiment, sodium polyacrylate, is not toxic. However, always protect your eyes when working with commercial chemicals. Do not discard any materials from this experiment until you are instructed to do so.

Cut away and discard all but the long padded section in the center of a baby diaper. Be sure to leave some plastic intact along the edges. This padded section will be called the diaper pad. With scissors, cut across the diaper pad from one side to the other. Make another cut 13 cm (5 in) above the first to make a square piece of diaper pad open at each end. Hold the square over a white sheet of paper and pluck away about 3 cm (1 in) of the stuffing from each of the two open ends. Place the removed stuffing on the sheet of paper. Fold the empty part of each end of the diaper pad at least once to cover the open ends. Leave plenty of room for the contents of the diaper to expand. Staple the ends closed to seal the diaper pad.

Obtain a colorless, wide-mouth, quart-sized glass jar. Use a measuring cup to fill the jar halfway with tap water, keeping a record of how much water you used. With a glass-marking pen, mark the jar on the outside to show the level of the water in the jar. Place the diaper pad into the jar and push it completely under the water. Allow the container to stand at least



twenty minutes. What do you observe? Is the immersed diaper pad swollen with water?

Pull the pad out of the water. Allow any drops of water from it to fall back into the jar. Place the wet pad on the table and press it gently with the palm of your hand to see if you can squeeze out any more water. Don't press with your fingers since that may tear through the covering. Can you squeeze any more water out?

How much water was used to swell the pad? To find out, you can subtract the quantity of water left in the jar from the quantity with which you started. You already know the quantity at the start. To measure the water left in the jar, pour a cup of that water into the measuring cup. Discard the cupful into the sink. Keeping track of the total quantity of water, continue pouring a cupful at a time until the water in the jar is gone. Subtract the total amount of water left in the jar from the initial amount. The difference equals the quantity absorbed by the diaper pad.

The chemical that works this magic is a polymer called sodium polyacrylate. Sodium polyacrylate is extremely hydrophilic. Is the stuffing inside of the diaper made of sodium polyacrylate or is the stuffing just a support for sodium polyacrylate? To find out, here's a clue. Go back to the stuffing placed on the sheet of paper. You will see tiny granules on the paper that dropped out of the small amount of stuffing.



How can you test the stuffing and the granules to see which is the sodium polyacrylate?

You can use water. Shake the stuffing that you removed from the pad over the paper. If you don't have a visible layer of polymer granules, pull out some more stuffing from the diaper and shake it over the paper. If any fluff from the stuffing is on the paper, you can remove it by gently rolling it with your fingers into a clump.

Place the collected granules into a cup and add about 1 cm ( $\frac{1}{2}$  in) of tap water. Allow this to stand for about twenty minutes. While you are waiting, add water to the stuffing and see if you can squeeze the water out again.

Have the granules swelled in the cup? Is the water thick? Keep adding small quantities of water to see how much the granules absorb until there is no change. What happened with the rest of the stuffing? What are your conclusions?

The ability of sodium polyacrylate to absorb water has to do with positive and negative electrostatic charge. Sodium polyacrylate has oxygen atoms in it that carry some negative charge. The negative charge is balanced by sodium atoms that carry positive charge. The sodium atoms are bonded to the oxygen atoms as shown in Figure 13a. When placed in water, the water molecules are attracted to both positive and negative sites and cluster around them (Figure 13b). The water gets trapped in the spaces left between the convoluted polymer molecules.

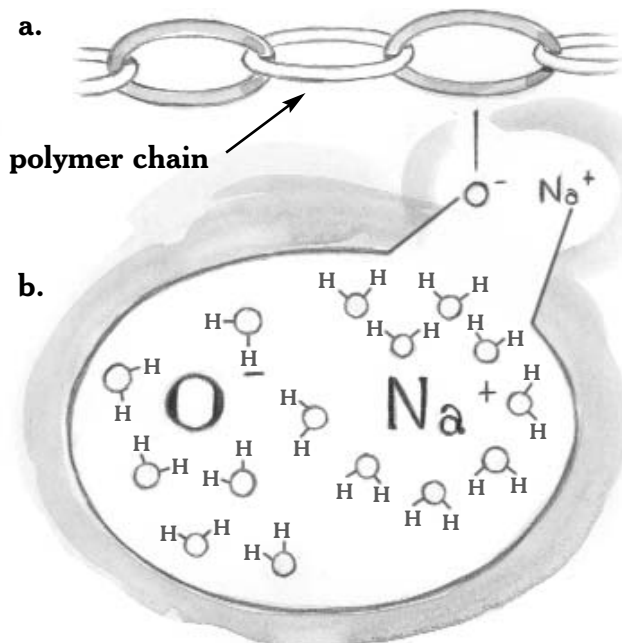


Figure 13.

a) The polymer, sodium polyacrylate, is represented by a chain in which the links stand for the repeating units. Each link has an oxygen atom (O) bonded to it with a sodium atom (Na) bonded to the oxygen atom. The oxygen and sodium atoms are shown for only one of the segments. The oxygen atom carries some negative charge and the sodium atom carries some positive charge.

b) When sodium polyacrylate is placed in water, it becomes surrounded by water molecules. Hydrogen atoms (H) in the water are attracted to and surround the oxygen atoms in the sodium polyacrylate chain. The oxygen atoms in the water are attracted to the sodium atoms and surround them. These attractions enable water to gradually get between the many chains of polymer. The water will eventually swell the polymer to a large volume. In this drawing, the water molecules have been reduced in size to show the way they face the oxygen and sodium atoms.



Globules of gel are formed. Enough water can penetrate the polymer to swell it up to many times its own size.

Take a teaspoonful of the thick water into which you added the polymer granules. Sprinkle a little table salt over it. What happens?

Table salt interferes with the ability of the polymer to hold water because table salt has atoms carrying strong negative and positive charge. These get between the polymer and the water and interfere with the polymer's ability to hold the water. As a result, some water comes out of the polymer. Other compounds with charged sites in them such as baking soda and vinegar have the same effect.

Before discarding the thick water with the polymer granules, add enough salt to it to liquefy all of it. Fill the container completely with water and pour it down the sink with the water running. Allow the water to run for another thirty seconds. Discard all solids into the garbage, including any unused polymer granules.

## *Science Project Ideas*

- How does the volume of tap water compare to the volume of purified water absorbed by a diaper pad? For purified



water, you can use distilled or deionized water or water from a dehumidifier. Investigate and explain the result.

- Carry out experiments on a diaper pad to find out how its ability to absorb water changes when dissolved sugar is present in tap water. Does the quantity of sugar make a difference? (Sugar does not have charged particles in it.)
- Allow a water-swollen diaper pad to stay on a counter top for several days. Does the swelling decrease? Does the pad continue to feel wet? Explain your observations. Continue your experiment for as long as you can to see if any changes occur.
- How much of a solution of 0.9 g of table salt dissolved in 99 mL of water is absorbed by a test sample of diaper pad? This is approximately the same concentration as the salts in baby urine. Would you expect a diaper to be more or less absorbent in actual use than when tested with tap water?
- How does temperature affect the water absorbency of sodium polyacrylate? Investigate and explain your results. How does this affect the use of a diaper?
- Compare the absorbency of a diaper pad to that of an equal weight of paper towel. Which is preferable to use for a diaper? Why? Which is preferable to clean up a spill of water on the floor? Why?
- Compare different brands of diapers to see which is the best buy based on the amount of simulated “urine” absorbed. Be sure the diapers are made for the same weight range of a baby.





Experiment 2.4

## ***Styrofoam: A Polymer That Does Not Like Water***

### ***Materials***

- ✓ small flat square or chunk of non-foamed polystyrene (such as the bottom of a transparent plastic drinking glass, a chunk from pen casing, or casings for hair dryers and other electrical equipment; these items are labeled  $\langle 6 \rangle$  in the Plastic Resin Identification Code used in recycling).
- ✓ acetone (or acetone-type nail polish remover)
- ✓ safety goggles
- ✓ small glass jar with lid
- ✓ metal spoon
- ✓ Styrofoam cup
- ✓ wide-neck glass jar (neck should be wider than the Styrofoam cup base)
- ✓ sink with running water

Foods, liquids, items displayed on racks, and fragile objects are very often encased in plastic for protection and/or for visibility. All of the plastic used for such packaging must be waterproof to both keep water from getting in and to keep water from getting out. Such plastics are hydrophobic (from the Greek words *hydro* meaning “water” and *phobos* meaning “fear”). They don’t “like” water.



Polystyrene is a hydrocarbon. Hydrocarbons are all insoluble in water. You probably already know that polystyrene is insoluble in water because it is used for drinking cups and other waterproof materials. It would not be convenient if a cup dissolved when water was poured into it.

Styrofoam is the trade name for polystyrene that has been expanded with gases during manufacture. The result is a white rigid, lightweight, spongelike, air-filled structure. It is used for hot and cold cups, food trays, and all kinds of packaging that need insulation and/or protection from bangs and bumps. Since it is made of polystyrene and air, we know that it is not soluble in water.

If these plastics are not soluble in water, is there another liquid that can dissolve them? This experiment will investigate acetone for this purpose. Acetone is a small molecule made of carbon atoms, hydrogen atoms, and an oxygen atom. It is very soluble in water. Will acetone dissolve polystyrene?

Acetone may be purchased in hardware stores. It is also the main ingredient of some nail polish removers. When a nail polish remover contains acetone, the acetone is ordinarily diluted by other ingredients. As a result, if you use acetone-type nail polish remover instead of acetone in this experiment, the changes will take longer to complete and be less striking. Separate instructions using an acetone-type nail polish remover may be found at the end of this experiment.



