SECTION VI - TOXICITY AND FIRST AID

ROUTES OF ENTRY:	*Inhalation?* Yes *Skin?* No *Ingestion?* No
HEALTH HAZARDS (Acute & Chronic) : Inhalation may cause mild irritation of upper respiratory tract. Inhalation experiments with animals on similar polyacrylate polymer (using very small particles of less than 10 microns) produced inflammatory tissue response in the lungs.	
CARCINOGENICITY:	*NTP?* No *ARC Monographs?* No *OSHA Registered?* No
SIGNS & SYMPTOMS OF EXPOSURE. Dust may cause reddening, drying of affected area with possible burning or other discomfort. Irritation of the upper respiratory tract and/or eyes.	
MEDICAL CONDITIONS AGGRAVATED by EXPOSURE: Existing respiratory and allergic conditions	
FIRST AID TREATMENT: <u>Eyes:</u> Flush with water or approved eye wash and obtain medical assistance if irritation persists. <u>Skin:</u> Clean thoroughly with large amount of water. <u>Inhalation:</u> Move to fresh air source. If discomfort continues, consult a physician.	

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

SPILL PROCEDURE: Collect material and avoid flushing with water if possible. Polymer becomes slippery if flushed with water.
DISPOSAL: Waste can be gathered and disposed of in accordance with existing local, state and federal environmental regulations. Nonhazardous material suitable for approved solid waste landfills
PRECAUTIONS FOR SAFE STORAGE & HANDLING: Avoid eye contact. Avoid prolonged or repeated skin contact. Do not inhale. Do not ingest. Store in a cool, dry place. Close bags or container when not in use.
OTHER PRECAUTIONS: Dusty conditions may irritate the eyes and respiratory system. Wear safety goggles and nuisance dust mask where dust is created.

SECTION VII - CONTROL MEASURES

RESPIRATION: Use high efficiency filter mask for dust particle levels above 0.05 mg/m³.			
VENTILATION: Local exhaust to remove airborne particles.			
PROTECTIVE GLOVES:	Recommended	*EYE PROTECTION:*	Safety glasses or goggles.
OTHER PROTECTION:	None	*HYGIENIC PRACTICES:*	Wash thoroughly after handling

file: aquakeep.msd

1-P

Educational Innovations, Inc.

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Activities With Sodium Polyacrylate (EI #GB-6)

Sodium polyacrylate is a white granular powder which rapidly absorbs water. It will instantly absorb from 500 to 1,000 times its mass of water. One of its greatest uses is in making diapers super-absorbent. Table salt, NaCl, destroys the gel and releases the water.

<u>SUGGESTIONS FOR USE</u>

1. How Much Water Will a Super-absorbent Diaper Hold? (Good for both large and small groups)

   Procedure:
   Show students a super absorbent diaper, a plastic glass and a pitcher of water which has been colored with yellow food coloring. Ask students to predict how many glasses of water the diaper will hold. While one student is holding the diaper open, slowly pour glasses of water into the entire length of the diaper. If you are careful, it will hold 7 to 10 glasses of water.
   Explanation:
   The fibers of the diaper contain a small amount of sodium polyacrylate granules which instantly gels the water.

2. What's Inside of a Super-absorbent Diaper? (Good for small groups)

   Procedure:
   Over a table top cut a super absorbent diaper in half and pull out some of the fibers. Shake the fibers and pull them apart allowing sodium polyacrylate granules and fibers to fall upon the bench top. With your hand push everything that has fallen into a pile. Pick up and discard the top fibers. The white granules that remain are sodium polyacrylate which makes the diaper super absorbent. Using a dropper, slowly add water to the granules and watch the gel instantly form. Show a bottle of sodium polyacrylate and ask students to predict how many super absorbent diapers could be made with this amount of powder.

3. How Many Drops of Water Can You Hold On the Tip of Your Finger?
   (Good for small groups or winning bar room wagers)

   Procedure:
   Ask students to guess the number of drops of water which can fit on one of their fingertips -- usually only a few. Then, with a dropper show them that you can keep as many as twenty drops of water on your fingertip.
   Explanation:
   Simply place a few granules of sodium polyacrylate on your fingertip and slowly add drops of water, allowing one drop to gel before adding another.

4. How Good Are Your Powers of Observation? -- "Three Cup Monty"
   (Good for both large and small groups)
   Procedure:
   Start with three tall white Styrofoam™ cups and a pitcher of water. After showing students that the cups are empty, half fill one cup with water. Tell students to carefully observe the cup with water as you quickly move the cups back and forth. Ask them which cup has the water? Then show them that they are correct by pouring the water into one of the other cups. Do this several times until finally everyone guesses wrong. Simply invert the cup they guessed. Then, ask them to guess among the two remaining cups. Wrong again, invert this cup on top of the first inverted cup. Finally, show them that the water has disappeared by inverting the remaining cup and adding it to the stack.
   Explanation:
   Beforehand, add a heaping teaspoon of sodium polyacrylate to one of the three cups. It is so white no one will notice when you initially show them that the cups are empty. In the initial pourings never pour the water into this prepared cup. Then, when you want the water to "disappear" pour the water into the cup containing the sodium polyacrylate. The water will instantly gel and stick to the inside of the Styrofoam™ cup.

5. Can you invert a glass of water without the water flowing out? (Good for both large and small groups)
   Procedure:
   Start with two beakers or two clear transparent plastic cups, one of which contains a heaping teaspoonful of sodium polyacrylate. From a pitcher pour water into the empty container. Holding both containers, one in each hand, pour the water into the one containing the sodium polyacrylate. Pour back and forth until the water completely gels. Then invert.

   To reverse the process and release the water, add a few heaping teaspoons of table salt to the gel and stir.

6. Can You Follow Directions? (Good for both large and small groups.)
   Procedure:
   Pour water into a Styrofoam™ cup, place a card over the opening, invert, and place on top of a student's head. Ask the student to hold this inverted cup on top of his head. Pull out the card and have the student who is still holding the cup, read what is on the card. It says: "DO NOT REMOVE THIS CARD FROM THE CUP!!" Pick up the cup and show that the water seems to have disappeared.
   Explanation:
   Before starting add a heaping teaspoon of sodium polyacrylate to the cup.

Sodium Polyacrylate "Water Lock"		
Item #	Quantity	Cost per Pkg.
GB-6A	4 oz pkg (113 g)	$6.50
GB-6B	16 oz pkg (454 g)	$19.95

MATERIAL SAFETY DATA SHEET

OSHA Standard 29 CFR 1910.1200

NE = not established
NA = not applicable

PRODUCT IDENTITY: Sudium Polyacrylate Superabsorbent Polymer #GB-6A & GB-6B

SECTION I

Manufacture	Sumitomo Seika Chemicals Co., Ltd.	***U.S. Contact:*** Educational Innovations, Inc.	
Address:	The Sumitomo Bldg. No.2,7-28,4 Chome Kitaham, Chuo-ku, Osaka, JAPAN telephone: 011-816-220-8539	***Emergency Telephone:*** (203) 229-0730 ***Date Prepared:*** June 17, 1998	

SECTION II - Hazardous Ingredients/Identity Information

Chemical Identity/common Name(s)	***OSHA PEL***	***OSHA STEL***	***ACGIH TLV***
Poly (sodium acrylate) homopolymer or sodium salt of polyacrylic acid CAS # 9033-79-8	NE	NE	NE
Other Limits Recommended:	0.05 mg/m³ recommended exposure limit (small, less 10 microns respirable polyacrylate). See section VI SARA Section 313 Reportable Toxic Chemicals - None		

SECTION III - Physical Data

Appearance: White, Granular Powder	***Odor:*** slight acrylate odor
Boiling Point: Solid N/A	***Melting Point:*** decomposes above 500° F
Vapor Pressure: Less than 10 mm Hg	***Vapor Density:*** N/A, >1
Evaporation Rate: Less than 1	***Specific Gravity:*** N/A, Bulk Density <1
Solubility: Insoluble, swells in water	

SECTION IV - Fire and Explosion Hazard Data

Flash Point: None	***Flammable Limits:*** N/E	***LEL:*** N/E	***UEL:*** N/E
Extinguishing Agents: Water, CO_2, Dry Chemical Extinguishants and Halon			
Special Fire Fighting Procedures: None			
Unusual Fire Hazards: Very slippery when product is in contact with water.			

SECTION V - Reactivity Data

Stability: Stable	***Conditions to Avoid:*** None Known
Incompatibility: Avoid contact with strong oxidizing agents.	
Decomposition Products: Carbon, oxides of carbon & sodium, water	
Hazardous Polymerization: Will Not Occur	***Conditions to Avoid:*** None Known

SECTION VI - TOXICITY AND FIRST AID

ROUTES OF ENTRY:	*Inhalation?* Yes	*Skin?* No	*Ingestion?* No
HEALTH HAZARDS (Acute & Chronic) : Inhalation may cause mild irritation of upper respiratory tract. Inhalation experiments with animals on similar polyacrylate polymer (using very small particles of less than 10 microns) produced inflammatory tissue response in the lungs.			
CARCINOGENICITY:	*NTP?* No	*ARC Monographs?* No	*OSHA Registered?* No
SIGNS & SYMPTOMS OF EXPOSURE: Dust may cause reddening, drying of affected area with possible burning or other discomfort. Irritation of the upper respiratory tract and/or eyes.			
MEDICAL CONDITIONS AGGRAVATED by EXPOSURE: Existing respiratory and allergic conditions			
FIRST AID TREATMENT: <u>Eyes:</u> Flush with water or approved eye wash and obtain medical assistance if irritation persists. <u>Skin:</u> Clean thoroughly with large amount of water. <u>Inhalation:</u> Move to fresh air source. If discomfort continues, consult a physician.			

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

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OTHER PRECAUTIONS: Dusty conditions may irritate the eyes and respiratory system. Wear safety goggles and nuisance dust mask where dust is created.

SECTION VII - CONTROL MEASURES

RESPIRATION: Use high efficiency filter mask for dust particle levels above 0.05 mg/m³.			
VENTILATION: Local exhaust to remove airborne particles.			
PROTECTIVE GLOVES:	Recommended	*EYE PROTECTION:*	Safety glasses or goggles.
OTHER PROTECTION:	None	*HYGIENIC PRACTICES:*	Wash thoroughly after handling

3-P

file: aquiakeep.msd

#GB-300	100 g	(1/5 lb)
#GB-315	454 g	(1 lb)
#GB-320	2270 g	(5 lb)

Instant Snow Polymer

When this granular white powder is added to water, it instantly expands to 40 times its original volume, producing a snow-like material. When more water is added, a slush forms. When allowed to dry, it returns to its powdered form ready to be used again.

Originally developed as a blood absorber, the unique properties of Instant Snow Polymer make it useful for many other applications. When wet, this polymer has the consistency of snow, adheres well to boots, and is very slippery. It is used as an artificial base for skiers and as an artificial snow on Hollywood sets. One of the first film uses was in Stephen Speilberg's mini-series, Band of Brothers. Because it rapidly absorbs and retains large volumes of aqueous solutions, converting them into gels, it is used for industrial spill containment.

In the classroom, Instant Snow Polymer is great for showing that there is No Law of Conservation of Volume – a common student misconception!
Note: This is a good substitution for the more hazardous ammonium dichromate demonstration, commonly used until recently.

Instant Snow Polymer is made by cross-linking molecules of the sodium polyacrylate polymer, the material that gives disposable diapers their super absorbent quality. These small individual cross-linked clusters appear as a white powdery substance. When water is added, the individual clusters internally hydrate and expand, forming small, fluffy clusters that do not cling to surrounding clusters. This appears as a powdery snow. When more water is added, the water molecules hydrate the external surface of these clusters and the clusters begin to adhere to one another. This appears as a slush.

Instant Snow Polymer is a Superabsorbent Polymer (SAP). The powder is able to absorb as much as 500 times its mass of pure water within a few seconds. In the dry state, the cross-linked network is folded up on itself, When hydrated, the highly hydrophilic ("water-loving") network quickly absorbs water, unfolds and expands. The hydration is dependent upon the purity of the water. Sodium chloride decreases the absorption due to Na^{1+} ions creating an electrostatic screening between the water and the hydration sites. Divalent ions of hard water, Ca^{2+} and Mg^{2+}, highly decrease the absorption properties because they compete with water for the hydration sites on the polymer chain. The maximum absorption with water is between a pH of 4 and 8.

PROCEDURE A

Place 10 g (ca. 1 teaspoon) of Instant Snow Polymer into a beaker. Quickly add 200 ml (ca 2 ounces) of water. The polymer will quickly absorb water and expand into a large quantity of "fluffy snow." Emphasize that this demonstrates that there is No Law of Conservation of Volume! Allow it to pour through your fingers. It even feels fluffy like real snow.

Experiment with different ratios of powder to water. A good place to start is 1 part powder to 20 parts water by mass (10 g powder to 200 ml water). If mixing by volume try 1 part powder to 12 parts water. The following ratios work well.

Instant Snow Polymer	Water
10 g	200 g
1 teaspoon	2 oz.
1/4 cup	3 cups

Sprinkle salt, e.g. sodium chloride, to the snow. Salt will cause the hydrated polymers to release the water. The effect looks very much like melting.

PROCEDURE B

Add different amounts of water to the powdered polymer. As the polymer absorbs more water, it becomes thicker rather than fluffier. Try the following:

1) Compare the water absorbing qualities of the cross-linked polymer to that of the sodium polyacrylate polymer which is not cross-linked (EI #GB-6A (113 g) & #GB-6B (454 g).
2) Experiment with different water qualities. What kind of water works best? Vary the pH, the hardness, or the salt content of the water.