**Safety:** *Acetone is flammable and should be used only where no flame is near. Because it evaporates readily, use it only in a well-ventilated room or outdoors. Wear safety goggles whenever you work with acetone. Keep any container of acetone tightly covered when not in use. You may wish to wear plastic gloves because acetone dries the skin. A little hand cream will re-moisturize your skin.*

Break off a small chunk of non-foamed polystyrene. Pour some acetone into a small glass jar and add your polystyrene sample to it. Stir well with a metal spoon. Does the polystyrene dissolve? Has the sample changed color? Cover the jar and let it stand with occasional shaking for about a half hour. Does the polymer swell in the acetone? Lift the sample out of the acetone with a metal spoon. Scratch the sample with your nail to see if it has softened.

After the test is completed, rinse the polystyrene sample with water and discard it into the recycling bin or waste basket. Pour the used acetone down the drain with the water running. Rinse the jar with water and pour the water down the drain. Keep the water running for at least a half minute.

Did the polystyrene dissolve? Did you detect any change in it?

Next, the test with acetone will be repeated on Styrofoam.

With your safety goggles on and taking the same safety precautions when using acetone as stated before, hold a Styrofoam cup centered over a wide-neck jar (see Figure 14). Pour a little



**Figure 14.**

**Pour acetone into a Styrofoam cup. What happens?**

acetone, just enough to cover the bottom, into the cup. What happens? What is in the jar? What does the cup look like now?

Use the metal spoon to push the Styrofoam cup into the jar. Keep pushing until all of the cup is under the acetone. What does the cup look like at this point?

With the aid of the spoon, retrieve all of the soft solid pieces floating in the acetone. Rinse the solid with running water from the sink. You can now safely handle the solid with your fingers. Roll it into a ball.



Discard the acetone down the drain with the water running and allow the water to run for at least half a minute afterward. Put the ball down on the sink counter.

Did the acetone dissolve the Styrofoam?

You have completed the experiment and may remove the safety goggles.

The polystyrene (not expanded) did not dissolve in acetone, but it may have softened a bit. The color of the polystyrene sample may have whitened. You may have detected slight swelling.

The results with the Styrofoam cup were quite different. When acetone is poured into a Styrofoam cup, it goes right through, leaving plastic hanging around a hole in the cup. It is astonishing how quickly the acetone cuts through the cup. Did the acetone dissolve the polystyrene? The answer is no. The foamed polystyrene was collapsed to a lump of polystyrene.

Acetone does not dissolve polystyrene whether or not the polymer is expanded. Styrofoam collapses because acetone replaces the air in it. You can allow the polystyrene ball to air-dry and then show it off as your collapsed Styrofoam cup.

You can also get a Styrofoam cup to collapse with acetone-type nail polish remover, as follows, but it will take a longer time. Put on your safety goggles. Obey the precautions that need to be taken when working with acetone. Place a Styrofoam cup upright into a clean glass jar. Pour acetone-type nail polish remover into the Styrofoam cup about one-fourth of



the way up. Keep the jar and its contents away from any flame and in a well-ventilated location and allow it to stand. Occasionally, push the cup downward so as to keep about one-fourth of it under the nail polish remover. You may need to replenish the polish remover. Continue until the entire cup is under the liquid. Then, remove the remains of the cup and squeeze it dry and into a ball. Discard the used polish remover into the sink drain and run the water down the drain for about a minute. You may remove the safety goggles. The speed at which the collapse takes place depends on the proportion of acetone in the nail polish remover.

## *Science Project Ideas*

- Test different plastics found in the home to see if any dissolve in acetone. Those that are numbered with the Plastic Resin Identification Code (see Appendix B) can be identified by chemical name. Which tend to be more soluble in acetone, polymers with oxygen in them or polymers without oxygen?
- Why does acetone cause Styrofoam to collapse? Find explanations or invent your own hypothesis. Show in a



## Plastics and Polymers Science Fair Projects

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display what takes place in the Styrofoam when acetone causes the collapse.

- How much air is enclosed in a sample of Styrofoam? One way to find out is to first measure the volume of a block of Styrofoam. Then, measure the volume of the same block after it has been collapsed in acetone and dried. What problems do you see that might cause your results to be too high or too low? Explain.
- What polymer is used for the packaging of olive, sesame, canola, or corn oil used in cooking? The oils are all hydrocarbons. Will they dissolve polymers that are also hydrocarbons? Conduct experiments to find out whether any of the oils dissolve in polymeric hydrocarbons. The polymers that are hydrocarbon compounds most resembling cooking oils are Numbers 2, 4, and 5 in the Plastic Resin Identification Code (see Appendix B).



Experiment 2.5

## ***Fabrics That Like Water, Fabrics That Don't***

### ***Materials***

- ✓ square of cotton fabric
- ✓ square of nylon fabric
- ✓ water
- ✓ thin string
- ✓ 2 chairs
- ✓ scissors

Is cotton hydrophilic or hydrophobic? That is, is cotton a comparatively waterproof fabric, or is it a fabric that is easy to wet? What about nylon? The following brief experiment shows a simple test to find out.

Make a short clothesline by tying a length of thin string from one chair to another. Cut one nylon and one cotton square of fabric, both equal in size. Try to find fabrics that are used for the same purpose, such as for undershirts, so that they are woven similarly. Place each of the fabrics in water until soaked. Lift each one from the water and hold it briefly until dripping slows. Fold each one separately over the string so that they are hanging the same way as shown in Figure 15. Observe how long each takes to dry. Based on your observations, is either one hydrophilic?

The fabric that dries much more slowly is hydrophilic, while the one that dries rapidly is hydrophobic.





*Figure 15.*

**Two fabric samples are hung to dry.**

## *Science Project Ideas*

- It is evident from Experiment 2.5 that cotton is made up of polymers that attract water whereas nylon has comparatively little attraction for water. Look up the structure of water in a chemistry book. Also, find out the structures of nylon and of cotton. Based on these structures, develop a hypothesis to explain why nylon is hydrophobic and



cotton is hydrophilic. You may need to consult with someone knowledgeable in chemistry to help you.

- Test other natural and synthetic fibers to determine whether they are hydrophilic or hydrophobic. Develop a hypothesis to explain differences in behavior.
- Compare fabrics made of nylon and of polypropylene to see which is more hydrophobic. Be careful to keep all variables under control, such as the thickness of the fiber and the type and closeness of the weave, and the amount of water left in the fabric before hanging.

### Experiment 2.6

## *Permeability to Water*

### *Materials*

- ✓ polyethylene food wrap (Handiwrap or Glad Wrap)
- ✓ polyvinyl chloride food wrap (Reynold's Plastic Wrap or "stretch-tite")
- ✓ polyvinylidene chloride (Saran Wrap, which is about 87 percent polyvinylidene chloride and about 13 percent polyvinyl chloride)
- ✓ measuring cup
- ✓ scissors
- ✓ water
- ✓ 4 drinking glasses, all the same size
- ✓ 3 identical rubber bands
- ✓ 3 labels
- ✓ pen
- ✓ box



How well does food wrap keep foods moist? How well does it keep outside moisture from getting in? A covering that allows water molecules to pass through it is said to be permeable to water. This experiment will test three different food wraps, or films, for their permeability to water vapor.

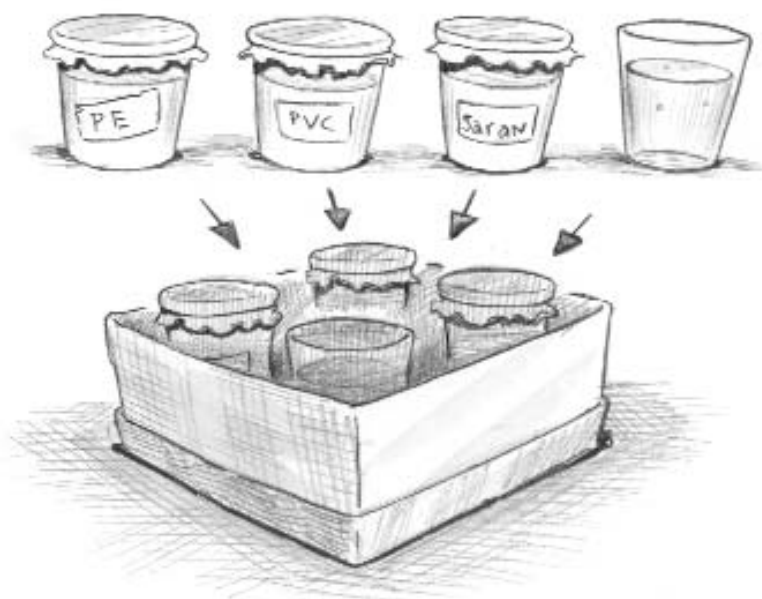
Label three drinking glasses in sequence as follows: polyethylene (PE), polyvinyl chloride (PVC), and polyvinylidene chloride (Saran Wrap). Add  $\frac{3}{4}$  cup of water to a measuring cup. Pour the water into one glass and allow the cup to drain into it for 5 seconds. Repeat for the next two glasses, measuring and pouring as carefully alike as you can for all three glasses. Repeat for the unlabeled fourth drinking glass.

Cut one square of each film to fit over a glass. Each square should be the same size. Cover the first glass snugly with polyethylene food wrap, the film that matches the label on that glass, trying not to stretch the film. Put a rubber band tightly around the glass to hold the plastic down. Repeat with the appropriate films for the other two labeled glasses, carefully doing them in the same way as for the first glass, as shown in Figure 16. Place all three glasses plus the open, unlabeled glass of water together in an open box and place the box at the back of a closet. Your purpose is to keep the four glasses undisturbed and at the same temperature during the experiment. By keeping all the variables the same except for the two variables that you are investigating (controlling the variables), you can compare the permeabilities of the three films. The two variables that are being investigated



are the identity of the film and how much of the water evaporates. Every few days, examine the three glasses to compare the levels of water in them. Continue until you can place the three glasses in order from greatest loss of water to least loss of water, or until you conclude that all three remain further unchanged over several weeks.