QUESTIONS FOR FURTHER STUDY

1) How is this artificial snow similar to real snow? How is it different?
2) Why does the hydrated snow polymer feel cold?
3) Examine a few clusters under a microscope. How do the "flakes" compare to ice crystals?
4) What happens when you freeze it?

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4-P

MATERIAL SAFETY DATA SHEET

OSHA Standard 29 CFR 1910.1200

NE = not established
NA = not applicable

PRODUCT IDENTITY:	Sudium Polyacrylate Superabsorbent Polymer

SECTION I

Manufacture	Sumitomo Seika Chemicals Co., Ltd.	***U.S. Contact:*** Educational Innovations, Inc.
Address:	The Sumitomo Bldg. No.2,7-28,4 Chome Kitaham, Chuo-ku, Osaka, JAPAN telephone: 011-816-220-8539	***Emergency Telephone:*** (203) 229-0730 ***Date Prepared:*** June 17, 1998

SECTION II - Hazardous Ingredients/Identity Information

Chemical Identity/common Name(s)	***OSHA PEL***	***OSHA STEL***	***ACGIH TLV***
Poly (sodium acrylate) homopolymer or sodium salt of polyacrylic acid CAS # 9033-79-8	NE	NE	NE
Other Limits Recommended:	0.05 mg/m³ recommended exposure limit (small, less 10 microns respirable polyacrylate). See section VI **SARA Section 313 Reportable Toxic Chemicals - None**		

SECTION III - Physical Data

Appearance: White, Granular Powder	***Odor:*** slight acrylate odor
Boiling Point: Solid N/A	***Melting Point:*** decomposes above 500° F
Vapor Pressure: Less than 10 mm Hg	***Vapor Density:*** N/A, >1
Evaporation Rate: Less than 1	***Specific Gravity:*** N/A, Bulk Density <1
Solubility: Insoluble, swells in water	

SECTION IV - Fire and Explosion Hazard Data

Flash Point: None	***Flammable Limits:*** N/E	***LEL:*** N/E	***UEL:*** N/E
Extinguishing Agents: Water, CO_2, Dry Chemical Extinguishants and Halon			
Special Fire Fighting Procedures: None			
Unusual Fire Hazards: Very slippery when product is in contact with water.			

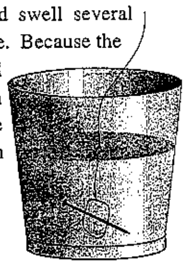
SECTION V - Reactivity Data

Stability: Stable	***Conditions to Avoid:*** None Known
Incompatibility: Avoid contact with strong oxidizing agents.	
Decomposition Products: Carbon, oxides of carbon & sodium, water	
Hazardous Polymerization: Will Not Occur	***Conditions to Avoid:*** None Known

Educational Innovations, Inc.

WATER GEL CRYSTALS

Water Gel Crystals are made from a polyacrylamide polymer with a strong affinity for water. Chemists call this property *hydrophilic*. A hydrophilic substance is one that takes up water easily - just as a dry sponge might if dropped into a pail of water. If placed into water, Water Gel Crystals will absorb water and swell several hundred times their original size. Because the amount of water Water Gel Crystals will absorb depends on the salt content of the water, we suggest you use pure clean water from the tap.



To prepare Water Gel Crystals, simply place them in clean water and allow to sit. While you may be able to observe changes in just a few minutes, the crystals take between two and four hours to reach their maximum size. Hot water may be used to speed up the process. To color the crystals, food coloring may be added to the water prior to adding the crystals.

Once fully expanded, Water Gel Crystals have an index of refraction almost identical to that of water. This means that when the clear, colorless, expanded crystals are placed in water, they are nearly invisible. It is difficult to see the crystals in water because light rays are not bent when they travel from the surrounding water, through the crystal, and back into the water. Put another way, both Water Gel Crystals and pure water bend (refract) light by the same amount.

Water Gel Crystals may be dried and expanded again and again. Simply spread the expanded crystals on a flat surface and allow to dry. When they have returned to their original size, store them in a plastic bag or container.

Approximate Mixing Proportions

2 TBSP Water Gel Crystals	1 Gallon Water
1.5 tsp Water Gel Crystals	1 Quart Water

Some experiments to try:

ONE

Disappearing Crystals

Tie a thread around a single expanded crystal. Lower the crystal into a cup of water and make an observation. This can be done on an overhead projector as a demonstration for an entire class. Try carefully pushing a small nail through the crystal. When lowered into water, the nail appears to be completely suspended.

TWO

Growing Bulbs

Grow flowering bulbs in the clear expanded crystals. This allows you see the roots as they grow. Simply expand the crystals by placing them in clean water overnight. Pour off any excess water and plant your bulb, stem side up, about 3/4 way into the crystals. Remember to use a clear container and to keep your crystals out of the sunlight. (Paperwhite bulbs work the best!)

While Water Gel Crystals are generally considered to be non-toxic, **they should not be consumed!!!**

IMPORTANT NOTE: Water Gel Crystals are sensitive to direct sunlight. Exposure to direct sunlight will decompose the polyacrylamide polymer and slowly destroy the crystals' ability to absorb water. (Teachers - this might be a good experiment!)

Educational Innovations

MEMBER:

MSDS
MATERIAL SAFETY DATA SHEET

PRODUCT IDENTIFICATION	TRADEMARK	SOIL MOIST™	Water retention aid
	CAS#	71042-87-0	
	SYNONYMS	None	
	CHEMICAL FAMILY	Crosslinked modified acrylic polymer	
	MOLECULAR FORMULA	Polymer	
	MOLECULAR WGT.	Polymer	
WARNING	SPILLS ARE SLIPPERY WHEN WET		
INGREDIENTS	SOIL MOIST contains polymer. No permissible exposure limits have been established.		
HEALTH INFORMATION	SOIL MOIST is a chemically neutral material. Prevent dust excape in the air, DO NOT breathe dust. A NIOSH, approved respirator for nuisance dust should be worn. After use, in horticulture work, normal hygenic practice should be followed.		
FIRE AND EXPLOSION HAZARD INFORMATION	FLASH POINT	Not Applicable	
	FLAMMABLE LIMITS	Not Applicable	
	FIRE FIGHTING	Use water, carbon dioxide or dry chemicals to extinguish fires. Wear self-contained, positive pressure breathing apparatus and full fire fighting protective clothing. Dust may be explosive if mixed with air in critical proportions and in the presence of a source of ignition.	
REACTIVITY DATA	STABILITY CONDITIONS TO AVOID	Stable None Known	
	POLYMERIZATION CONDITIONS TO AVOID	Will Not Occur None Known	
	INCOMPATIBLE MATERIALS	Strong oxidizing agents	
	HAZARDOUS DECOMPOSITION PRODUCTS	Thermal decomposition or combustion may produce carbon monoxide and/or oxides of nitrogen	
PHYSICAL PROPERTIES	APPEARANCE AND ODOR	Granular free flowing white material with typical odor	
	BOILING POINT	Not Applicable	
	MELTING POINT	Not Applicable	
	VAPOR PRESSURE	Not Applicable	
	SPECIFIC GRAVITY	Not Applicable	
	VAPOR DENSITY	Not Applicable	
	% VOLATILES	Approx. 4-10 % (H^2O)	
	pH	Not Applicable	
	SOLUBILITY IN WATER	Swells (does not dissolve). pH of aqueous system approx. 6.4 - 7.0	
SPILL PROCEDURES	Spilled material is slippery when wet. Remove sources of ignition. Sweep up spills and place in a waste disposal container. Disposal must be made in accordance with applicable governmental regulations.		
SPECIAL PRECAUTIONS	Maintain good housekeeping to control dust accumulations. DO NOT ALLOW MATERIAL TO ENTER DRAINS.		

NOTE: This information is given without any warranty or representation. We do not assume any legal responsibility for same. It is offered solely for your consideration, investigation and verification. Before using any product read its label.

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phone (203) 229-0730, fax (203) 229-0740
Educational Innovations

Todd S. Simmons, Ph.D.

6-P

TECHNICAL DATA

SOIL MOIST™

Material:	Crosslinked Modified Acrylic Polymer
Granular Size:	1-2 mm (small granular), 2-4 mm (coarse granular)
Density (gr/ml):	.729
Absorption (gr/gr)	
Deionized Water	418
*Tap Water	238
**Fertilizer Solution	216
Specific Gravity	1.07
Time to achieve 50% Absorption:	19 minutes
Time to achieve 100% Absorption:	56 minutes

SOIL MOIST™ FINES

Material:	Crosslinked Modified Acrylic Polymer
Granular Size:	0.05 - 0.5 mm
Density (gr/ml):	.902
Absorption	
Deionized Water	334-350
*Tap Water	115-130
Specific Gravity	1.08
Time to achieve 50% Absorption:	14 minutes
Time to achieve 100% Absorption:	40 minutes

*Salt as NaCl, tap water rated at 160 mg/l
**Fertilizer Solution Contains 210 ppm - 220 ppm of Nitrogen

Soil Moist Hydro	0.1 - 0.7 mm
Soil Moist Seed Coat	0.05 - 0.5 mm Graphite Coated

Chemical Interactions – Polymers/The Super Absorber

(Recommended Grade Levels: 5-12)

Adapted from the American Chemical Society's "Kids & Chemistry" program.

Equipment/Materials

Tables will share:

- Sodium polyacrylate
- Small scoop
- HDPE powder

Each set of lab partners will have:

- 1 Bottle of colored water
- 1 Bottle of salt water
- 1 Paper towel
- 1 Popsicle stick
- 1 Pencil
- 1 Plastic cup

Procedure

1. Place the paper towel on your work surface.
2. Use the top of the cup to draw two circles on the paper towel.
3. Place two level scoops of sodium polyacrylate in a pile in the center of **one** of the circles.
4. Place two level scoops of High Density Polyethylene (HDPE) powder in a pile in the center of the **other** circle.
5. Slowly add drops of colored water to the center of the circle with the HDPE powder. Count the drops and continue adding them until the water reaches any part of the circle. Record the number of drops and what happened here.
6. Now add the same number of drops in the center of the pile of sodium polyacrylate. How does this compare to the way the water spread in the first circle?
7. Continue to add about 100 more drops. How would you describe the pile of sodium polyacrylate now?

Now try this!

1. Split the sodium polyacrylate gel in half with a popsicle stick and then move each half to a clean and dry part of the paper towel.
2. Add 5 drops of the colored water to one pile and 5 drops of salt water to the other pile. Watch the gels closely with each drop. Which pile is getting the paper towel wetter? What seems to be happening here?

Observe & Record

- Gel
- Absorbent
- Get bigger
- Get smaller
- Hydrophillic
- Hydrophobic

1. When you added colored water to the sodium polyacrylate, the granules began to ____________________.
2. When you added salt water to a pile of wet sodium polyacrylate, the pile began to ____________________.
3. Sodium polyacrylate is a very ________________ powder.
4. When sodium polyacrylate is wet, it becomes a ________________.
5. When a polymer absorbs water it is called a ____________________ polymer because it "loves" water.
6. When a polymer floats on water it is called a ______________________ polymer because it "fears" water.

Apply It!

Sodium polyacrylate is used in some baby diapers. If you took apart one of these diapers, you would find this powder inside. Can you think of other uses for this unique polymer?

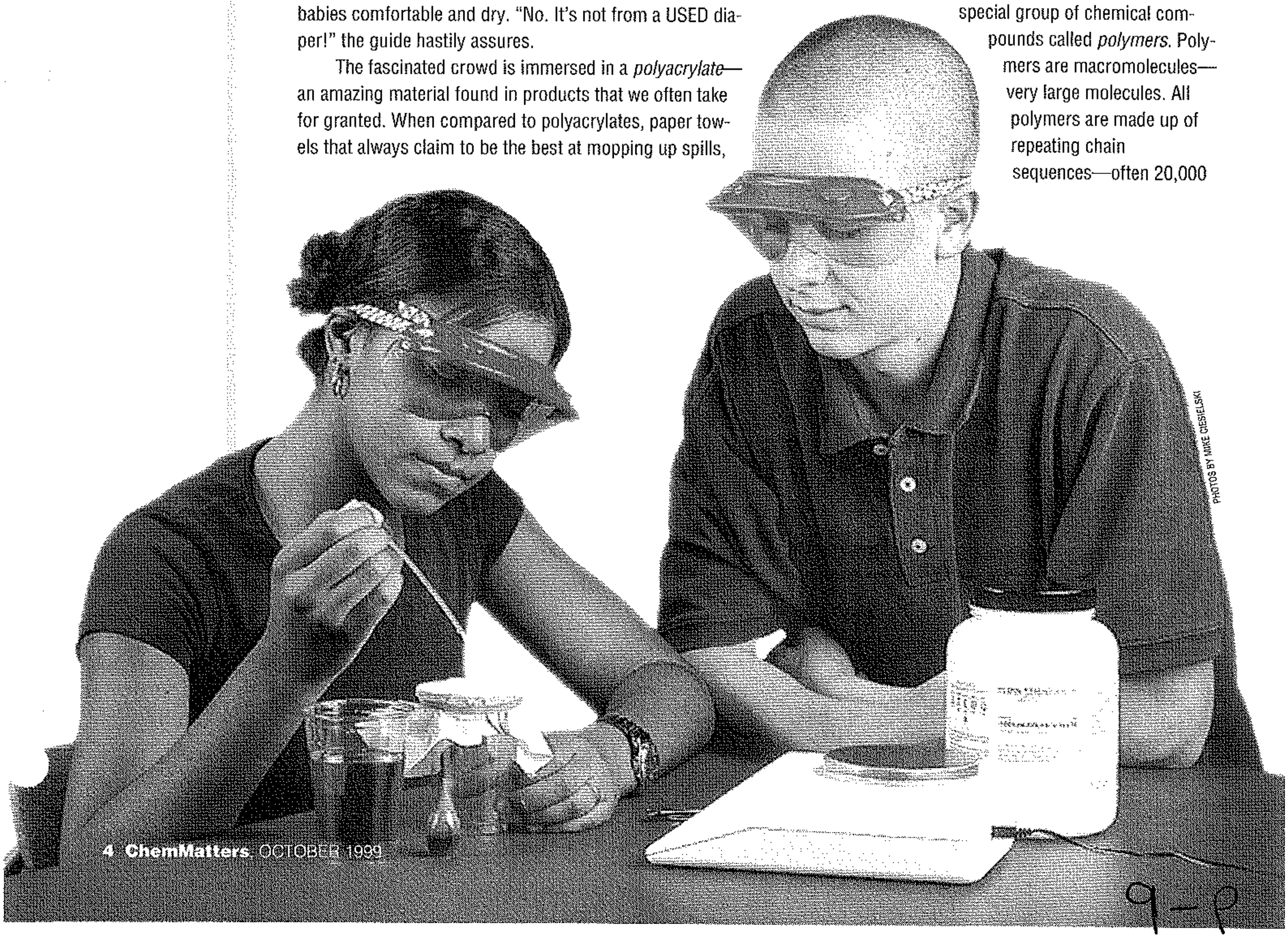
The Absorbing Story of the Thirsty Polymer

By Cynthia Anderson

"EEWWW! What is this?!" asks a museum exhibit visitor. Students stand with hands sunk to the wrists in a clear, cool, globular gel, while the demonstrator explains that the substance simulates the inside of a cactus. "But what is it?" someone insists. Hands withdraw fast when the guide identifies the source to be the inside of a disposable diaper used to keep babies comfortable and dry. "No. It's not from a USED diaper!" the guide hastily assures.

The fascinated crowd is immersed in a *polyacrylate*—an amazing material found in products that we often take for granted. When compared to polyacrylates, paper towels that always claim to be the best at mopping up spills, seem obsolete. Yet, for all their incredible properties, polyacrylates have only begun to approach their potential usefulness in products.

Like the inside of a cactus, polyacrylate has an enormous capacity for absorbing water. Capable of holding 800 times or more its weight in distilled water, it is a champion in the world of super slurpers. Polyacrylate belongs in a special group of chemical compounds called *polymers*. Polymers are macromolecules—very large molecules. All polymers are made up of repeating chain sequences—often 20,000



PHOTOS BY MIKE CIESIELSKI

to 40,000 of these repeating units. Familiar examples of polymers include rubber, nylon, Teflon, polyester, latex, and polystyrene.

Superabsorbent polyacrylate molecules are not simply linear, however. Their long chains are tied together in many places by cross-links made from organic molecules known as *alkenes*. The strong covalent bonds of these cross-links are responsible for holding the molecule together when it is placed in water.

In the absorption process, water *solvates* or surrounds the three dimensional polymer. The resulting solution of positive and negative ions has some unique features. All of the negative charges remain attached to the polymer backbone. Attracted by these negative charges, the positively charged sodium ions (Na^+) are trapped inside the polymer network as well.

By diffusion, molecules that are free to move will travel from a region in which they are more concentrated to a region of lower concentration until an equilibrium is achieved. If you apply this rule to the distilled water in which you have placed this superabsorbent polymer, you can predict the result (see Figure 1).

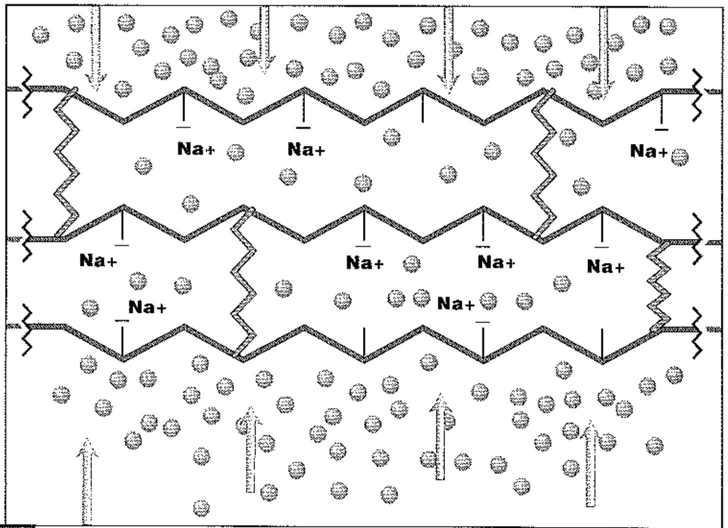
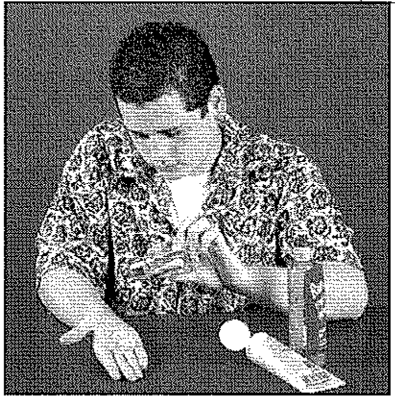


Figure 1. The distilled water on the outside will always be purer or more concentrated than the water that has flowed into the polymer. The water molecules reaching the inside share the spaces with all of the trapped ions. Water continues entering the polymer. The thirsty polymer swells to many times its former size until, constrained by its strong cross-links, it can hold no more.

Now, think about a slightly different example. Suppose that the water in which you place the polyacrylate were not pure? What would happen if you placed the polymer in a salt solution? This time, the water on the outside of the polymer might have a concentration that is not very different from the water on the inside of the polymer. Would the amount of water absorbed by the polymer be affected?



Many hair gels contain superabsorbent polymers with properties that are similar to polyacrylate. Try this simple experiment to see the effect of salt on an aqueous solution of one of these ingredients. Cover a glob of hair gel with table salt. What happens? Can you explain what you observe?

Polyacrylates have been around since the 1950s. But only in the past two decades have polyacrylates become common in household items throughout the world. Polyacrylates absorb liquid better than cotton, resulting in an improved diaper that is thinner and dryer for a baby. Hair gel, you discovered, is another polyacrylate—a viscous medium for styling and even sculpting unmanageable hair. The packaging industry puts polyacrylates to use in packaging meats for market. The thin sheet of material under the meat product contains polyacrylate, which is used to absorb excess liquids, improving both the shelf life and the flavor of the meat. Polyacrylates are becoming important in the industrial workplace to keep damp or wet areas dry, or—in thin layers in the walls of rooms—to control humidity. They may even be found in protective barriers for pipelines and tunnels underwater.

Currently, polyacrylates are being tested as fire retardants. First suggested by John Bartlett, a Florida firefighter who noticed at the scene of a trash fire that baby diapers had not burned, the commercial product is named Barricade®. As a fire deterrent, polyacrylate, with its capacity to absorb many times its weight in water, is a natural. Although it is not anticipated that it will be used in fighting fires, polyacrylates seem effective in preventing them. When saturated polyacrylate is spread over the surface of materials, it acts as a barrier to the spread of fire. It has been tested in treating the outer surfaces of buildings and trees. Bartlett describes it "like sticking water on the wall." The polyacrylate, pumped full of water, coats the surface, and, with its gel polymer holding the water tightly, effectively retards the flames.

So far, the trials have been impressive. One recent success was its effectiveness in controlling the spread of brush fires in California. The potential for this application of polyacrylate coatings for the protection of valuable and cherished items when fires threaten is particularly promising.

The number of applications for this remarkable polymer is growing. From keeping a baby's bottom dry to potentially saving both human and wildlife, polyacrylates play an increasingly important role. The students experiencing polyacrylate in the science museum for the first time will encounter it many more times in many more places as these thirsty polymers continue to appear in a growing variety of products. ▲

Cynthia Anderson is a chemistry teacher at Lee High School in Fairfax County, VA. She was the coauthor of the article "A Mark of Color", which appeared in the October 1998 issue of *ChemMatters*.

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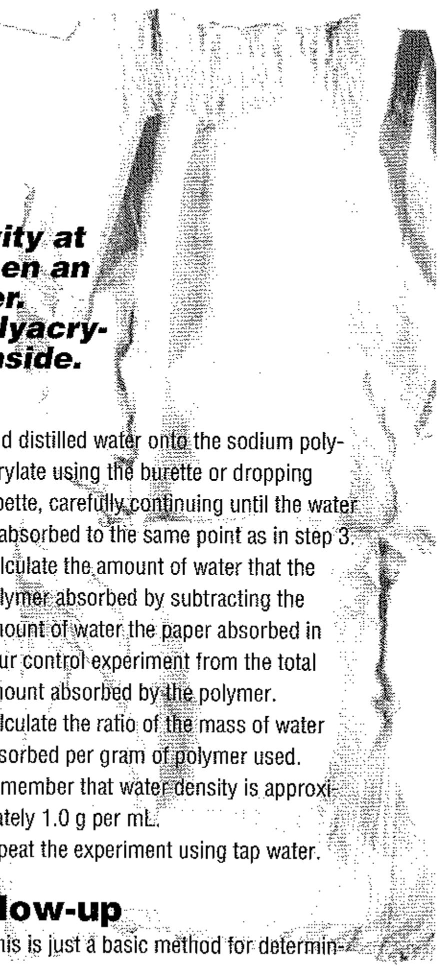
Bjerklie, D. Quicker Picker Uppers. *Technology Review* **1994**, May/June, pp 14–15.

Garner, C.; Nething, M.; Nguyen, P. Synthesis of a Superabsorbent Polymer. *Journal of Chemical Education* **1997**, *74* (1), pp 95–96.

RELATED ARTICLE

Alper, J. Polymers. *ChemMatters* **1986**, *4* (2), pp 4–7.

Super Soakers—Just How Super Are They?



Try this activity at home; cut open an unused diaper. You'll find polyacrylate "stuff" inside.

Objective

The polymer *sodium polyacrylate* and related compounds have an amazing reputation for the amount of water they can soak up and hold. A common claim of sodium polyacrylate is that it can absorb 800 times or more its own weight of water. How could you go about testing this claim?

Here is a basic scheme for testing the ability of water-absorbing polymers to absorb various liquids and solutions.

Materials

Safety goggles and lab apron
8 oz. plastic cups
Several pieces of absorbent paper (coffee filters, paper towels, filter paper—all are satisfactory)
Rubber bands
Sodium polyacrylate powder or equivalent
Dropping pipettes or burette
100 mL distilled water
Tap water
10-mL graduated cylinder or similar measuring device
Lab balance

Optional materials

Food coloring (to make it easier to see absorbed liquid)
Table salt (for extension activity)

Procedure

1. Put on safety goggles.
2. Place a coffee filter or piece of paper towel over the plastic cup and secure it with a rubber band, so that it fits tight, like a drum head.
3. If you are using a burette, fill it with distilled water, otherwise calibrate the dropping pipette by counting how many drops it takes to fill the graduated cylinder to the 1-mL mark.
4. Add distilled water to the surface of the coffee filter or paper towel until the moisture just uniformly reaches the edge of the cup. Proceed gradually to allow the water to be absorbed into the paper.
5. Measure in milliliters how much water it took to just moisten the paper. Record your results as your control. (If you are using a dropping pipette, you will need to check the calibration you made in step 3.)
6. Repeat steps 1–5 for a fresh experimental setup, except this time add approximately 0.1 g of the sodium polyacrylate to the top of the filter paper. Use the lab balance to measure how much you have added.
7. Add distilled water onto the sodium polyacrylate using the burette or dropping pipette, carefully continuing until the water is absorbed to the same point as in step 3.
8. Calculate the amount of water that the polymer absorbed by subtracting the amount of water the paper absorbed in your control experiment from the total amount absorbed by the polymer.
9. Calculate the ratio of the mass of water absorbed per gram of polymer used. Remember that water density is approximately 1.0 g per mL.
10. Repeat the experiment using tap water.

Follow-up

This is just a basic method for determining the amount of water absorbed by the sodium polyacrylate. Compare your results with other students or try repeating the experiment to see how precise your measurements are. Think about ways you might be able to improve the procedure to obtain more precise or accurate results.

Extension

Try this activity with other household liquids. For starters, try making a solution of *physiological saline* (0.9% NaCl) solution. Physiological means the same salt content as body fluids. Additionally, try stronger or weaker salt solutions. Or, try other liquids such as soft drinks, vegetable oil, milk, vinegar, and soap solutions. See if you can explain the effects you observe based on the chemistry of the water-absorbing polymer.

Find out how you can connect this polymer investigation to some exciting plans for National Chemistry Week (November 7–13) by going to www.acs.org/ncw.

PHOTOS BY MIKE CIESIELSKI AND ACS PHOTO FILE

11-P

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Sodium Polyacrylate

Superabsorbent Polymers

Catalog No.: W0012, W0013, W0014

Publication No.: 755.10

Introduction:

Water in one cup is poured into an "empty" cup (actually containing sodium polyacrylate) and the water "disappears"!

Chemical Concepts:

- Polymers
- Superabsorbents
- Osmosis
- Industrial chemistry

Materials Needed:

Styrofoam® cups or other opaque containers, 2

Sodium polyacrylate, 0.5 g

Distilled or deionized water, 100 mL

Caution:

This activity requires the use of hazardous components and/or has the potential for hazardous reactions. Please review the Safety Precautions section on the following page and relevant Material Safety Data Sheets before beginning this activity.

Pre-Lab:

Before the students come into the room, place 0.5 g of sodium polyacrylate in one of the Styrofoam cups.