How much water, if any, was lost from each glass? Use the measuring cup to find out. Be sure to dry the measuring cup between measurements and to drain each glass for the same



*Figure 16.*

**Cover the three glasses, which are partially filled with water, with plastic wrap. Leave the fourth cup uncovered.**



period of time. What are your conclusions? What is the purpose of testing the glass of water with no cover on it? That glass of water is called an “experimental control.”

Which film is most permeable to water? What about the other two? How does the water loss in the covered glasses compare to that of the glass with no cover on it?

### *Science Project Ideas*

- Which food wrap of those available in the local store provides the best protection from oxygen in the air, that is, which is impermeable to oxygen? To find out, some kind of indicator is needed to show when oxygen has passed through the film. A slice of apple is very convenient for this purpose, since the flesh discolors on exposure to the oxygen in the air. Keep in mind that it is important to control all the variables except the two that you are testing. The apple slices will start discoloring as soon as exposed to air, so be sure to prepare the slices and to enclose them all at the same time. Which provides better protection, wrapping the apple slice completely with film or placing it in a glass and covering the glass with film? In Experiment 2.5, an uncovered glass of water was used as



a control. What will you use for this investigation? Compare your results to those of Experiment 2.5.

- Are the results obtained in Experiment 2.5 the same when the temperature changes? One way to control the temperature is to carry out the experiment in a refrigerator that is usually kept closed. Compare the permeabilities of the food wraps at the refrigerator temperature. How does permeability to water change with temperature? Carry out a similar experiment for permeability to oxygen.
- Television commercials about food wraps often claim that their product provides the best seal to itself. Devise and carry out an experiment to test how well each wrap sticks to itself. State the variables that you controlled and how you did it. Indicate whether there were variables that you could not control and how these affected the outcomes. Is there a difference between the ability of a wrap to cling to itself and to cling to a glass surface? Does this affect the usefulness of the wrap? What are your conclusions?
- Test how well different food wraps cling to a container. Does the material out of which the container is made make a difference? Does it make a difference if the outside of the container is wet?

## Chapter 3

# Testing Plastics

**B**eginning in the 1950s, the manufacture of plastics began to change from a minor industrial process to a major part of the worldwide economy. Plastics were developed to meet all kinds of needs, and the use of every type of polymer multiplied. This resulted in a totally new problem: plastic pollution. The accumulation of plastics in the garbage became frightening. Landfills grew uncontrollably when the plastics and wax-coated paper in them failed to decay. Piles of plastics were found floating in the middle of the oceans, trapping fish and bringing pollution. There was clearly a need for some way to reduce the pollution. Environmentalists called for regulations to control this growth of plastics.

It was then that serious thought was given to recycling. Before re-use of the plastic materials could take place, the plastic trash



had to be separated. Unfortunately, there were so many different plastics that there was no easy, inexpensive way to do this. A decision was reached internationally, a decision of the utmost importance. It was decided to greatly cut back on the number of materials used in packaging. Code numbers from <1> to <6> were assigned to the chosen plastics. The numbers, set inside a triangle made of bent arrows, were to be placed somewhere on each plastic product. The number <7> was chosen for a category in which to lump all the plastics used for special packaging not covered by the first six categories. Compliance with this scheme by the manufacturers was voluntary.

Town by town, village by village, city by city, the entire United States began to cooperate to help recycle plastics. Residents and businesses separated their plastics into bins according to the local rules and set them out for pickup. In many places, homeowners and businesses paid for the waste collectors to pick up garbage and plastics separately. In other places, the local government paid for it. Little by little, the frightening wave of plastic pollution began to decrease. It was a major victory.

Plastics have brought us an abundance of benefits, but every plus carries some minuses with it. Watchfulness must not be relaxed in the fight against plastic pollution, and the cooperation between manufacturers and consumers must continue. Only in this way can we all gain in the benefits brought to us by plastics.





Experiment 3.1

# *Identification and Separation of Plastics for Recycling*

## *Materials*

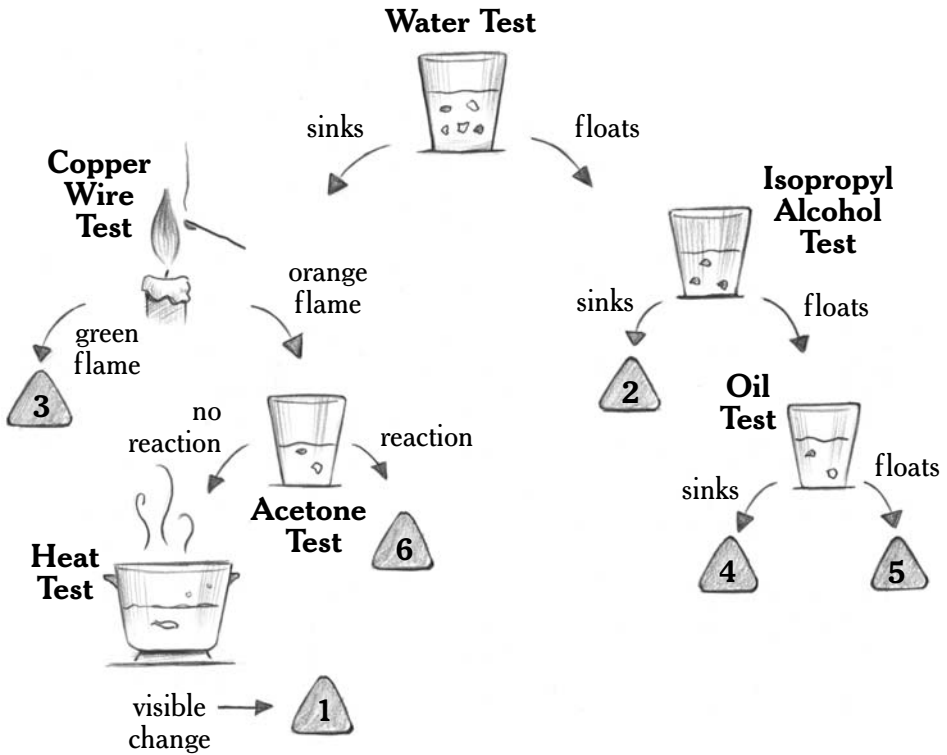
- ✓ 1 sample each of plastics numbered <2>, <4>, and <5> (see Appendix B)
- ✓ 2 samples each of plastics numbered <1>, <3>, and <6>
- ✓ finger-sized strip of PET (code <1>) cut from a 2-liter soda bottle
- ✓ cup or bowl of water
- ✓ clean wooden craft or popsicle sticks
- ✓ paper towels
- ✓ goggles
- ✓ 100 mL graduated cylinder or household glass or metal measuring cup
- ✓ isopropyl alcohol (70 percent)
- ✓ sink with running water
- ✓ Mazola corn oil
- ✓ copper wire 23–30 cm (9–12 in) long and about the thickness of the wire used for a No. 1 paper clip
- ✓ flame from stove burner or Bunsen burner
- ✓ **an adult**
- ✓ cork, large size
- ✓ cookie sheet or other flat metal pan
- ✓ tongs
- ✓ acetone
- ✓ drinking glass
- ✓ scissors
- ✓ pot



There are several ways to separate and identify the six plastics (also called resins) in the recycling system. The technique in this experiment uses materials usually available in the home or local store. It was developed by the American Plastics Council. The tests to be used are not conclusive because the addition of additives to the polymer to form the plastic can alter the responses to the tests. However, the tests are extremely useful as a guide to separate polymers for recycling.

The list of used plastics that are picked up for recycling or disposal may be found in Appendix B. Note that there are two kinds of polyethylene listed: low density polyethylene (LDPE) and high density polyethylene (HDPE). LDPE is made under conditions that cause extensive cross-linking to occur. As a result, the chains cannot get close to each other. Because the chains are farther apart, the density is lowered. HDPE, on the other hand, is made to produce long chains without cross-linking. The chains tend to line up close to each other causing the polymer to be denser than LDPE.

It is always a good idea to first try out a set of tests using “knowns,” that is, samples whose identities are known. That is what you can do next. Carry out the test on samples cut from empty containers marked with the recycling code number. Cut out one sample of each plastic listed in Appendix B (recycling codes <1> through <6>). A sample about the size of a



*Figure 17.*

**This chart shows the scheme for identifying the six polymers collected in the recycling system.**

large aspirin pill is satisfactory. The sample should not have a label or writing on it since that may change the density. The shape is not important, so you can use shape to help identify the sample for yourself. **If difficult to cut, be sure to have an adult help you.** A thicker sample is better than a thin one; do not use food wrap.



In Figure 17, the steps and choices in the identification process are charted. The chart is an excellent aide to consult at any time during the experiment.

### ***Water Density Test***

Fill a cup or bowl with water and let it stand a while to reach room temperature. Put one of the samples into it. Poke the sample with a clean wooden craft stick or popsicle stick to knock off any bubbles on it that might cause it to float. Add the other five samples and poke them similarly. Three samples should float, and three should sink as shown in Figure 18. Remove the



***Figure 18.***

**During the water density test, three samples will float and three will sink.**



samples that float and dry them. Set them aside on a paper towel marked to identify them. Remove the samples that sink, dry them, and set them aside on another paper towel marked to indicate that they sink. The samples that float are less dense than water. The samples that sink are denser than water. Based on Table 2, identify the samples that floated.

Wear goggles during the remainder of this experiment.

### SAMPLES THAT FLOAT IN WATER

#### *Isopropyl Alcohol Test*

Obtain 70 percent isopropyl alcohol (also called isopropanol) from the supermarket or drugstore (do not use any other

*Table 2.*

#### DENSITY OF POLYMERS IN RECYCLING SCHEME

Abbreviation	Name	Density
H <sub>2</sub> O	Water	1.00
(1) PET	Polyethylene terephthalate	1.38–1.39
(2) HDPE	High density polyethylene	0.95–0.97
(3) PVC	Polyvinyl chloride	1.16–1.35
(4) LDPE	Low density polyethylene	0.92–0.94
(5) PP	Polypropylene	0.90–0.91
(6) PS	Polystyrene	1.05–1.07



percentage). Isopropyl alcohol is flammable, so be sure to use it in a well-ventilated area away from any flame, and keep it covered.

Pour 60 g (65 mL or 2.6 fl oz) of isopropyl alcohol 70 percent into a graduated cylinder or glass or metal measuring cup. Add enough water to make 100 mL (4 fl oz) in all. This has to be done very carefully and is best done using graduated cylinders for measurements. Mix well with a stick. If measured with a graduated cylinder, pour the alcohol solution into a drinking glass. Place into the alcohol solution all three of the samples that floated. Poke each sample with a wood stick to knock it under the surface and dislodge any air bubbles on the sample. One sample will sink. Based on their densities, which sample sinks?

The sample that sinks is the one that is the densest of the three samples. It is high density polyethylene (HDPE), code <2>. Remove the HDPE sample, dry it, and discard it along with the wooden sticks into the waste bin.

Remove the two samples that floated and dry them for the next test. Pour the isopropanol down the sink and run water after it for half a minute.

### ***Oil Test***

Fill a drinking glass (not plastic) half full of Mazola corn oil. No other oil may be substituted since it may have a different density. Place the two unidentified samples into the oil. Poke



each with a wooden stick to be sure bubbles are bumped off it. One sample will slowly sink and the other will end up floating. What is the name of the sample that sinks? What is the name of the sample that floats?

Discard the oil into a covered container and throw it away.

Dry the samples and discard them along with the sticks into the waste bin.

### SAMPLES THAT SINK IN WATER

#### *Copper Wire Test for Chlorine in PVC*

**Adult supervision is required for this test.** Note: polyvinyl chloride is no longer being recycled so you may choose to skip this test. However, you may need to know how to do the test in order to identify an unknown plastic.

Place one of the three samples that sank onto a cookie sheet or other flat metal pan. Obtain a copper wire 23 to 30 cm (9 to 12 in) in length. Holding a large cork firmly on a desk with one hand, twist one end of the wire partway into the cork so that you can use the cork to lift the wire. For the remainder of this test, do not touch the wire with your fingers. **Always use the cork to move the wire. Have an adult turn on the flame.** Place the exposed tip of the wire into the upper part of the flame as shown in Figure 19. When the wire tip is red-hot, remove it from the flame and quickly touch the tip to the sample so as to melt some plastic. Then, quickly lift off the wire so that a bit of plastic sticks to it. Place the wire tip with the



plastic on it back into the tip of the flame and observe the flame while you are holding it there. A green color will identify PVC, polyvinyl chloride, code <3>. An orange color in the flame is a negative result. Place the cork on the metal sheet until the wire is cool.

If the test is positive, you may go on to the next step. Otherwise, start again by heating the tip of the wire in the flame. Check the remaining two samples in the same way as the first one. One of them should give a positive test.

The samples not identified so far are PS and PET.



**Figure 19.**  
**The copper wire test.**





### **Acetone Test**

**Safety:** *Acetone is flammable and should be used only where no flame is near. Because it evaporates readily, use it only in a well-ventilated room or outdoors. Wear safety goggles whenever you work with acetone. Keep any container of acetone tightly covered when not in use. You may wish to wear plastic gloves because acetone dries the skin. A little hand cream will re-moisturize your skin. Small quantities of acetone may be safely disposed down the sink, but be sure to wash it down with running water for at least 30 seconds.*

You will need to use new samples of PS and PET.

Pour acetone into a drinking glass until one-fourth full. With tongs, place the two unidentified samples under the acetone until one of them turns whitish. Remove the whitened sample with the tongs and hold it for a few seconds to drip dry. Press the sample firmly with your fingers. The polymer may feel softer and a little sticky. With your fingernail, try to scrape off some of the plastic from the surface. If the sample whitens, or feels softened, or if you can scrape it a bit, this is a positive result that identifies polystyrene (PS), code <6>. The other sample should be unchanged. Continue to the last confirming test, which should be used on both samples.

### **Heat Test**

**Adult supervision is required for this test.** This test is more dramatic if you cut a strip from a 2-liter soda bottle. The



bottle is made of PET. Place a pot of water on the stove and heat it to gentle boiling. Make sure the pan doesn't dry. Use tongs to grasp the sample to be tested. Place it into boiling water. You can expect to see a surprising change. The change is a positive test for polyethylene terephthalate (PET), code <1>. You may discard the remaining samples into the waste bin.

This separation scheme should have identified each of your samples correctly. Sometimes, as mentioned earlier, the presence of additives in the plastics may have altered the properties of the plastic to give a misleading result. For recycling purposes, this system is still satisfactory.

Try this scheme on a sample of a plastic container that does not have the code number. Can it be identified? What problems were encountered, and how did you resolve them?

## *Science Project Ideas*

- Invent a new scheme to separate the six packaging materials in the recycling process by making solutions of different densities that will help the separations. You may use materials available in a high school laboratory if you obtain the cooperation of your chemistry teacher. For your process to be industrially accepted, the materials to be



used for the separations should not be expensive and must be safe to use. Write complete instructions and construct a flow chart like the one in Figure 17.

- How successful has the recycling program been? How well has it carried out its original purpose? Has it failed in some ways? Prepare a report on this and include your assessment of its success.
- Are plastic spoons and forks made out of recyclable material? Usually, they are not marked because there is no convenient space for a mark. Test both the white and the transparent spoons or forks using the scheme in Experiment 3.1 to identify them.

### Experiment 3.2

## *Measuring the Stretch*

### *Materials*

- |  |                |
|--|----------------|
| ✓ roll of plastic film used<br>to wrap foods | ✓ tape measure |
| ✓ permanent ink marker                       | ✓ scissors     |
|  | ✓ friend       |

The thin plastic films used for food wraps can usually be stretched. How far do they stretch? Do they stretch more in one direction than in another? Do they shrink back to the original size? This experiment will investigate these questions using



a plastic film of your choice. Having a friend to help will make the preparations and measurements much easier.

Unroll some plastic film. Be careful not to stretch any of the film as you work with it. Most films used for food wrap are about 30 cm (12 in) from side to side. Cut a strip from one side to the other that is about 3 cm (1¼ in) wide (see Figure 20). Label the strip “W” for “Width” with permanent ink. Cut and label two other such strips. It is important that you cut all strips with smooth, straight edges.

Gently extend the roll until you have pulled out a length of about 30 cm (12 in). Cut a strip about 3 cm (1¼ in) wide up the long side of the film and label it “L” for “Length.” Cut a second strip of the same size in the same way and label that “L” too.

Place one of the W strips so it lays smoothly on the table. Measure how long it is. Keep the tape measure along the long side of the strip while you extend the tape measure to make it



**Figure 20.**

**Measure a piece of plastic wrap before and after stretching.**



at least twice as long as the strip. Ask your friend to gradually stretch the film along the tape with a steady pull until the strip breaks. Note how long the strip was before it broke. Repeat, but this time stretch the film only about 5 cm (2 in) before releasing it. How long is it after it is released? Did it go back to the original length?

Repeat the stretching and measuring with the second strip of W film until it breaks. Be careful to stretch the film at the same speed as before. Average the two results. Now, repeat the entire process with the two strips of L film.

Which stretched more, film from the width or film from the length of the roll? Compare the elasticity of each strip, that is, how close to its original length it came after moderate stretching.

The difference in directional stretching is due to the manufacturing process. When manufactured, the film is pulled along its length. As a result of the lengthwise pulling, the long polymer chains line themselves up along the length of the roll. The bonds between the atoms in the chains are quite strong, so the chains are difficult to stretch any further. Attractions between the chains, however, are quite weak. When the film is pulled along its width, the chains can be pulled away from each other. As a result, it is much easier to stretch the film along its width than its length before the film breaks.



## *Science Project Ideas*

- Use the method of Experiment 3.2 to test the stretchability and elasticity at different orientations of various types of plastics used for packaging, such as food bags, garbage bags, and supermarket packing bags. Also test Reynolds Food Wrap (polyvinyl chloride) and Saran Wrap (principally polyvinylidene chloride).
- How does temperature affect the stretchability of a food wrap? The elasticity?
- How is the stretchability and elasticity of a food wrap affected when it is stretched out over a wet counter top? How might this affect its use?
- Invent a method to measure the tensile strength of a plastic wrap. The tensile strength measures the weight needed to break apart a given strip of plastic wrap by pulling on it. This differs from the length to which the film stretches before breaking. The weight needed can be obtained by hanging a bag from the bottom of a vertical strip held at its top and adding water or beans or steel balls or other materials that can be weighed until the strip breaks. Submit your plan for approval to a responsible adult or science



teacher before carrying it out. Compare different brands of the same type of film, such as food wrap or trash bags, to see which has the greatest tensile strength. Are there differences? Why? Explain why tensile strength is important for this product.

- Does the direction of the pull on a plastic, whether along the length or width, make a difference in the tensile strength? Investigate and report on it for a variety of different films.

### Experiment 3.3

## *Shrink Wraps*

### *Materials*

- |  |   |
|--|---|
| ✓ scissors   | ✓ ruler   |
| ✓ 3 thin, transparent food containers labeled code <6>, each having a flat surface in it such as a supermarket salad container, plastic bakery box, and/or lid from a yogurt container | ✓ fine-tip permanent pen                              |
|  | ✓ aluminum foil                                       |
|  | ✓ <b>an adult</b>                                     |
|  | ✓ oven  |
|  | ✓ oven mitts  |
|  | ✓ heat resistant surface such as the top of the stove |

How does a manufacturer get plastic to wrap tightly around a product? Shrink wrap does the job. Although shrink wrap



is not sold in retail stores, there are other types of plastics available for experimentation that shrink when heated.