Procedure:

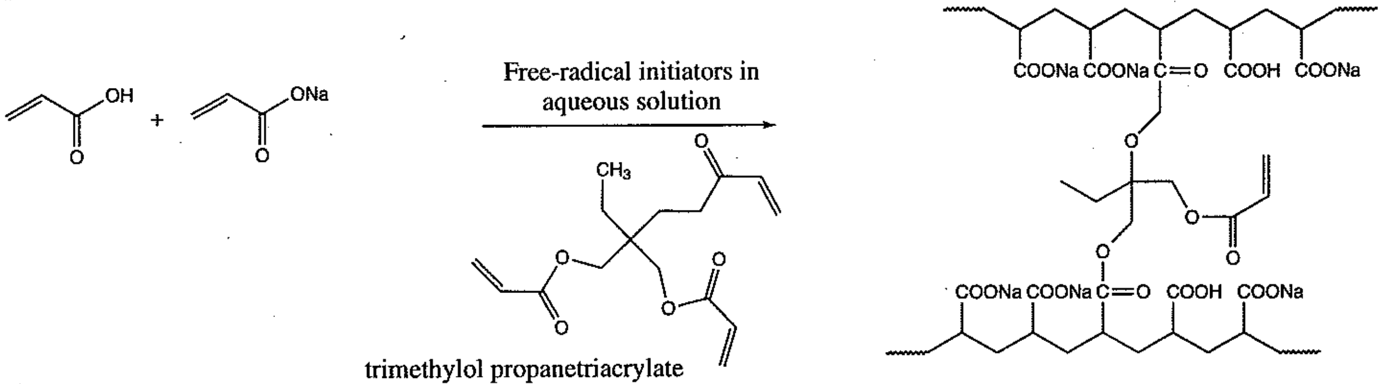
1. Add approximately 100 mL of distilled or deionized water to the second Styrofoam cup.
2. Tell the students that the water will "disappear" when poured into the other cup. (You can tip the cup forward somewhat to show that it is "empty"; it will be difficult to see the 0.5 g of sodium polyacrylate against the white Styrofoam cup.)
3. Slowly pour the water into the cup containing sodium polyacrylate. Swirl the cup a bit (give the sodium polyacrylate time to absorb the water).
4. Tip the cup downward slightly to show the students that the water has "disappeared"! (Don't turn the cup upside down, or you may dump the jelly-like mass on the floor!)

Tips:

After you have discussed with students what really happened in the demonstration, gradually add granulated salt to the gelled polymer. The addition of sodium chloride will break the "gel" as water leaves the polymer to dilute the salt concentration outside the polymer network. The result will be the apparent "deflation" of the gelled polymer.

Discussion:

Sodium polyacrylate is an example of a superabsorbent polymer. Superabsorbents operate on the principle of osmosis: the passage of water through a membrane permeable only to the water. Here, osmotic pressure results from the difference in sodium ion concentration between the inside of the polymer and the solution in which it is immersed. This osmotic pressure forces water into the solid polymer lattice in an attempt to equilibrate sodium ion concentration inside and outside the polymer. The electrolyte concentration of the water will effect the osmotic pressure, subsequently affecting the amount of water absorbed by the polymer. For example, sodium polyacrylate will absorb approximately 800 times its own weight in distilled water, but will only absorb about 300 times its own weight in tap water, due to the high ion concentration of tap water. Sodium polyacrylate is manufactured by the free-radical polymerization of a mixture of sodium acrylate and acrylic acid, and a cross linker such as trimethylol propanetriacrylate:



Sodium polyacrylate is the main ingredient in high-absorbency diapers. (It can absorb about 30 times its own weight in urine). It is also commonly used in alkaline batteries, feminine hygiene products, nursery potting soil, water beds, and as a fuel filtration material to remove moisture from automobile and jet fuels.

Safety Precautions:

Sodium polyacrylate is non-toxic. However, it is irritating to the eyes and to nasal membranes if inhaled. As always, wear chemical splash goggles, a chemical-resistant apron, and chemical-resistant gloves. Sodium polyacrylate is an obvious choice for student pranks. Be careful students do not have access to sodium polyacrylate outside of chemistry class.

Disposal:

Sodium polyacrylate and the gelled material can be disposed of in the trash according to Flinn Suggested Disposal Method #26a. Do not put sodium polyacrylate down the sink!

Reference:

Buchholz, F. L. *J. Chem. Ed.* **1996**, *73* (6), 512–515.

Acknowledgment:

Special thanks to Mr. Tom Dugdale, ARCO Chemical Corp., Newton Square, PA; and Mr. David Katz, Professor of Chemistry, Cabrini College, Radnor, PA.

Materials for Sodium Polyacrylate are available from Flinn Scientific, Inc.

Catalog No.	Description	Size	Price/Each
W0012	Sodium Polyacrylate, Powder	25 g	Consult Your Current *Flinn Catalog/Reference Manual*
W0013		100 g	
W0014		500 g	

13-P

Intro to Polymers

Define polymer

poly- = many
-mer = part

Long, chain-like molecule made of repeating units.

What elements are used:

Nonmetals:	
carbon	$-\overset{|}{\underset{|}{C}}-$
hydrogen	H-
oxygen	-O-
nitrogen	$-\overset{|}{N}-$
chlorine	Cl-
fluorine	F-
silicon	$-\overset{|}{\underset{|}{Si}}-$

Types of bonding:

Making of chains – **covalent** bonding

- sharing of electrons – makes long chains
- discuss # of bonds each element wants to make – have students refer to periodic table
- does make compounds because the octet is satisfied

Polymers are compounds with formulas. Carbon is the backbone of many polymers and since it wants 4 bonds it can make very long chains, with or without branches.

Holding chains together – affects many properties

1. covalent bonds – stronger – ex. rubber
2. intermolecular forces – weaker – ex. slime
3. entanglement – ex. HDPE – (analogy: 50 pieces of yarn – each 6 feet long – jumble and wad them up – throw them down in a pile on the ground – try to pull out one piece – what happens???)

Have students brainstorm what they perceive to be typical properties of polymers (plastics) – especially in comparison with metals and ceramics/glass. Guide them towards physical (density, optical properties, thermal properties, electrical properties, etc.), chemical (reactivity, stability, corrosion), and mechanical properties (strength, hardness, toughness, elasticity, plasticity, etc.). Help them to realize that polymers show a wide range of properties that we try to manipulate.

Length of Chains:

Beaded chain demo

- 6 beads equal the # of carbon atoms in a glucose molecule.
- Entire chain equals # of carbons in a smallish to medium size polyethylene molecule - 61 feet of chain with 72 beads/ft = 4,392 beads - many polyethylene molecules will have 10,000 carbon atoms.
- Molecular weights can be in the hundreds of thousands.

Classification of Polymers:

Natural vs. Synthetic

Synthetic = manmade = plastics

- Raw material for many plastics is petroleum or natural gas.
- Have students name examples (PVC, polystyrene - Styrofoam, epoxy, ABS, polyurethane..............)

Natural - have students name examples (proteins, starch, cellulose, DNA, RNA, lipids, latex rubber, silk..........)

Add a little bit about the history of polymers here.....................

Packing Peanuts Lab

(natural vs. synthetic)

Give each student a packing peanut made of polystyrene and a packing peanut made of starch. Do not tell the students what they are made of. Call the one made of starch "peanut A" and the one of polystyrene "peanut B". Have the students compare/contrast the two types - listing as many different properties of each as they can. Encourage them to think of both physical and mechanical properties. As a demo of chemical properties, burn a small piece of each.

Give the students two beakers - each containing a clear liquid. Do not tell the students the identity of the liquids. Beaker A contains acetone and Beaker B contains water. Have the students test the solubility of the peanuts by performing trials in the following order:

Peanut A in Beaker A
Peanut B in Beaker B
Peanut A in Beaker B
Peanut B in Beaker A

Demo the dissolving of a PS coffee cup in a small amount of acetone. Pose the question: why might it be a bad idea to carry gasoline in a Styrofoam coffee cup? A discussion of polar and non-polar molecules and their effect on solubility fits in nicely at this point. Water and starch are both polar while polystyrene and acetone are mostly non-polar. The PS doesn't completely dissolve in the acetone.

As a final discussion, ask the students which type of packing peanut is the best. Students may bring up biodegradability and recycling at this point. Lead the students to the conclusion that choosing which type of peanut is best is determined by the conditions in which it will be used. Have the students write scenarios or situations for which each type of peanut would be best suited. Have them justify their answers by discussing properties.

The PS residue in the acetone beaker can be formed into jewelry or other shapes and left to harden as the acetone evaporates overnight on the counter or in a fume hood.

Classification of Polymers:

Types of Polymerization - formation of chains by putting together smaller repeating units.

1. **Addition polymerization** - rapid chain reaction where molecular units (monomers) are added to one another - usually by breaking double bonds.

Cover basic hydrocarbon chemistry

hydrocarbon - compound made only of carbon and hydrogen

alkanes - hydrocarbon w/ only single bonds - ex. methane, ethane, propane, etc. Draw several chemical and structural formulas. # of hydrogen atoms is (# of C x 2) + 2. Do several examples.

alkenes - hydrocarbon w/ double bonds - ex. ethylene, propylene, etc. The double bond is stronger but also more chemically reactive than the single bonds in alkanes. Draw chemical and structural formulas. Draw an example of 2 ethylene molecules (monomers) joining together to make a dimer.

- monomer - simple molecule used as a repeating unit in a polymer
- dimer - molecule made of two monomers
- trimer - molecule made of three monomers
- polymer ……………………

Hand-holding simulation:
Have students pair up and ask them to figure out a way to physically represent an ethylene molecule. This is fun. Then tell them that they all need to do it the same way to continue the simulation. I like to have them face each other and join both hands w/ each other. The joined hands represent the double bonds. The trunk of their body is a carbon atom. Their head is one H atom and their legs together are the other hydrogen atom. Have the pairs of students spread out around the room but near enough to each other that they can reach out and touch the next pair. As the teacher, put one arm behind your back and raise your other arm. Call yourself an initiator (and a radical) and announce that you are looking for a bond. Reach out and take the hand (steal a bond) of a student in an ethylene pair. This student is still a carbon atom with 4 bonds but his partner now has just 3 bonds and is looking to make another. This student then grabs the hand of another student in a nearby pair (breaking that double bond) and so the chain reaction continues (hopefully fairly quickly). If you originally had an odd number of students and someone did not have a partner - that student can also be an initiator. They can be at the end of the chain and complete the polymer or they can start the "reaction" at the same time as the teacher but from the opposite end. The 2 growing chains should meet up to form one polymer chain.

Ask the students how the length of the chains can be controlled in the process? The answer is by controlling the amount of initiator molecules. More initiator molecules - shorter chains form - and vice versa. Can the exact length of the chains be controlled? No, but most chains will be within a certain range of lengths. Will all the chains be the same length? No.

Go back to the discussion about alkenes. Draw the monomers of recycling codes #2 through #6. Check out the following websites:
http://www.americanchemistry.com/s_plastics/sec_learning.asp?CID=1102&DID=4256
http://www.earthodyssey.com/symbols.html

#2 and #4 = polyethylene
#3 = polyvinyl chloride
#5 = polypropylene
#6 = polystyrene
Also draw polytetrafluoroethylene (Teflon)
Also draw polyvinyl alcohol

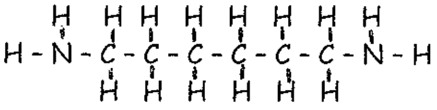
Discuss the use of the term "vinyl". It is used if one or more of the hydrogen atoms in ethylene is replaced w/ something other than carbon and hydrogen.

2. **Condensation polymerization** - method of forming molecules between 2 different monomers. A smaller molecule is also formed as a by-product. (Also known as a step reaction)

Nylon 6-10 demo

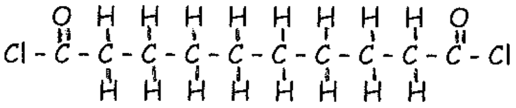
Safety: Safety glasses, lab apron, and chemical resistant gloves are required. Perform in a well ventilated area.

hexamethylene diamine



$H-\overset{H}{N}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{H}{N}-H$

sebacoyl chloride



$Cl-\overset{O}{\overset{\|}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-Cl$

Produces nylon 6-10 and HCl (hydrochloric acid) as a by-product.

The hexamethylene diamine is in solution with NaOH (sodium hydroxide) as the solvent. Sebacoyl chloride is also in solution with hexane as the solvent. These solutions are readily available from scientific supply companies such as Flinn Scientific.

Place 5 mL of the hexamethylene diamine solution in a 25 mL beaker.

Gently pour 5 mL of the sebacoyl chloride solution down the side of the beaker to form a layer on top of the other solution.

The hexamethylene diamine solution is denser so be sure to put it in the beaker first.

The condensation reaction which forms the nylon polymer occurs at the interface between the two liquids.

With a pair of forceps, reach down to the interface and grasp the polymer film that has formed. Pull it up and wind it around a test tube or preform. Wash the nylon thoroughly in acetone and then distilled water before handling. Place the beaker with any remaining chemicals in fume hood to evaporate.

This is a "raw" form of nylon. To be useful, it would need to be washed, chopped, melted, and spun through spinnerets to form elastic fibers.

The hexamethylene diamine solution may have food coloring added to it to produce colored nylon. Also, phenolphthalein can be added to the hexamethylene diamine solution. As the condensation reaction occurs and produces hydrochloric acid, a color change will occur in the indicator.

Cross-linking - holding chains together - can be strong (covalent) or weak (intermolecular forces) - determines many properties.

- **Happy/Sad balls** - this is a great demonstration to use at this point.
- **Slime Lab** - see separate document.