Obtain three thin, transparent food containers marked code <6> (see suggestions under *Materials*), each with a flat surface in it. Cut a flat rectangular piece from each of these, about 10 cm (4 in) x 5 cm (2 in). If you can't find three different containers, take extra samples from what you have. With permanent pen, place a number or letter on each rectangle to identify it. Keep records of the markings and of all the measurements that you take. Measure the length and width of each rectangle.

**With adult supervision**, heat the oven to 355°F. Space the rectangles apart from each other on a sheet of aluminum foil. Wearing mitts, place the foil with samples on it into the oven and close the door. After five minutes, put on the mitts and remove the foil with plastic samples on it from the oven. Place the foil on a heat-resistant surface. Allow it to cool completely. Measure the length and width of each sample after cooling.

Did all the samples shrink to the same size in length? In width? Do you see any other changes? What was the percent change in length and the percent change in width for each sample? You can calculate the percent from the following formula, first for length and then for width.

$$\frac{\text{amount of the decrease in length}}{\text{original length}} \times 100\% = \text{percent change in length}$$





The change may vary slightly from rectangle to rectangle if the heating in the oven is uneven.

The explanation for the shrinkage has to do with the way polystyrene sheets are shaped in the manufacture of the product. The polystyrene is heated, stretched out to a sheet, and then rapidly cooled. The quick cooling fixes the long, stretched-out polymer chains in the shape they have at that moment. When the plastic is heated in the oven, the chains gain the energy to become free again, and return to their shorter, unstretched shape. Since the sheet tends to be pulled more in the length than the width, the percent change on heating is greater in the length.

### *Science Project Ideas*

- Investigate whether there is also a change in weight when shrinkable polystyrene is heated.
- Compare the shrinkage of flat rectangular samples of the same shrinkable polystyrene container at different oven temperatures. Try starting at 250°F and increasing the temperature by 35°F each time, measuring the change in size as in Experiment 3.3. Hypothesize an explanation of what you observe.
- Does the thickness of a sample affect the shrinkage?



- How long do plastics last in the environment? Collect several different paper cups and several different plastic cups. To make comparisons, these should all be similar in size and shape. Bury each of these separately in the soil outdoors. Once each month, dig them all up and examine their condition. When you have accumulated enough information to reach a conclusion, even if tentative, construct a report on your findings. Extend this project to test additional kinds of plastics.

### Experiment 3.4

## *Heat Insulation*

### *Materials*

- ✓ 3 or more 10-oz hot-drink cups, all of similar diameter and height. One cup should be Styrofoam, one should be polystyrene or another plastic, and one should be paper.
- ✓ measuring cup
- ✓ hot sink water
- ✓ sink
- ✓ scissors
- ✓ candy thermometer (sold in some hardware stores and craft stores)
- ✓ clock
- ✓ pencil and paper

Obtain three or more 10-oz cups (see Materials). You may have to cut the top off a cup to make it the same height as the



others. Which of these cups is the best insulator for a hot drink? That is, which one will best keep a hot liquid from cooling off?

Allow hot water from the faucet to flow until it is quite hot. Fill a measuring cup with the hot water and let it stand to heat up the cup itself. Put the candy thermometer into the measuring cup in such a way that the weight of the thermometer will not tip the cup over. After a minute, remove the thermometer and hold it in your hand. Pour out the water and immediately refill with hot water to the 1-cup level. Quickly empty the water into one of the cups being tested. Place the candy thermometer into the cup so that it stands safely. Prop the cup if needed to prevent it from tipping. If the thermometer shows that the temperature is still rising, wait until it is steady. Read the thermometer and record the reading. Each minute after that, stir the water once with the thermometer and read the temperature without removing the thermometer from the cup. Continue for a total of twelve minutes. Write down your observations. Remove the candy thermometer. Discard the hot water.

Repeat the above for each of the cups. Be sure that the timing for each starts at the same hot water temperature. Stir in the same way each time.

Draw time-temperature graphs for each cup. They all can be placed on one chart. See Figure 21 for an example.



TIME-TEMPERATURE GRAPH FOR COOLING  
WATER IN CUPS OF DIFFERENT COMPOSITIONS

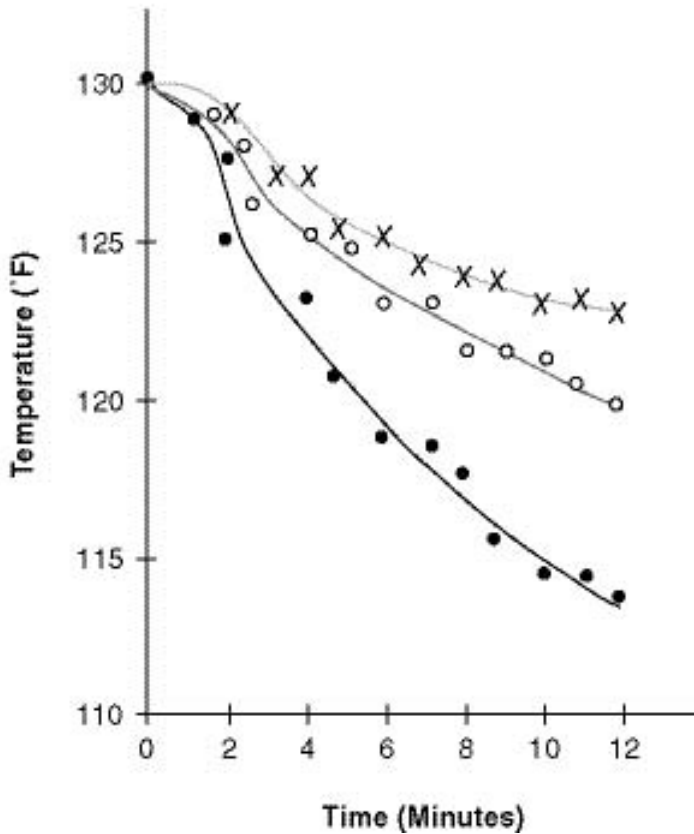


Figure 21.

In the graph, the X- and Y-axes need to be labeled and marked with appropriate values. The graph curves shown are “lines of best fit.” That is, they are each smooth lines that come as close to the data points as they can. Data points are shown by Xs, circles, and filled circles respectively. Your graph lines will probably not be identical in shape with the ones shown here. Based on your experiment, which of these curves is Styrofoam?



Which of the cups provided the best insulation, that is, cooled the least in twelve minutes? Which of the cups was the worst insulator? How does plastic compare to paper?

Note that the paper cup probably had a wax or plastic coating over it to help make it waterproof.

### *Science Project Ideas*

- Now that you have experience with testing for heat insulation, devise an experiment to test the insulating properties of different polymers. Identify each of the plastics that is tested. Discuss how the variables are controlled and which, if any, were not able to be controlled. Make a chart comparing the results of your work.
- How important is the presence of air in Styrofoam to its insulating qualities? Devise an experiment to carefully compare the insulating qualities of Styrofoam and polystyrene.
- How important is the thickness of the plastic to its ability to insulate? How does the insulating ability change with the thickness of the container? Conduct experiments to find out.



- A property that is important to industry but that has not been tested in this chapter is the impact strength of a film, that is, how the material responds to an object dropping onto it. This is called a falling dart test. For your test, devise a way to tightly hold a film of plastic stretched out. For example, the film might be stretched over the top of a coffee can and held in place with a thick rubber band. For the dart, small balls of different weight can be used. The variables you will need to test to find out the impact strength needed to break the film include the type of film (such as food wrap, grocery bags, dry-cleaner garment bags, and supermarket bags), the weight of the dart, and the height of the drop. Keep in mind that only two variables may change during each experiment.
- What happens to the impact strength of a sample of film after it has been previously tested without breaking?

## Chapter 4

# The Mysterious Case of Natural Rubber

Natural rubber was probably the first elastic material discovered by humans. The early Indians of South and Central America made rubber balls for sports. As early as the 1700s, rubber was used to rub out pencil marks, a use that gave rubber its name. Natural rubber comes from a milky liquid called latex found in the stems of some plants. The great rubber plantations harvest their latex from a tree originally found in the Amazon valley, *Hevea brasiliensis*. You can, if you wish, get your own latex from goldenrod or dandelion plants. Simply rub the white liquid from a broken stem between your fingers, and you will soon have a tiny ball of rubber.



Charles Goodyear (1800–1860) was very interested in rubber. His interest began after the “rubber fever” in the early 1830s suddenly ended. It ended because the exciting new gum from a tree in Brazil that could be used to make balls and waterproof products turned out to be a mess. It melted in the summer and became stiff and hard in the winter. Investors in the new product lost many millions. Goodyear started experimenting with rubber, hoping to improve its properties. Although he was a bankrupt inventor at the time, he nevertheless spent his time trying to make rubber into a satisfactory waterproof solid for both winter and summer temperatures. After five years, he still had not conquered the problem. He was so poor by then that his children were reduced to eating donations of milk and potatoes obtained from local farmers.

It was in 1839 in Massachusetts that Goodyear made his great discovery. On a cold day in February, he is said to have again gone into the general store to show off his latest product to the men gathered there. This time, the rubber was supposedly improved by the addition of sulfur. The sticky gum he displayed met with snickers. Goodyear became upset and, in his anger, waved the gum in the air. As he did so, the gum flew out of his fingers and landed on a hot pot-bellied stove. When Goodyear went to scrape the blob of rubber off the stove, it was remarkably changed. Instead of melting, it had charred in the middle with a brown springy rim around the





outside. The bouncy rim was rubber, pliable at high and low temperatures and waterproof.

Commercial success did not come to Goodyear quickly or easily. Goodyear developed a process based on the added sulfur, which he called vulcanization, and patented the process in 1844. He struggled to produce a saleable product but made bad business deals. He had to fight patent infringement cases in court but, even so, was honored by some. When he died, he was heavily in debt. Today, rubber production and manufacture is a multimillion dollar industry.