Classification of Polymers:
Reaction to Heat (physical properties)

1. **Thermoplastics** - soften when heated and resolidify when cooled. Primary types of polymers used for recycling.

2. **Thermosets** - polymers that set into a solid form permanently when heated and cannot be softened by heat.

3. **Elastomers** - polymers that show a high degree of elasticity such as rubber

Demo for thermoplastics - milk jug and heat gun
Discuss amorphous versus crystalline polymers. Most polymers are amorphous with some regions of crystallinity. The more amorphous a polymer - the more transparent it appears. The more crystalline a polymer - the more translucent or opaque it becomes. When a polymer exhibits crystallinity, it isn't the individual atoms that are arranging into a repeating pattern, it is the

molecules themselves (the chains) that exhibit some long-range order. This is evident in the difference between HDPE and LDPE. LDPE, because of its branched chains exhibits little crystallinity, and therefore is more transparent than HDPE which shows a higher degree of crystallinity with its unbranched polyethylene chains.

Heat the side of a milk jug, distilled water jug, or Sunny Delight bottle (#2 recycling code plastics) with a heat gun. The polymer chains will start to relax as they gain energy and will lose some of their crystallinity. The heated area will become more transparent and softer (flexible). When it reaches this point, gently blow into the opening of the container. This will demonstrate blow molding. The polymer will stretch and expand and take on a new shape. As the jug cools, it will become less transparent as the chains lose mobility and regain some crystallinity.

Drinking bottles, such as soda bottles or water bottles, can also be used to demonstrate properties of thermoplastics. These bottles are made of polyethylene terephthalate (recycling code #1). Heat a bottle with a heat gun and it will begin to soften and shrink back to its original preform shape.

Have students do the "Shrink to Fit" lab to demonstrate thermoplastics. See separate document.

Have students do a polyurethane casting (Eurocast clothespins) to demonstrate thermosets. See separate document.

Have students do the latex rubber ball lab to demonstrate elastomers. See separate document.

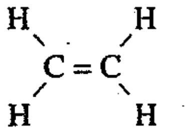
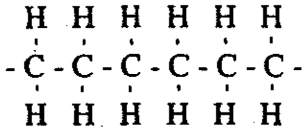
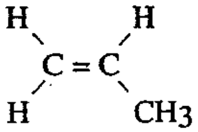
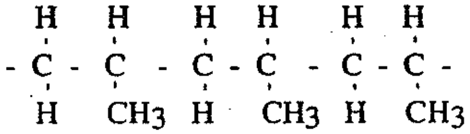
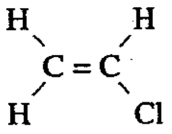
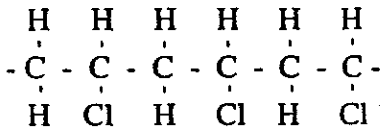
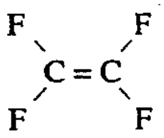
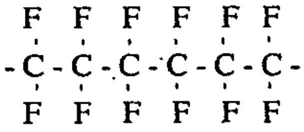
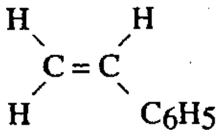
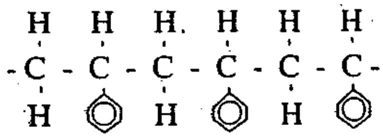
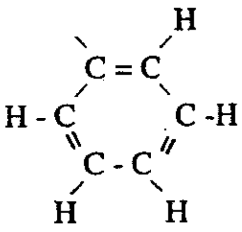
Recycling Codes

Recycling Symbol	Name of Polymer	Sample Uses
1 **PETE**	polyethylene terephthalate	• soft drink bottles • carpets • fiberfill • rope • scouring pads • fabrics • Mylar tape (cassette and computer)
2 **HDPE**	high density polyethylene	• milk jugs • detergent bottles • bags • plastic lumber • garden furniture • flowerpots • trash cans • signs
3 **V**	vinyl	• cooking oil bottles • drainage and sewer pipes • tile • bird feeders • institutional furniture • credit cards
4 **LDPE**	low density polyethylene	• bags • Elmer's® Glue bottles and other squeeze bottles • wrapping films • container lids
5 **PP**	polypropylene	• yogurt containers • automobile batteries • bottles • lab equipment • carpets • rope • wrapping films
6 **PS**	polystyrene	• disposable cups and utensils • toys • lighting and signs • construction • foam containers and insulation
7 **other**	all other polymers	• catsup, snack, and other food containers • hand cream, toothpaste, and cosmetic containers

Density Table

Floats On / Type of Plastic	Vegetable Oil	Alcohol/Water	Water	Glycerin
PETE #1	no	no	no	no
HDPE #2	no	no	yes	yes
V #3	no	no	no	no
LDPE #4	no	yes	yes	yes
PP #5	yes	yes	yes	yes
PS #6	no	no	no	yes

20-P

Name	Mer	Polymer
Polyethylene		 $-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-$
Polypropylene		 $-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{CH_3}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{CH_3}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{CH_3}{C}}-$
Polyvinyl Chloride		 $-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{Cl}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{Cl}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{Cl}{C}}-$
Polytetrafluoro-ethylene (Teflon)		 $-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-$
Polystyrene*		
*The structural formula for C_6H_5 is:		Abbreviated: 

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Plastic Packaging Resins

Resin Codes	Descriptions	Properties	Product Applications	Products Made with Recycled Content*
1 PET	**Polyethylene Terephthalate (PET, PETE).** PET is clear, tough, and has good gas and moisture barrier properties. This resin is commonly used in beverage bottles and many injection-molded consumer product containers. Cleaned, recycled PET flakes and pellets are in great demand for spinning fiber for carpet yarns, producing fiberfill and geo-textiles. Nickname: Polyester.	• Clear and optically smooth surfaces for oriented films and bottles • Excellent barrier to oxygen, water, and carbon dioxide • High impact capability and shatter resistance • Excellent resistance to most solvents • Capability for hot-filling	Plastic bottles for soft drinks, water, juice, sports drinks, beer, mouthwash, catsup and salad dressing. Food jars for peanut butter, jelly, jam and pickles. Ovenable film and microwavable food trays. In addition to packaging, PET's major uses are textiles, monofilament, carpet, strapping, films, and engineering moldings.	Fiber for carpet, fleece jackets, comforter fill, and tote bags. Containers for food, beverages (bottles), and non-food items. Film and sheet. Strapping.
2 HDPE	**High Density Polyethylene (HDPE).** HDPE is used to make many types of bottles. Unpigmented bottles are translucent, have good barrier properties and stiffness, and are well suited to packaging products with a short shelf life such as milk. Because HDPE has good chemical resistance, it is used for packaging many household and industrial chemicals such as detergents and bleach. Pigmented HDPE bottles have better stress crack resistance than unpigmented HDPE.	• Excellent resistance to most solvents • Higher tensile strength compared to other forms of polyethylene • Relatively stiff material with useful temperature capabilities	Bottles for milk, water, juice, cosmetics, shampoo, dish and laundry detergents, and household cleaners. Bags for groceries and retail purchases. Cereal box liners. Reusable shipping containers. In addition to packaging, HDPE's major uses are in injection molding applications, extruded pipe and conduit, plastic wood composites, and wire and cable covering.	Bottles for non-food items, such as shampoo, conditioner, liquid laundry detergent, household cleaners, motor oil and antifreeze. Plastic lumber for outdoor decking, fencing and picnic tables. Pipe, floor tiles, buckets, crates, flower pots, garden edging, film and sheet, and recycling bins.

22-p

Resin Codes	Descriptions	Properties	Product Applications	Products Made with Recycled Content*
3 PVC	**Polyvinyl Chloride (PVC, Vinyl).** In addition to its stable physical properties, PVC has good chemical resistance, weatherability, flow characteristics and stable electrical properties. The diverse slate of vinyl products can be broadly divided into rigid and flexible materials.	• High impact strength, brilliant clarity, excellent processing performance • Resistance to grease, oil and chemicals	Rigid packaging applications include blister packs and clamshells. Flexible packaging uses include bags for bedding and medical, shrink wrap, deli and meet wrap and tamper resistance. In addition to packaging, PVC's major uses are rigid applications such as pipe, siding, window frames, fencing, decking and railing. Flexible applications include medical products such as blood bags and medical tubing, wire and cable insulation, carpet backing, and flooring.	Pipe, decking, fencing, paneling, gutters, carpet backing, floor tiles and mats, resilient flooring, mud flaps, cassette trays, electrical boxes, cables, traffic cones, garden hose, and mobile home skirting. Packaging, film and sheet, and loose-leaf binders.
4 LDPE	**Low Density Polyethylene (LDPE).** LDPE is used predominately in film applications due to its toughness, flexibility and relative transparency, making it popular for use in applications where heat sealing is necessary. LDPE also is used to manufacture some flexible lids and bottles as well as in wire and cable applications. Includes Linear Low Density Polyethylene (LLDPE).	• Excellent resistance to acids, bases and vegetable oils • Toughness, flexibility and relative transparency (good combination of properties for packaging applications requiring heat-sealing)	Bags for dry cleaning, newspapers, bread, frozen foods, fresh produce, and household garbage. Shrink wrap and stretch film. Coatings for paper milk cartons and hot and cold beverage cups. Container lids. Toys. Squeezable bottles (e.g., honey and mustard). In addition to packaging, LDPE's major uses are in injection molding applications, adhesives and sealants, and wire and cable coverings.	Shipping envelopes, garbage can liners, floor tile, paneling, furniture, film and sheet, compost bins, trash cans, landscape timber, and outdoor lumber.
5 PP	**Polypropylene (PP).** PP has good chemical resistance, is strong, and has a high melting point making it good for hot-fill liquids. This resin is found in flexible and rigid packaging, fibers, and large molded parts for automotive and consumer products.	• Excellent optical clarity in biaxially oriented films and stretch blow molded containers • Low moisture vapor transmission • Inertness toward	Containers for yogurt, margarine, takeout meals, and deli foods. Medicine bottles. Bottle caps and closures. Bottles for catsup and syrup. In addition to packaging, PP's major uses are in fibers, appliances and	Automobile applications, such as battery cases, signal lights, battery cables, brooms and brushes, ice scrapers, oil funnels, and bicycle racks. Garden rakes, storage bins, shipping pallets, sheeting, trays.

23-P

Resin Codes	Descriptions	Properties	Product Applications	Products Made with Recycled Content*
		acids, alkalis and most solvents	consumer products, including durable applications such as automotive and carpeting.	
6 PS	**Polystyrene (PS).** PS is a versatile plastic that can be rigid or foamed. General purpose polystyrene is clear, hard and brittle. It has a relatively low melting point. Typical applications include protective packaging, foodservice packaging, bottles, and food containers. PS is often combined with rubber to make high impact polystyrene (HIPS) which is used for packaging and durable applications requiring toughness, but not clarity.	• Excellent moisture barrier for short shelf life products • Excellent optical clarity in general purpose form • Significant stiffness in both foamed and rigid forms. • Low density and high stiffness in foamed applications • Low thermal conductivity and excellent insulation properties in foamed form	Food service items, such as cups, plates, bowls, cutlery, hinged takeout containers (clamshells), meat and poultry trays, and rigid food containers (e.g., yogurt). These items may be made with foamed or non-foamed PS. Protective foam packaging for furniture, electronics and other delicate items. Packing peanuts, known as "loose fill." Compact disc cases and aspirin bottles. In addition to packaging, PS's major uses are in agricultural trays, electronic housings, cable spools, building insulation, video cassette cartridges, coat hangers, and medical products and toys.	Thermal insulation, thermometers, light switch plates, vents, desk trays, rulers, and license plate frames. Cameras or video cassette casings. Foamed foodservice applications, such as egg shell cartons. Plastic mouldings (i.e., wood replacement products). Expandable polystyrene (EPS) foam protective packaging.
7 OTHER	**Other.** Use of this code indicates that a package is made with a resin other than the six listed above, or is made of more than one resin and used in a multi-layer combination.	Dependent on resin or combination of resins	Three- and five-gallon reusable water bottles, some citrus juice and catsup bottles. Oven-baking bags, barrier layers, and custom packaging.	Bottles and plastic lumber applications.

***Recycling may not be available in all areas. Check to see if plastics recycling is available in your community.**

American Chemistry Council, Plastics Division
Last Updated: March 2007

24-P

WOW! One molecule is THAT long?

The length of the piece of yarn represents the relative size of the molecule. Each "kink" or "zig" in the yarn [under 1/3 cm] represents a carbon atom.

1 carbon atom === methane
natural gas for cooking and heating

10 carbon atoms === decane
like charcoal lighter fluid

100 carbon atoms == a waxy poly(ethylene)

10 000 carbon atoms == a typical poly(ethylene)

AND, some polymers may have **100 000** carbon atoms. That would take a piece of yarn 300 meters long!

Developed from an idea presented on behalf of I I. Kohan [MIK Associates, 1913 Longcome Drive, Wilmington DE 19810 mel95pa@aol.com] at the Division of Chemical Education Symposium at the 218th ACS National Meeting, New Orleans, August, 1999. It is part of the Delaware Science Kit project.

Lynn Higgins--Illinois POLYMER AMBASSADOR 708.447.6339 April 2000

25-P

FEATURES OF ALKANES OF DIFFERENT SIZES

Number carbon atoms	Feature	Name	Example	Scale length	Melting point in C
one	smallest hydrocarbon	methane	natural gas	.3 cm	-183
six	smallest liquid hydrocarbon	hexane	charcoal lighter fluid	2 cm	-95
18	smallest solid hydrocarbon	octadecane	very soft paraffin wax	5 cm	28
100	a “waxy” poly(ethylene)	deca-decane		30 cm	110
1 000	a ”small” poly(ethylene)		poly(ethylene)	3 m	softens at 130
10 000	typical poly(ethylene)		poly(ethylene)	30 m	softens at 150

Lynn Higgins 708.447.6339 lynhiggins@aol.com

Browse the article **What is the difference between gasoline, kerosene, diesel fuel, etc.?**

What is the difference between gasoline, kerosene, diesel fuel, etc.?

The "crude oil" pumped out of the ground is a black liquid called **petroleum**. This liquid contains **aliphatic hydrocarbons**, or hydrocarbons composed of nothing but hydrogen and carbon. The carbon atoms link together in chains of different lengths.

It turns out that hydrocarbon molecules of different lengths have different properties and behaviors. For example, a chain with just one carbon atom in it (CH_4) is the lightest chain, known as methane. Methane is a gas so light that it floats like helium. As the chains get longer, they get heavier.

The first four chains -- CH_4 (methane), C_2H_6 (ethane), C_3H_8 (propane) and C_4H_{10} (butane) -- are all gases, and they boil at -161, -88, -46 and -1 degrees F, respectively (-107, -67, -43 and -18 degrees C). The chains up through $C_{18}H_{32}$ or so are all liquids at room temperature, and the chains above C_{19} are all solids at room temperature.

The different chain lengths have progressively higher boiling points, so they can be separated out by **distillation**. This is what happens in an oil refinery -- crude oil is heated and the different chains are pulled out by their vaporization temperatures. (See How Oil Refining Works for details.)

The chains in the C_5, C_6 and C_7 range are all very light, easily vaporized, clear liquids called **naphthas**. They are used as solvents -- dry cleaning fluids can be made from these liquids, as well as paint solvents and other quick-drying products.

The chains from C_7H_{16} through $C_{11}H_{24}$ are blended together and used for **gasoline**. All of them vaporize at temperatures below the boiling point of water. That's why if you spill gasoline on the ground it evaporates very quickly.

Next is **kerosene**, in the C_{12} to C_{15} range, followed by diesel fuel and heavier fuel oils (like heating oil for houses).

Next come the **lubricating oils**. These oils no longer vaporize in any way at normal temperatures. For example, engine oil can run all day at 250 degrees F (121 degrees C) without vaporizing at all. Oils go from very light (like 3-in-1 oil) through various thicknesses of motor oil through very thick gear oils and then semi-solid greases. Vasoline falls in there as well.

Chains above the C_{20} range form solids, starting with paraffin wax, then tar and finally asphaltic bitumen, which used to make asphalt roads.

All of these different substances come from crude oil. The only difference is the length of the carbon chains!

www.howstuffworks.com
http://auto.howstuffworks.com/question105.htm

POLYMER
AMBASSADORS

POLYMER BASICS

Many common items can be used to demonstrate the structure of a polymer.

1. **Paper clips** hooked together in a chain can be used to simulate the way that monomers link up to form very long chains. You can even simulate the process of polymerizing by placing a few "PC" (paper clip) monomers into a container (with a screw-top lid), in which you have already placed a large number of clips hooked together to make a chain. You can simulate the addition of energy, which is necessary to begin the polymerization process, by shaking the closed container. Then you can remove the entire polymer (paper clip) chain; however, it is probable that, when you pull out the chain, you will have short branches of clips extending off the main, long chain of paper clips, and some unlinked (monomer) molecules in the bottom of the reaction vessel. In real polymers, the length of the entire chain helps to determine the polymer's properties. The important points in this simulation are:
   a. A polymer chain is made up of a repeating monomer unit (the paper clip).
   b. The number of monomer paper clips in this chain is far smaller than the number of monomer units in a useful polymer.
   c. Producing a polymer doesn't always give a single long chain, but it produces chains with side branches, and frequently leaves some monomer molecules unreacted.

2. **Strands of beads** (costume jewelry) can also represent a chain of monomers. This long strand will usually emerge from a container as a single chain, with few entanglements and side-branches. One extra use of this analogy is to demonstrate auto-siphoning; you must prepare the chain by carefully arranging the beads in the container in a continuous single strand, starting at one end and laying the chain into the container in a layered fashion. Then allow a short segment of the chain to hang down over the side of the container. If it is long enough (roughly one container-length), the entire chain will tumble out of the container. This illustrates the same peculiar property (auto-siphoning) shown by several very long-chain polymer substances.

   Steel chain has the added advantage of being attracted to a magnet. This allows you to simulate the effect of adding borax solution to polyvinyl alcohol or to Elmer's glue – the borax acts as a cross-linking agent and forms bonds between segments of the polymer chains. This makes the previously liquid substance behave as a viscous gel, aka "slime or "Gluep". The magnet, when placed in the middle of the pile of chain, will attract the rest of the loops of chain close to it, causing it to be much more solid-like than before, simulating the cross-linking bonds that form between the borax and the polymer.

   Pop beads, once a rage in the 50's, are also a useful product to simulate polymers. Different-colored beads can be used to introduce the idea of a co-polymer, one that has two monomers. The monomers can either alternate single monomer units (called, "A-B" copolymer) or alternate groups of monomers (random or block copolymers). Also, the larger size of the pop beads (compared to the steel bead chain) makes the self-siphoning demonstration much more easily observable for a class.

Prepared by William Bleam, Jr., Polymer Ambassador for Pennsylvania, Emeritus
For the NSTA National Convention, San Diego, CA, 3/27-3/30, 2002

POLYMER BASICS cont'd.)

3. **Clothes pins** can be used to show many of the same properties as the other aforementioned items. With clothes pins you have the added advantage of being able to show students that the clothes pins can be thought of as being difunctional – having a reactive site at both ends of the clothes pin. When one reacts, the other one is still intact to react again. No matter how many monomers link together, at each end is yet another reactive site to react again. In this way, a polymer can grow to be hundreds of thousands of monomers long. The process will continue to grow an ever-larger polymer molecule until the chemist adds a chemical to bond with those ends of the huge chain and stop the chain growth.

4. At the elementary levels, a commercial toy/game called, **"Barrel of Monkeys"** uses this concept of difunctionality. Each little monkey in the barrel has its two arms extended, their hands forming little hooks. The goal of the game is to hook the monkeys together as you extract them from the can to get the longest continuous chain of monkeys – just like a polymer in real life.

5. Perhaps **cooked spaghetti** is more like a polymer (and also messier!) than any of the above analogies. The spaghetti has many long strands, all interwoven. These entanglements more closely resemble the interactions of polymer chains, resulting in polymer properties like flexibility and elasticity. The bead chains can also be used in a similar manner if you simply pick up a mass of the chain and allow the long strand to weave back on itself repeatedly, rather than stringing it out in one long strand.

6. The **"Poly People Activity"** is a way to get students actively involved in the lesson. Students actually join hands/arms to link up in much the same way that actual polymers form from monomers. If you begin by linking just two students, they form a "dimer", two monomers joined. If you continue in this fashion, you build trimers, tetramers, etc. Eventually they form a chain long enough to be considered a useful polymer, one that has properties that allow it to be processable into useful products. You can show how flexibility decreases with increased numbers of people in a chain, just as flexibility decreases with increased chain length in real polymers. Allow the dimers and trimers that have formed in the early stages of the exercise to "flow" freely, to roam about the room. Then link several of the groups together and ask them to roam independently. They have a much more difficult time as the chain length increases. This corresponds to an increase in rigidity of the polymer.

One drawback to any of the simulations mentioned in this paper is that one never gets the chain long enough to truly represent the length of an actual polymer molecule. A hundred, or even five hundred, do not begin to represent the numbers of monomers in a polymer chain. To form a processable plastic requires thousands, tens of or even hundreds of thousands of monomers in the chain.
Another drawback is that none of these show interactions between strands or parts of strands that overlap each other. Branching and cross-linking are common in polymers, but not in simulations. These two factors, along with the length of the polymer chain, contribute significantly to the physical characteristics of the specific polymer.

29-8

(a) Mostly amorphous

(b) Semicrystalline
(crystallites encircled)

(c) Mostly crystalline

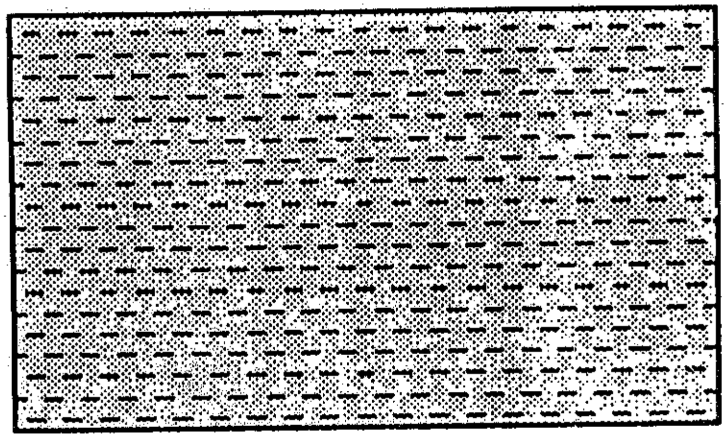
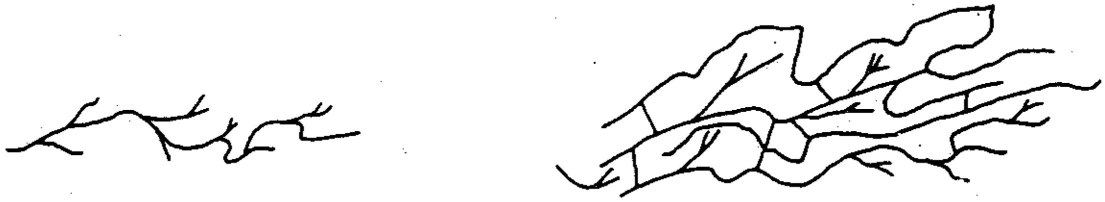


Figure 6-7 Degrees of crystalline structure of polymers.

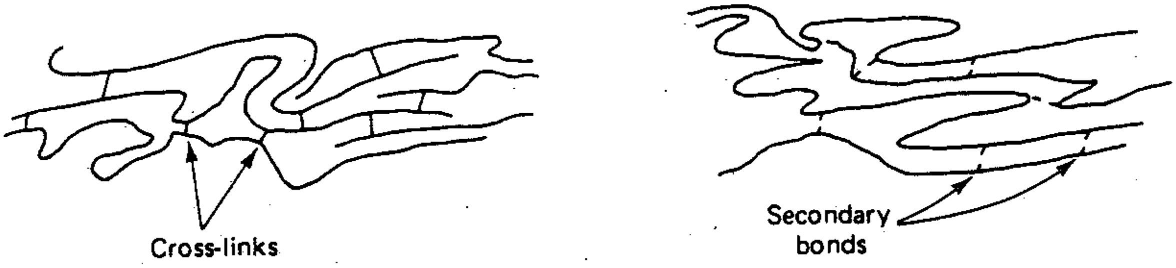
(a) Single linear polymer

(b) Multiple linear polymers



(c) Single branched polymer

(d) Network – crosslinked branched polymers (e.g., phenolic, epoxy, and silicones)



(e) Crosslinked linear polymers (e.g., polyesters and diene elastomers)

(f) Thermoplastic polymer

Figure 6-10 Various polymer structures.

Plastics Recycling Poster Assignment

Objective: To become aware of and gain an understanding of the impacts of plastics as a post consumer product, including the problems created by consumer plastics and alternative solutions to these problems. To know what you as a consumer can do to minimize the effects of consumer plastics on society.

Assignment: To produce a poster that creatively and clearly shows the recycling alternatives for plastics. Your poster must include the following information.

1. Correctly identified and spelled names of the seven plastics covered in the recycling guidelines. This might include more than one name, a trade name and a scientific name. (i.e.: Styrofoam and polystyrene.) (2 points for each one, 14 total.)
2. Two samples of each of the seven recyclable plastics. These samples must include the recycle number molded into the product. There is only one of these on each product. (1.5 points for each one, 21 total.)
3. A correct, original diagram of the "**mer**" of the plastic that you are identifying. (2 points for each one, 14 total.)
4. Identify where your sample came from and list common uses. (There are thousands of uses!!!) (2 points for each one, 14 total.)
5. The recycle symbol with the correct number inside. (1 point for each one, 7 total.)

Format: Your assignment is to be done on a rigid poster board type of material. It must be visually pleasing and factually accurate. Whatever arrangement you decide upon must have some reason and logic behind it. Either drawing by hand or using a computer is acceptable. However, the poster must be neat and clean. Items must stay attached so select an adhesive that will do the job on a permanent basis. (15 points total.)

Total points possible for assignment: 85

Due Date = ________________________

For each date your poster is turned in late, 15% will be deducted from the final point total.

Some class time will be given to work on your poster. However, you will need to bring materials from home to be able to complete the project. These materials will need to be at school so that your class time is used efficiently.

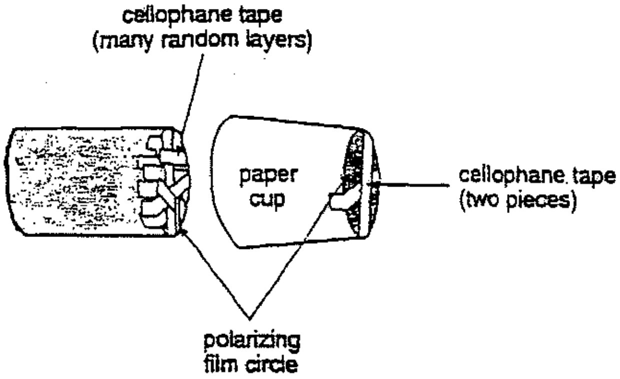
32-P

Plastics and Polarization

How do Polaroid sunglasses work? Sunglasses are polarizers that have the ability to block out some of the sunlight. In this activity you will be able to duplicate this process using polarizing film. You will observe how an optically active material like cellophane, when placed between such polarizing films, will rotate certain light waves. As more layers of cellophane are added in the activity, the degree of rotation of the wavelengths of light is increased and more colors become visible.