Although the potbelly stove discovery has often been described in history as a mere accident, Goodyear always said that it was more than that. What happened with the blob on the stove had meaning, said he, only for that person “whose mind was prepared to draw an inference.” An accident such as that can happen at any time, but a great discovery can be made only by one who sees what it means.

This chapter will present some of the unique properties of polymers. You will examine the behaviors of some polymers used in the home. As you go through the experiments, you will find that the unique properties of polymers provide clues to why vulcanization changed the properties of natural rubber so drastically. Your challenge is to put all the clues together to solve this mystery. The case is not easy to solve. Good luck!



Experiment 4.1

## *Making a Plastic Fiber*

### *Materials*

- ✓ Elmer's Washable School Glue
- ✓ glass rod or pencil
- ✓ acetone
- ✓ very small container made of glass, metal, or plastic
- ✓ toothpicks
- ✓ safety goggles
- ✓ sink with running water
- ✓ paper towel

A unique property of some polymers is that the tangled chains can be pulled, twisted, and spun into long, continuous fibers. Fabrics are made by weaving fibers together into different patterns. In the earlier times, these fibers were spun of natural polymers, mostly wool, cotton, silk, and flax. Today, around the world, cotton is still the chief fiber produced, but synthetics run a close second. Synthetic polymers may be pulled, drawn, or extruded to form a fiber. This experiment will demonstrate one way to make a fiber from a polymer. The industrial process is called cold drawing. The experiment calls for the use of acetone, which may be purchased in the paint section of hardware stores.

**Safety:** *Acetone is flammable and should be used only where no flame is near. Because it evaporates readily, use it only in a well-ventilated room or outdoors. Wear safety goggles whenever you work with acetone. Keep any container of acetone*



*tightly covered when not in use. You may wish to wear plastic gloves because it dries the skin. A little hand cream will re-moisturize your skin.*

Elmer's Washable School Glue, which is used in this experiment, is a solution of a hydrophilic polymer with a carbon backbone (polyvinyl acetate). The glue also contains some water and other ingredients needed to improve its effectiveness.

Obtain a small container such as a cap on a spray can or metal bottle cap or a very small glass. Put on your safety goggles. Pour a little acetone into the container to check that the acetone doesn't damage it. Select a different container if this happens. Pour the used acetone into the sink, run water after it for about thirty seconds, and dry the container with a paper towel. Pour Elmer's Washable glue into your container to a height of about 1 cm ( $\frac{1}{3}$  in). Dip one end of a toothpick into the glue and try to lift a strand out of it with the aid of the toothpick.

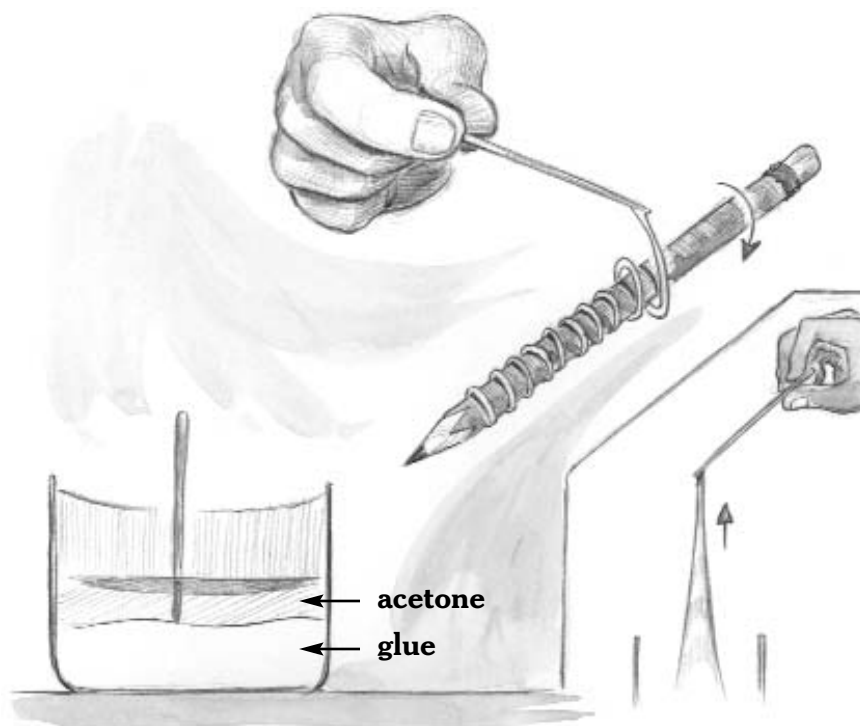
You will find that the glue flows off the toothpick.

You will need a glass rod for the next part of this experiment. If you cannot obtain a rod, you may substitute a pencil. Any paint on the pencil should be removed by using acetone-moistened paper towels. Be sure that no flame is nearby when you do this. Allow the paper to air-dry in a well-ventilated location before discarding it.

Tilt the container a bit and carefully pour an equal height of acetone over the glue. With the glass rod nearby, lower the



point of the toothpick into the container until it is where the two layers meet as shown in Figure 22. Use the toothpick to gently lift a bit of the lower layer upward in the form of a strand. It may take a little practice to get this to work, and you may have to pull out a clump to get it started. When you have one end of an unbroken strand (fiber) lifted above the container, bring the glass rod over to it and lay the fiber around it. Keep



*Figure 22.*

**Pass a toothpick through the acetone to where the acetone and glue layers meet.**



the rod slightly above the container because the wet fiber is weak and will break if extended. Carefully wind the fiber in a spiral around the rod. With practice, you will find that you can wind the spiral along the entire length of the rod.

Rinse the little container thoroughly with water. Remove the goggles. The fiber can be allowed to dry on the rod in a well-ventilated location. When dry, you can unwind it from the rod.

Acetone was used in this experiment because water is very soluble in it. The acetone dissolves the water in the polymer mix as the polymer is drawn from the solution, allowing the fiber to form. Nylon fibers for fabrics and ropes are made by cold drawing in a process similar to the one in this experiment. However, nylon is made by reacting two different monomers. One monomer is in the upper layer, and the other is in the lower layer. The reaction takes place at the interface where the two layers meet.

### *Science Project Ideas*

- Test the dry glue fibers produced in Experiment 4.1 for stretchability. How far do they stretch compared to the original length? Do they snap back after stretching? Produce enough fiber to weave a small patch of fabric.



Include this in your project display. Would this make a good fabric for family use? Discuss the pros and cons. Would it be good for insulation? How would you find out? Test it and give your method and conclusion.

- Try the method of cold drawing used in Experiment 4.1 with other water-soluble glues to see if a fiber can be drawn.

### Experiment 4.2

## *Are Plastic Food Containers Safe to Use in a Microwave?*

### *Materials*

- ✓ 2 transparent or translucent polystyrene cups (code <6> in the recycling system; see Appendix B)
- ✓ microwave oven
- ✓ safety goggles
- ✓ paper plate
- ✓ sink water
- ✓ **an adult**

What happens when a solid polymer is heated? Experiments 4.2 and 4.3 will examine this.

A microwave oven heats food largely by heating the water in the food. In effect, the water is boiled from the outside in. Since the water in the food is heated to its boiling point (100°C, 212°F), the container chosen to hold the food should



not sag or melt at the boiling point of water. Also, the container should not be made of a material that is itself heated by the microwave to where it can become dangerously hot or even melt. Hydrocarbons are among the materials not heated up by microwaves and so should be safe to use for containers. Polystyrene is a thermoplastic hydrocarbon. Is polystyrene safe to use in the microwave? You will check this.

**An adult must supervise this experiment.** Obtain two transparent or translucent polystyrene cups. Put on your safety goggles. Place one empty cup into the microwave and operate the machine for 3 minutes at full power. Remove the cup and inspect it. Set it aside. Is polystyrene the kind of material that heats up in a microwave?

Fill the other cup about one-fourth full of tap water. Place a paper plate into the microwave to catch any water that might spill out. Put the cup of water into the microwave. If the machine has power levels, operate it at level seven (such machines usually, but not always, have higher wattages than those without power levels). Set the microwave for 3 minutes and start it. Watch carefully through the microwave window throughout. If at any time the cup appears to be leaking, shut off the microwave immediately, but keep the door closed. You never want to open the microwave until the water is cooled. When the water starts to boil, allow it to microwave for another minute and then shut off the power. Allow the cup to cool for a minute or two before you open the door to look at the cup.



You must allow the water to cool to room temperature before you remove the cup from the microwave, probably 4 to 5 minutes. Did the cup melt? Did you observe any part of it become liquid? What happened to the cup? You can discard the water left in the cup. You may remove the goggles.

Compare the cup that was heated with water to the one that was heated without water. When you are done with the cups,



*Figure 23.*

**The cup that had water in it sagged and deformed as the water boiled, but only in the part that held water. The cup did not melt.**





they may be discarded into the waste bin. Is it safe to heat water in a polystyrene cup?

The cup that was empty was not changed by the microwave. It may have warmed up a bit due to an additive in the plastic, or moisture trapped in the plastic during manufacture, or moisture on it from the air in the microwave. The cup that had water in it sagged and deformed as the water boiled, but only in the part that held water, as shown in Figure 23. The cup did not melt. A melting cup would have formed some liquid, but this cup just changed shape. When removed from the microwave, it remained deformed and did not return to its original shape. It is concluded that it is not safe to microwave foods in a polystyrene container.

### *Science Project Idea*

- **With adult supervision**, investigate containers numbered <1>, <2>, <4>, and <5> in the recycling system (see Appendix B) using the method of Experiment 4.2 to see whether they can be safely used to heat water in a microwave.



Experiment 4.3

## *Does Polystyrene Melt in Boiling Water?*

### *Materials*

- ✓ polystyrene cup (<6>);
- ✓ water
- may be transparent or translucent, depending on the additives in it
- ✓ table salt
- ✓ safety goggles
- ✓ **an adult**
- ✓ stove
- ✓ large stainless steel soup ladle or slotted spoon
- ✓ pot large enough to hold at least 4 cups of liquid
- ✓ oven mitts

Experiment 4.2 showed that boiling water in a polystyrene cup caused the cup to sag below the water level. Will the entire cup melt if it is covered by boiling water?

Place a 1- or 2-quart pot on the stove and fill it about  $\frac{2}{3}$  full of water. Once pure water boils, the temperature stays at 100°C (212°F) as long as there is any water present. To obtain a slightly higher temperature, impurities may be added. For this purpose, add several tablespoons of salt to the water. Put your goggles on. Place the polystyrene cup into the water. **Have an adult heat the water to boiling, and have the adult continue to supervise the experiment until completed.** Put on oven mitts. As the water boils, gradually



push the cup flat under the water as shown in Figure 24 with the aid of a stainless steel soup ladle or slotted spoon. Keep enough boiling water in the pot to cover the collapsed cup. Does the cup melt? When the cup is collapsed, **ask an adult** to remove it from the hot water. Turn off the burner and allow the hot water to cool before pouring it out.

Carefully inspect the cup. Can you pull it back into shape? Did it melt? You may remove your safety goggles.

Have you ever seen another solid behave this way? When other solids are heated up, they ordinarily melt and flow like



*Figure 24.*

**Using a stainless steel soup ladle or slotted spoon, gradually push the cup flat under the water.**



melted ice or margarine, or they scorch, or even decompose (come apart chemically). They don't gradually sag without any liquid appearing.

The sagging and deforming of the cup that you observed is unique to certain polymers. The solid polymers that undergo the sagging are stiff and glassy below the temperature at which the change begins. Above that temperature, these solids become pliable, can be bent, and will give when pressed. The temperature at which the sagging takes place has a special name. It is called the glass transition temperature, abbreviated as  $T_g$ .

That is what happened with the polystyrene. Below its glass transition temperature, it was stiff and transparent or translucent. Once the  $T_g$  was reached, the polystyrene container became flexible and could be easily bent. When it was removed from the water, its temperature dropped to below the  $T_g$ , so it could no longer be reshaped.

Each polymer has its own  $T_g$ , which is partly dependent on how the polymer was made and on the additives and impurities in it.



# Science Project Ideas

- Polyvinyl acetate has a  $T_g$  of  $28^\circ\text{C}$  (about  $82^\circ\text{F}$ ). It can be used to make a demonstration of the change in stiffness from glassy to rubbery near room temperature. Make a solid strip of the polymer from Elmer's Glue-All by pouring the glue into a plastic bowl and allowing the solvent to evaporate for several days. The additives in the glue may lower the  $T_g$  to perhaps  $15$  to  $20^\circ\text{C}$ . Cut a narrow strip of the polyvinyl acetate piece that you have made. Dip it into hot water and immediately twist it into a spiral. Allow it to cool. Dip this into ice water, and it will become glassy. Can it be untwisted? What happens when you put it back into hot water? Can it be twisted or straightened? To show your results as a display, exhibit the strips before and after each step, with an explanation. The viewer can touch the strips.
- Polymethyl methacrylate (a.k.a. Plexiglass, Lucite) is a typical glassy polymer. Find out what happens to it in a refrigerator, in a freezer, and in boiling water. Is there any indication of a change from glassy to rubbery at any of the temperatures? Try bending at each stage to observe whether there is any change. **An adult must be present during the boiling water test.** Explain the results.



- Obtain different balls that bounce at room temperature. Find out if the height of the bounce and the sound of the bounce is affected when at refrigerator temperature, freezer temperature, and when kept for a while in very hot water. If possible, examine the bounce in liquid nitrogen **with adult supervision**. What do you conclude about each  $T_g$  based on your observations?
- When polymers are prepared for commercial or industrial use, they usually have small quantities of different additives placed into them to improve them for the purposes needed. Thus, the nylon used to make fibers for stockings may be a little different from the nylon threads used for sewing or the nylon solid used in machine parts. Collect samples of several different products made of nylon. The  $T_g$  of pure nylon is about  $50^\circ\text{C}$ . **With adult supervision** of your experimental work, investigate the glass transition temperatures of the different nylon products. Note that the melting point of nylon is not far above its  $T_g$ .
- Candles are usually made of paraffin, a mixture of chains with backbones of 18 to 36 carbon atoms and with hydrogen atoms at all the other bonds. The very long chain lengths put candle wax somewhat between ordinary hydrocarbon molecules and the shortest polymers (100 repeating units). **Under adult supervision**, find out whether candle wax has a glass transition temperature. If so, determine its approximate value.



Experiment 4.4

## *Elastomers*

### *Materials*

- ✓ small sheet of wax paper
- ✓ pencil
- ✓ ruler
- ✓ rubber cement

Practically all synthetic substances that feel like hard rubber are polymers. They feel like rubber because they are above the  $T_g$  and can be depressed at least a bit. However, not all rubbers are highly elastic. A highly elastic material can at least double or triple in length when pulled and then snap all the way back when released. Highly elastic materials are called elastomers. An elastomer is made of intertwined chains. The chains elongate and line up when the elastomer is stretched, and snap back when it is released.

Unfortunately, natural rubber is an elastomer only at moderate temperatures. In hot weather, it becomes soft and sticky. In cold weather, it becomes hard and brittle. When Goodyear added sulfur to natural rubber, we know now that the sulfur cross-linked the polymer chains. Recall that cross-links are atoms or short chains of atoms that are bonded at each end to a different chain.

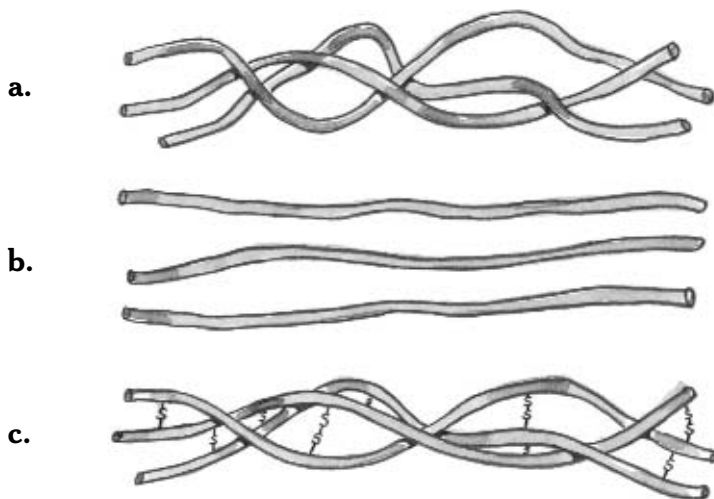
Figure 25a shows some chains of untreated natural rubber. Although not shown in the figure, these chains are coiled and



kinked along their entire length. When heated and stretched (Figure 25b), the chains elongate and line up. They stay elongated when released. The addition of sulfur to hot rubber changes this because the cross-links form (Figure 25c).

If all the rubber chains are cross-linked, the cross-linked rubber becomes one giant molecule. Such a polymer is impossible to melt because the chains can not slide past each other. It becomes a thermoset. Indeed, most synthetic elastomers burn on heating.

Natural rubber is made mostly of isoprene (see Appendix A) and was the only kind of rubber used until World War II.



*Figure 25.*

**Configurations of rubber chains. a) Natural rubber chains. b) Stretched rubber chains. c) Cross-linked rubber chains.**





When the Japanese seized the plantations that grew the rubber trees, the United States initiated a crash program to develop synthetic rubber. The program was outstandingly successful. Today, there are many different types of rubber that are manufactured for different uses including polybutadiene and styrene-butadiene-styrene (SBS) rubber (see Appendix A).

Elastomers may be formed into different shapes by molding, extruding (pushing through a narrow opening), and foaming, among other ways. In this experiment, you will make a rubber band from *rubber cement* simply by spreading out a few layers of it and allowing the solvent to evaporate. The “rubber” part of the name rubber cement comes from the fact that the product is actually a slow-flowing solution of natural rubber (or, in some brands, synthetic rubber) in a hydrocarbon solvent called hexane ( $C_6H_{14}$ ). The rubber is intended to be used as an adhesive, but this experiment will take advantage of the fact that the rubber is an elastomer.

**Safety:** *Read the instructions that are on the container for safe use of rubber cement. The experiment should be carried out in a well-ventilated room. Small quantities of rubber cement do not harm the skin, but it is good practice not to allow any solvent on the skin.*

Use a pencil and ruler to mark a rectangle about 15 cm (6 in) long by 2.5 cm (1 in) wide on a piece of wax paper. Paint this rectangle with a layer of rubber cement. Allow the rubber cement to dry. Place at least three more layers



successively on top of the first, allowing each to dry before painting the next one. Four layers is the minimum needed, although you can add additional layers, if desired. When dry, roll the long side of film with your fingers off the wax paper. You may need to pry the edge of the film free at the start. You will have a thin cylinder of rubber. Stretch it gently to test its elasticity. Lay the rubber on the wax paper in the form of a circle with the ends touching. Place a glob of cement over the two ends to seal them together. When dry, remove your rubber band.

The rubber band that you have made will strengthen a little as the remnant of solvent evaporates. It may not be the most evenly shaped rubber band, but it is a useful one.

You now have all the clues needed to solve the Mysterious Case of Natural Rubber. Why does the vulcanization of natural rubber change it from being sticky at high temperatures and stiff at low temperatures to being rubbery and pliable at high, medium, and low weather temperatures? The solution to the mystery may be found next.

## **SOLUTION TO THE MYSTERY**

When Goodyear added the sulfur to the rubber with heat, cross-links formed between the chains. The cross-links did two things. First, they prevented the rubber from stretching too far. Second, the cross-links pulled the stretched chains back to the starting configuration when the rubber was released. The result



was that the vulcanized rubber was still an elastomer even in hot weather.