Materials (per group)

- 2 square pieces of polarizing material (about 1" x 1")
- 2 small paper cups with bottoms removed
- cellophane tape
- scissors
- pieces of other types of clear plastic

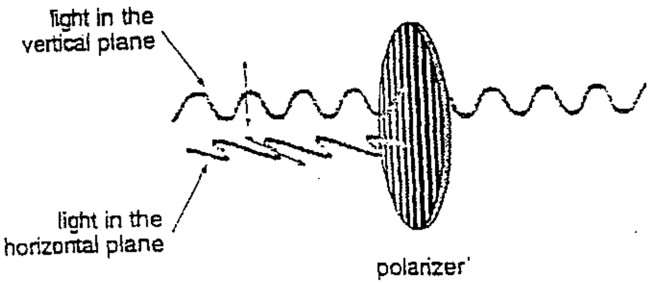


Procedures:

1. Cut out the bottom of each of the small cups.
2. Tape a piece of polarizing material to the bottom of each cup with clear tape.
3. Take at least two more pieces of tape and cover the bottom of the cup in a variety of directions - more layers of tape placed over the polarizing film will produce more "colorful" results.
4. Repeat the above procedure with the other cup.
5. Place one cup inside the other and look through the opening holding the cups to the light. Rotate the paper cups and observe the colored lights that are visible.
6. As you experiment with your set of polarizing lenses, read the "Background Information" packet and answer the questions on the worksheet.

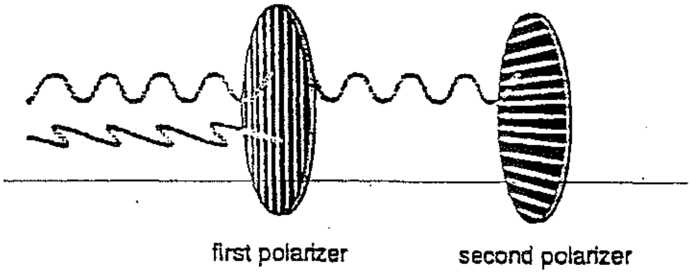
Background Information

Ordinary light from the sun or a lamp is composed of waves that vibrate in all directions perpendicular to the light beam. Polarized light vibrates in a single direction perpendicular to its path. Ordinary light can be polarized by passing it through a polarizing filter. This filter allows only the waves that vibrate in one perpendicular direction to pass through. The structure of the light-polarizing filter prevents the passage of light waves that vibrate in other perpendicular directions.



33-P

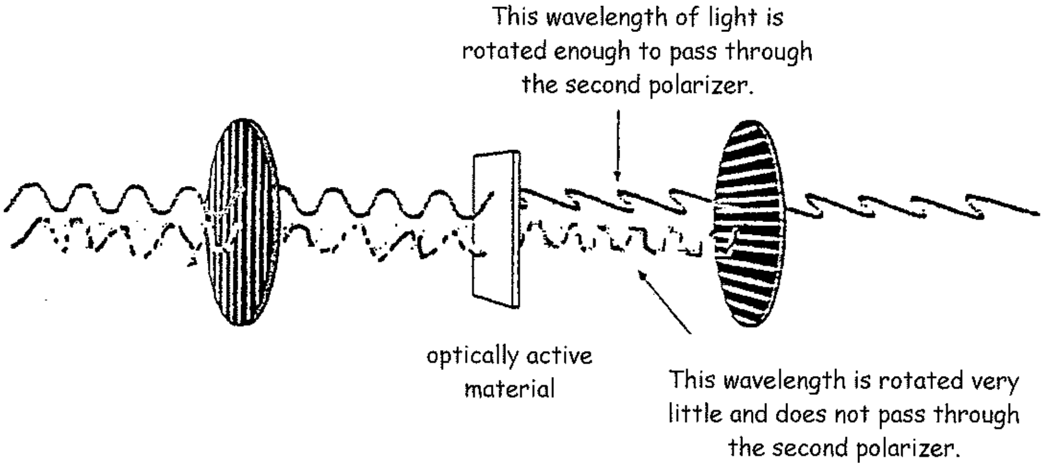
Polarized light can pass completely through a second polarizing filter, which is parallel to that of the first polarizing filter. If the second polarizer is rotated, it will gradually dim the light that comes through it. The second polarizer will cut off the light entirely when its axis is 90° to the axis of the first polarizing filter.



The effect of the second polarizer's orientation on plane polarized light.

Many applications of polarized light are based on this phenomenon. Polarized sunglasses, with their transmission axis set vertically, block the horizontally polarized light. Photographers use polarizing filters to cut down on glare and reflections from shiny surfaces.

When a piece of cellophane tape is placed between two crossed polarizing films, light now passes through because the cellophane has the ability to rotate the plane of light. This is referred to as optical activity. Many polymer films are optically active because they have been stretched during manufacturing and their molecules are aligned in the direction of the stretch. As light passes through the stretched polymers, they rotate the light waves. Not all optically active substances rotate all wavelengths of light to the same degree. This causes certain frequencies not to pass through the second polarizer. The wavelengths passing through the second polarizer will appear a certain color. As the outer polarizing film is rotated in our activity, the orientation of the polarizer changes. Different wavelengths pass through and different colors are visible. As you rotate by 90 degrees, a color changes to its complementary color.



The effect of optically active materials on plane polarized light.

Plastics and Polarization

Name: ______________________

Date: ______________ Period: ________

As you experiment with your set of polarizing lenses, read the "Background Information" and answer the following questions:

1. How is ordinary light different than polarized light?

2. How does a polarizer affect ordinary light waves?

3. How would you know if two polarizing filters were parallel to each other?

4. How would you know if two polarizing filters were perpendicular to each other?

5. Give two examples of the use of polarizing films.

6. What effect does the cellophane tape have on the light that passes through it?

7. If you locate the color red in the polariscope and then turn one of the films 90 degrees, what color do you get?

Collect two other types of clear plastic. One should be from a plastic box (available from the instructor) and another from a 2 liter pop bottle. Place them between the polarizing films and record your observations before and after rotating the films 90 degrees. Also, include a record of the results from just the cellophane tape.

Type of plastic	Initial color	Color after 90 degree rotation

35-P

materials@home: Play with plastics!

Torture-test some plastics around your house - which is toughest when the tension mounts?

Torture Test #1: Here's what you do:

1. Hold a plastic shopping bag up to the light. Can you see the *grain* of the material? It will look like faint lines all running in the same direction.
2. Very slowly stretch the plastic in the same direction as the lines. What happens? Try again on another portion of the bag, only this time stretch very slowly "against" the grain. What difference do you notice?
3. Write down your observations.

You'll need:

- several different types of plastic film - garbage bags, food wrap, freezer bags, plastic milk bags, microwave wrap, or grocery bags
- 4 different-sized food cans with different weights - for example, try a small can of cat food, a small can of soup, a can of beans and a large can of tomatoes.
- household string
- 1 metal "S" hook
- pencil and paper to write down observations

Torture Test #2: Here's what you do:

4. Cut strips about 1 inch wide and 5 inches long from each type of plastic.
5. Tie each can with string, making a tail with a loop on one end. This loop will allow you to hang the can from the "S" hook.
6. Hold up one end of a plastic strip, then attach the lightest can to the other end using the "S" hook. If the strip doesn't rip, try attaching the next heaviest can.
7. Note the heaviest can each strip will hold before breaking. Repeat with all your samples. Also note how far each particular sample stretches before it breaks.

Which plastic comes out the winner?

what's happening?

Plastics are made of long molecules called *polymers*, which are made of lots and lots of repeating units connected together into chains. The "grain" indicates the general direction of the plastic's polymer chains.

Pulling *against* the grain forces the chains to re-organize in the direction of the tension. Most plastics are strongest when they're stretched *with* the grain. How much strain a plastic can take when it's stretched is called *tensile strength*.

Games, experiments, videos and more...
http://www.strangematterexhibit.com

Strange MATTER

TYVEK vs REGULAR POLYETHYLENE

PURPOSE: To compare the rate that water evaporates from two containers. One container is covered with Tyvek. The other container is covered with regular polyethylene film.

DATA:

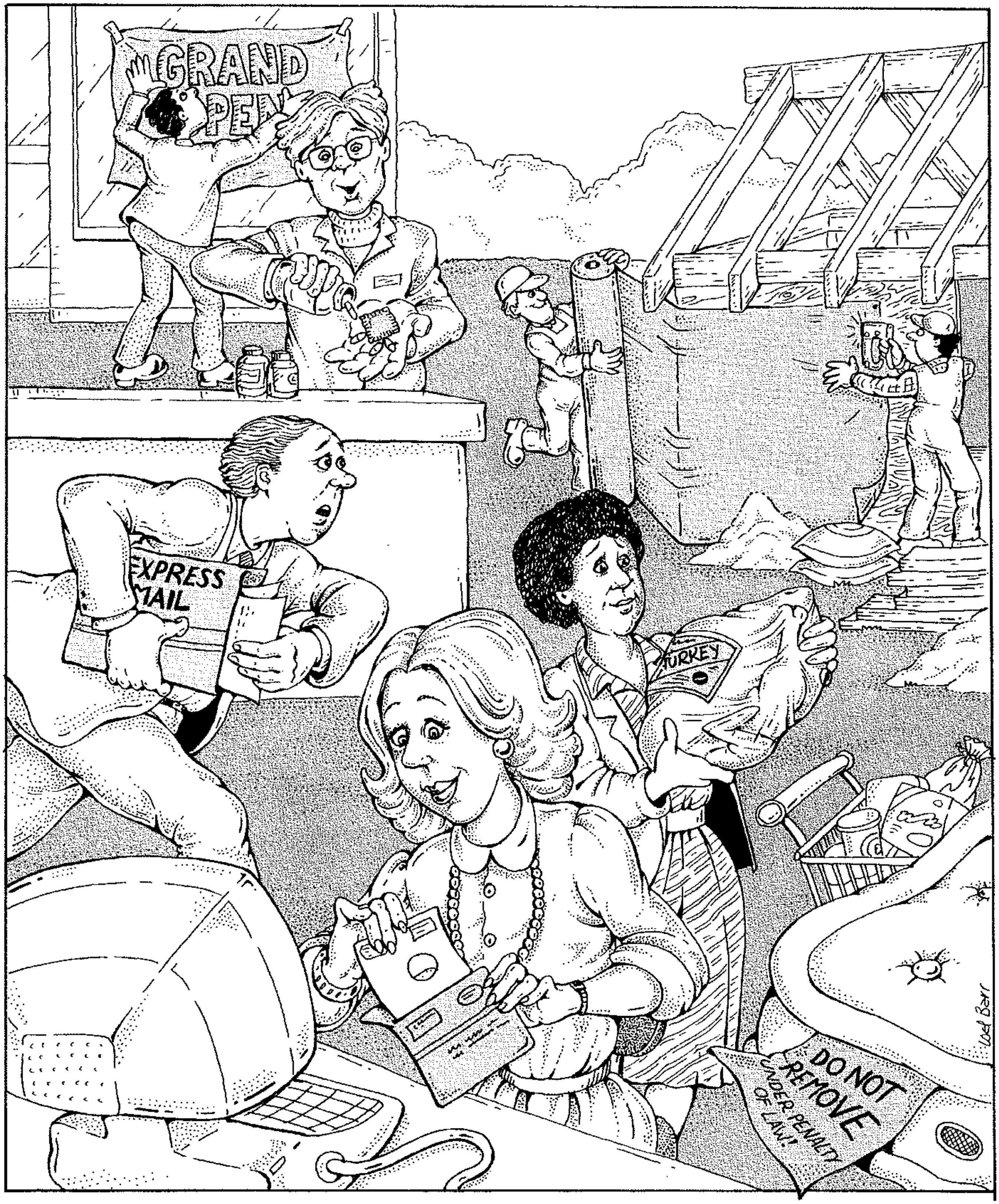
Day Number	Tyvek Mass (g)	Tyvek △ Mass (g)	Polyethylene Mass (g)	Polyethylene △ Mass (g)
1				
2				
3				
4				
5				
6				
7				

INTERPRETATION:

37-P

T

TYVEK


GRAND
OPEN
EXPRESS
MAIL
TURKEY
DO NOT
REMOVE
UNDER PENALTY
OF LAW!

38-P

by *Stephen P. Scheinberg*

The new house is halfway completed. The walls are up, the roof is on, and the workmen are applying what looks like a giant roll of paper as though they were gift-wrapping the house. In fact, they are applying a new plastic material called Tyvek* before putting on the final siding.

A student sits in front of a computer, flipping through a box of disks. She finds the right one, withdraws it from its protective sleeve, and slips it into the disk drive. She notices that the protective sleeve has shiny fibers and feels waxy. It is made of Tyvek, the house-wrap material.