Why did natural rubber become stiff when the weather became cold? That was because cold weather temperatures in Massachusetts were below the  $T_g$  of natural rubber. In the cold, the rubber converted to the glassy state and became stiff. Cross-linking changed this. The cross-linking lowered the  $T_g$  of the rubber. Hence, vulcanized rubber remained an elastomer even when it got cold.

### *Science Project Ideas*

- What additives are put into synthetic rubber to improve its qualities for different uses? List the additives in a chart with samples of each, and describe their purposes.
- Use rubber cement to make different sizes of rubber bands. Mount them and note how you made them.
- Invent a way to make a rubber band out of rubber cement so that it is formed as a ring without needing to have the ends cemented together.
- Compare the stretchability of a rubber-cement rubber



band with a similarly shaped store-bought rubber band. Which breaks first on stretching? Contact the manufacturer to find what causes the difference.

- Investigate the mechanical process by which rubber bands are manufactured for sale. Describe it with diagrams and explanations.
- Demonstrate the elasticity of a rubber balloon by piercing an inflated one with a bamboo skewer without breaking the balloon. The skewers are usually sharp, so be careful with the points. Keep the balloon away from the face in case your demonstration fails and the balloon is popped. Clean off any splinters on the bamboo stick with fine sandpaper before use. Put a light coating of petroleum jelly on the skewer. The best place to insert the skewer is near the tied end of the balloon. Try this same process on a Ziploc bag filled with water. Try it on a paper bag of water. Explain the results.



Experiment 4.5

## *Chewing Elastic for Fun*

### *Materials*

- ✓ postal scale or other scale that can weigh small quantities
- ✓ piece of chewing gum

A familiar use of rubber is as an ingredient in chewing gum. Modern chewing gum is made up of six ingredients: a gum base, sugar and corn syrup (or a sugar substitute), softeners to improve the texture of the gum, color, flavors, and a synthetic rubber polymer to make the gum stretchy. The gum base recipe is a mixture of waxes and paraffins (hydrocarbon solids obtained from petroleum) and is a closely guarded secret of the gum manufacturer.

Gums of different kinds were chewed at least as far back as the ancient Greeks, and chewing gums were made in America in colonial days. Manufactured chewing gum first appeared in the mid-nineteenth century, and bubble gum was first manufactured in 1928. The polymer added to make bubble gum elastic enough to blow into a bubble is a latexlike vinyl rubber. The rubber was originally made from trees but is now made with the same rubber used for truck tires, namely SBR (styrene-butadiene-rubber). As a result, it can be said that anyone chewing bubble gum is chewing the stuff of truck tires. Although the human stomach can digest a remarkable number



of things, it cannot digest rubber. Chewing gums shouldn't be swallowed.

How much of a sample of bubble gum (not the sugar-free kind) is soluble in water, and how much remains in the chewy rubber?

Obtain some chewing gum. Weigh a single piece. Place it in your mouth and chew it until the flavor is gone, or knead it under water for a while, testing to see if it still has flavor. How long does it take to lose the flavor? Allow the chewed piece to air-dry. Weigh the dry, chewed piece, being careful to keep it from sticking to the scale you are using. What percentage of the original gum was water-soluble?

Chewing gum must be soft enough to chew easily but strong and flexible enough to be stretched to a thin film. Some of the chemicals added to chewing gum are there to hold down the size of the bubbles. Manufacturers and parents don't want a gum bubble to be larger than a grapefruit, although the largest bubble on record was nearly 60 cm (24 in) in diameter. By incorporating shorter, non-stretchy materials such as waxes, the tendency to break on expansion is increased.



# *Science Project Ideas*

- Compare the amount of water-soluble ingredients in sugar-sweetened chewing gum and in artificially sweetened chewing gum. Do the labels show the differences in the ingredients used and the amounts of ingredients? Explain.
- Compare the amount of water-soluble ingredients in sugar-sweetened bubble gum to that of ordinary chewing (not bubble) gum.
- Consider any of the following projects. Find out
  1. which brand of gum has the most gum base
  2. which gum's flavor lasts the longest
  3. which gum has the most intense flavor and how long the flavor lasts

In this book, you have been given a brief introduction to an extensive and fascinating field of chemistry. Plastics make up a vast group of the chemical products of our time, and the uses of plastics are still growing. The next decades will unquestionably produce a great growth in new polymers and plastics. Maybe you will be a part of it. Keep experimenting!

# Glossary

**chemical bond**—A force that holds two atoms together in a particle.

**chemical reaction**—A process when one or more substances are changed into other substances by reorganizing which atoms are connected.

**chewing gum base**—The part of chewing gum that makes it chewy; a mixture of waxes and paraffins (hydrocarbon solids obtained from petroleum).

**cross-linked**—Referring to adjacent polymer chains that are linked by an atom or groups of atoms.

**density**—The mass of a material per one volume of it.

**elastomer**—A highly elastic material that can at least double or triple in length when pulled and can then snap all the way back when released.

**gel**—A cross-linked polymer that has absorbed a large quantity of solvent.

**glass transition temperature**—The center of the temperature range at which a polymer changes from hard and brittle (glassy) to pliable and at least slightly elastic (rubbery).

**glassy polymer**—A hard, brittle polymer; polymer below its glass transition temperature.

**hydrophilic polymer**—A polymer with a structure into which water can enter causing it to swell, form a gel, or dissolve.





**hydrophobic polymer**—A polymer that resists penetration by water.

**hypothesis**—A guess about what would happen to one variable if a change were made in another variable.

**impact strength**—A response of a film, usually by stretching or breaking, to an object falling on it under specified conditions.

**model**—A flat, three-dimensional, or mathematical representation of something that we cannot actually see.

**molecule**—The smallest bit of neutral matter that can be identified as a specific substance.

**monomer**—A small molecule that may react chemically to link together with other molecules of the same type to form a polymer.

**permeable**—Referring to a layer of material that allows something, such as water molecules, to pass through it.

**plastic**—A material consisting largely of one or more polymers.

**polymer**—Substance made by linking together at least a thousand of the same repeating segments.

**polymer additive**—A chemical added to a plastic to alter its properties.

**polymer chain**—A polymer made up of repeating monomer units attached end to end.

**polymer fiber**—A long thin strand made from a polymer.

**polymer network**—Polymer chains that are all connected to each at various spots.



**polymerization**—The process by which monomers join together to form polymers.

**rubbery polymer**—A polymer that gives a little when pressed; polymer that is above its glass transition temperature.

**scientific process**—The logical development of a theory based on finding evidence to support it.

**solution**—A mixture of two or more different substances in which the individual particles of the substances are so intermixed that all parts of the solution are the same.

**structural formula**—A diagram that shows the kinds and numbers of atoms in a particle and which ones are connected to which other atoms.

**tetrahedron**—A geometric figure whose four corners are equidistant from the center and are as far from each other as they can get in three-dimensional space.

**theory**—A logical explanation of a natural observation that is supported by much evidence and that is not contradicted by any observation.

**thermoplastic polymer**—A polymer that melts when heated so that it can be molded and shaped and that may be cooled to a solid and then remelted.

**thermoset**—A polymer that scorches and/or burns without melting first.

**variable**—A property that can change under the given conditions.

**vulcanization**—A process in which sulfur is added to natural rubber with heat.

# Appendix A:

## SOME COMMON SYNTHETIC POLYMERS, THEIR MONOMERS, AND APPLICATIONS

Monomer Name	Polymer Name	Uses of Polymer
Butadiene	Polybutadiene	Tires and hoses
Ethylene	Polyethylene	See Appendix B
Ethylene glycol and terephthalic acid	Polyethylene terephthalate (polyester)	See Appendix B
Isoprene	Polyisoprene (same as natural rubber)	Vulcanized products: rubber, rubber cement, waterproof and elastic products
Methyl methacrylate	Polymethyl methacrylate (Lucite, Plexiglas)	Substitute for unbreakable glass and for curved glass
Propylene	Polypropylene	See Appendix B
Styrene	Polystyrene	See Appendix B
Butadiene and styrene	Styrene-butadiene-styrene copolymer (SBS)	Hard rubber for tires, shoes, and other rubber uses where toughness is required
Tetrafluoroethylene	Polytetrafluoroethylene (Teflon)	Lining for pots and metals, piston rings, car bearings, insulation
Vinyl chloride	Polyvinyl chloride	See Appendix B
Vinylidene chloride	Polyvinylidene chloride	Food wrap

# Appendix B:

## RECYCLING RESIN IDENTIFICATION CODES

Code	Name	Abbreviation	Uses	Recycled Uses
<1>	Polyethylene terephthalate	PETE (PET)	Flexible transparent or opaque containers such as 2-liter soft drink bottles, peanut butter jars, Mylar, fabrics	Laundry bottles, carpeting, fleece
<2>	High density polyethylene	HDPE	Bottles made by blow molding, such as milk, juice, and shampoo bottles; garden furniture; trash cans; pails	Pails, trash cans, toys, pipe, base of soft drink bottles
<3>	Polyvinyl chloride	PVC	Flooring and tile, plumbing pipes, pill bottles, shower curtains, house siding, wire and cable, garden hoses. cooking oil containers, leatherlike luggage and upholstery	No longer recycled
<4>	Low density polyethylene	LDPE	Food wrap, diaper liners, squeeze bottles, bags, container lids	Usually not recycled
<5>	Polypropylene	PP	Indoor-outdoor carpeting, fabrics, packaging, pipes, tents, steering wheels, kitchenware	Usually not recycled
<6>	Polystyrene	PS	Transparent cups, casing for hair dryers and other electrical equipment, Styrofoam for hot cups, egg containers, packing "peanuts," insulated containers	Insulation, plastic wood, pens, and uses that are same as original
<7>	Other		Toothpaste and cosmetic containers, food containers	

Some of the plastics picked up for recycling are used to make chemicals and fuels. Most of those not re-used are incinerated at high temperatures, with air pollution controls during the process. This reduces the bulk by 80 to 90 percent. The incinerated product is sent to landfills.

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