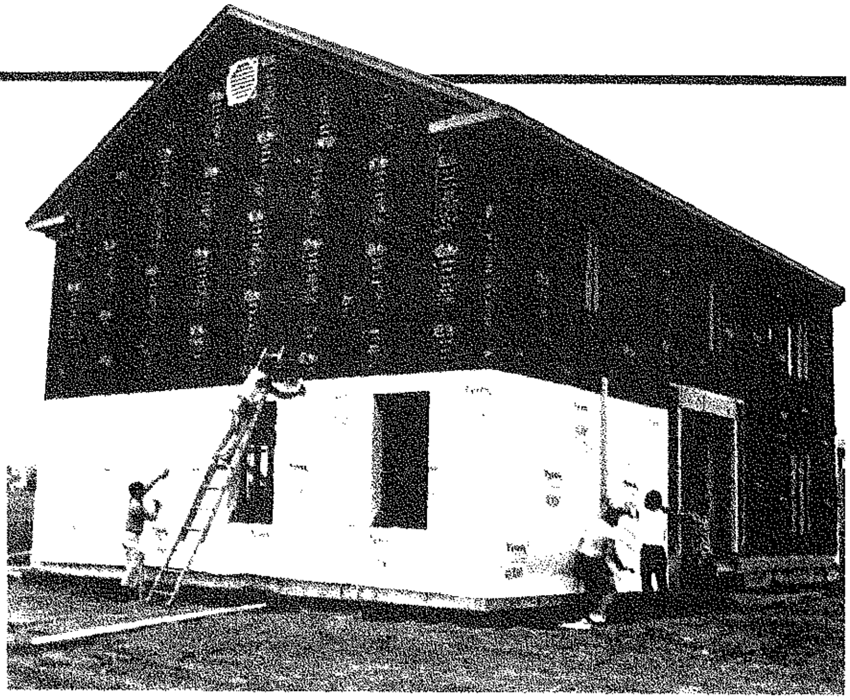
An attorney rushes to the post office with a two-pound stack of papers—the written record of a trial. He stuffs the documents into an express envelope and asks for next-day delivery to Washington. The envelope is made of Tyvek.

What is this Tyvek? Why is it showing up in such diverse products? Tyvek is polyethylene—the most common polymer—fashioned in an unusual way.

Polyethylene

When ethylene gas is exposed to a catalyst at high temperature and pressure, it reacts with itself, producing polyethylene, a solid with long molecules (see Figure 1, p. 5). Polyethylene molecules have a "backbone" of carbon with hydrogen atoms attached. The polyethylene in Tyvek is *linear,* which means that the carbons are strung in a line like pearls on a necklace.

Linear polyethylene can be melted and rolled into a thin film that is used to make sandwich bags and garbage bags. These plastic films are airtight and waterproof, but—as anyone who has tried to lift an overstuffed garbage bag knows—they are not especially strong.



A new house is wrapped with Tyvek before the final siding is applied. The materi stops drafts yet lets the walls "breathe."

Tyvek, a product of the Du Pont Company, is made from a very high grade of the same chemical—linear polyethylene—that has been processed in an unusual fashion. The fibers used in nylon stockings and polyester shirts are stretched to force the molecules to line up with each other, making the fibers stronger; they are then woven into fabric. In making Tyvek, both of these steps are omitted. The polyethylene is formed int extremely fine fibers (about 0.005 in diameter). Instead of being wove the fibers are allowed to fall onto a flat, moving belt (Figure 1). It's som what like unrolling a spool of thread randomly onto the floor. Next, the of fibers is exposed to heat and pre sure, and the fibers are melted to-

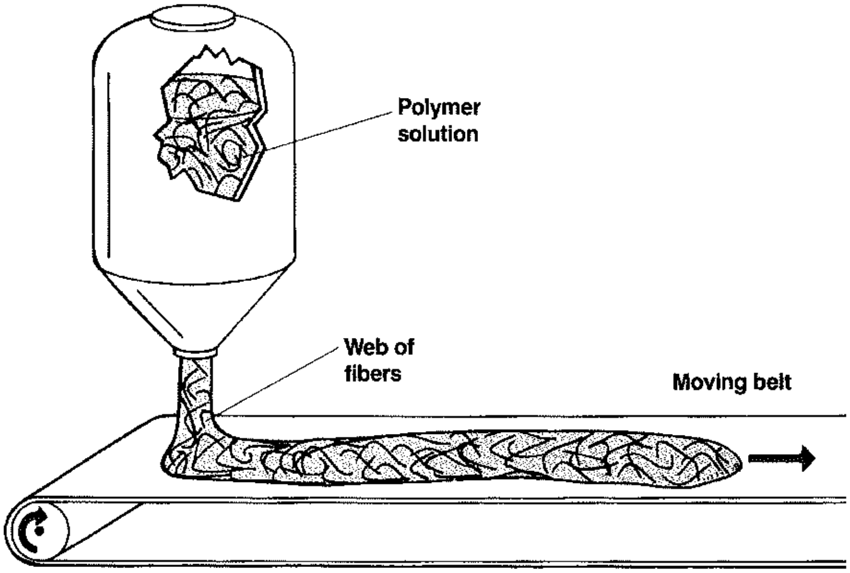


Figure 1. **In making Tyvek, interconnected fibers that resemble spider webs are formed by squeezing a high-pressure polyethylene solution through a small ope ing. Many such webs are collected on a moving belt to form the final product.**

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*Registered trademark of the Du Pont Company.

gether. If most of the fibers are fused together, the material is paper-like (a sample is enclosed with this issue). If only a few are joined, a softer, more cloth-like material results.

Nonwoven fabric

At first, there was no name for materials like this. Because it is neither woven nor knitted, Tyvek is not a conventional textile. It is not a paper or a film. It is something else. It is a spunbonded nonwoven fabric.

Tyvek is exceptionally strong compared with paper and film. The individual fibers are strong because their molecules are highly oriented. Also, many fibers are bonded together, lending the strength of numbers. Tyvek may be flexed thousands of times without breaking (try *that* with paper). The tightly bonded surface is resistant to abrasion; that means little pieces don't rub off as they do in paper.

Tyvek is hydrophobic—afraid of water. This means water will run off it or lay in drops on the surface. Water will not soak in and weaken Tyvek, as it weakens paper. Tyvek is not solid, like a conventional film. There are air spaces in Tyvek that wind around and between the tiny fibers. These are too small to allow dust, wind, bacteria, or drops of water to penetrate, yet air, water vapor, and other gases can slowly diffuse through (Figure 2).

Tyvek has unique properties that make it suitable for a wide range of applications. Most of its uses are hidden . . . in full view! When you understand the properties of Tyvek you will easily be able to spot it in products. Here are some of the ways these unusual properties are put to use:

Mailing envelopes and courier packs. High-strength, lightweight Tyvek envelopes save postage and protect valuable documents from damage. They are used by Express Mail, Federal Express, and other overnight mail services.

Computer disk sleeves. Check out the protective sleeves in which computer disks are stored. They are made of Tyvek because, unlike paper, it doesn't shed lint that could abrade the disk.

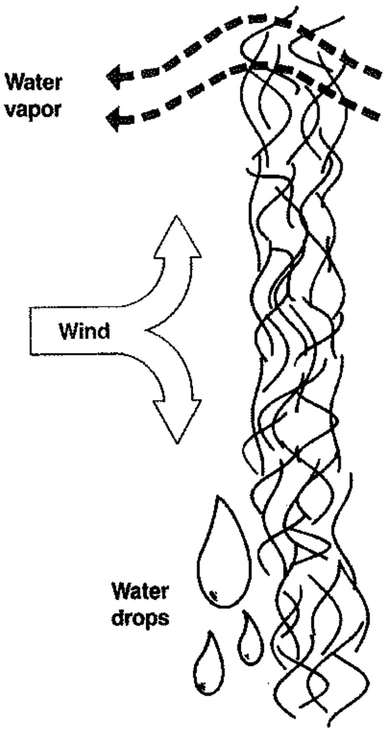

Figure **2. The fibers in Tyvek are packed tightly enough to block drops of water and the wind, but the minute spaces allow individual molecules of air or water to diffuse through slowly (shown by broken lines).**

Tags and labels. Tyvek is used for labels that must be strong wet or dry: price tags on frozen turkeys, washing instruction labels on clothing, and those labels on mattresses and furniture that say "Do not remove under penalty of law."

Signs and banners. These must stand up to high winds in sun and rain for up to three months when advertising that grand opening or tire sale. Wet strength, abrasion resistance, toughness, and printability are important requirements.

Dessicant bags. Teabag-sized pouches containing calcium chloride absorb moisture from the air. They are placed in packages with cameras, electronic equipment, and vitamins to prevent moisture damage. The pouch material must be strong but permeable to water vapor.

Sterile medical packages. Manufacturers seal surgical instruments, gloves, and sutures in Tyvek packages then put the packages in closed containers with ethylene oxide gas. This toxic gas diffuses through the package and kills any microbes. Finally, the ethylene oxide is pumped out and replaced with air. The contents of the package will remain sterile for more than five years.

Protective garments. The softer, fabriclike style of Tyvek is used to make lab coats, coveralls, and protective suits for cleaning up chemical spills. If you put on an airtight protective garment, you'd soon be hot and sweaty. Tyvek garments provide a barrier to dust and liquids, yet are comfortable because they "breathe."

House wrap. Have you ever felt cold air flowing from an electrical outlet or light switch in the winter? In some houses, these drafts waste 15% of the heat. The walls of a house can be sealed tightly by covering them with a conventional plastic film. Unfortunately, this can damage the house. The air inside the house is warm and moist. When it diffuses through the walls and meets the cold film near the outside, liquid water condenses. The water drips down inside the wall, where it may rot the wood. How can the walls be sealed without causing condensation? Use a material that stops cold drafts but is not completely airtight. Before the siding is installed, many new houses are wrapped with Tyvek. The pores in Tyvek are so small that they effectively block the wind, yet they allow air and water vapor to gradually diffuse through. If it should rain before the siding is installed, there is nothing to worry about; Tyvek is waterproof. It is a barrier to liquid water but lets water vapor through.

This nonwoven, nonfilm polymer is solving practical problems where conventional materials don't measure up. Watch for it in kites, maps, book bindings, banners and . . .

***Stephen Scheinberg** is a chemical engineer in the Textile Fibers Department of Du Pont. He helped develop the process for making Tyvek.*

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Happy/Sad Balls

Catalog No. AP1971

Publication No. 1971

Introduction:

Happy and Sad balls appear the same, but do they have the same properties? Bounce the balls, put them in the freezer, heat them in boiling water, compare their densities—observe the very interesting results.

Concepts:

- Polymers
- Density

Materials:

Happy/Sad Ball Set

Freezer or ice water bath

Boiling water bath

Glycerin

Procedure:

Bouncing Ball Activities:

1. Drop a Happy Ball onto a hard surface (tile or cement floor preferred). Describe its behavior.
2. Repeat this procedure with a Sad Ball. Describe its behavior.
3. Repeat this procedure with both balls simultaneously, dropping them from a measured height. Measure how high they bounce.
4. Find a volunteer. Ask the subject if he/she can drop a ball and spin around and catch it before it bounces a second time. Demonstrate this using the Happy Ball. Switch the balls and hand the subject the Sad Ball.
5. Different formulations of Super Balls producing bright colors or translucent balls have different resiliencies. Obtain a number of different colored Super Balls and have a ball bouncing contest. Line up students and have them drop the balls at the same time to see which bounces higher.

Effect of Temperature on the Happy/Sad Ball:

1. Put both balls in a freezer or beaker of ice water. Drop both balls. Does their behavior change when they are cold? The Sad ball becomes even less elastic when frozen and will not bounce at all.
2. Boil both balls in a beaker of water. At about 85 °C, the Happy ball will float to the surface. When the water starts boiling, carefully remove the balls from the beaker and drop them on to the floor. The Sad ball will now bounce better than it did at room temperature.

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Comparing Densities:

1. Place the Happy and Sad balls in a tall beaker half full of water. Do the balls float or sink? (*Note:* Save the water for step 3). What does this tell about the density of the balls?
2. Place the Happy and Sad balls in a tall beaker half full of glycerin (glycerol). Observe. Glycerin has a specific gravity of approximately 1.3 g/mL.
3. Pour the water from step 1 into the beaker of glycerin containing the balls. Observe and compare the specific gravities before mixing the glycerin and water.
4. Mix the glycerin and water. Observe.

Discussion:

The Happy Ball is a sphere having an extremely high resilience factor in excess of 90% and a high coefficient of friction. These two qualities cause the ball to react in an extraordinary and unpredictable manner when bounced or struck. Thus, any spin applied to the ball will be accentuated when it rebounds from a hard surface.

The Happy Ball has a specific gravity of 1.03 g/mL (the specific gravity of water is 1.0 g/mL). It is composed of about 100 parts polybutadiene, 0.5 to 15 parts sulfur vulcanizing agent, and 5 to 15 parts of filler such as hydrated silica, carbon black or lithium oxide. The sulfur vulcanizing agent is added in excess to products such as automobile tires (which contain about 3 parts sulfur) to produce cross-linking between polybutadiene chains resulting in the high resiliency. The ball is molded at a pressure of between 500 and 3,000 p.s.i. for 10 to 30 minutes at a temperature of 285–340 °F (140–171 °C). This produces the Happy Ball with the properties described above. In addition, it has been found that these balls also exhibit an ability to conserve energy. That is, when bounced, the ball will dissipate very little of the energy imparted to it in the form of heat.

The Sad Ball may be composed of several different materials. Common materials used are butyl rubber and a block co-polymer of poly(styrene-butadiene) or a block co-polymer of poly(vinyl-butadiene). These materials have a specific gravity of 1.17 g/mL and have a structure that has a low resiliency, low elasticity, and the ability to absorb energy. Thus, when the ball is dropped, it does not bounce.

These properties make the Sad Ball material useful for a number of applications. The poly(styrene-butadiene) co-polymer is used in automobile tires where it helps to absorb some of the bumps encountered on the highway. This type of material has also found use in lining the ballistic containers used by bomb squads (these look like big trash cans). Should a bomb explode, this material will absorb a significant amount of energy.

Safety Precautions:

Wear protective eyewear. A Happy Ball can rebound in unexpected directions. Take care in bouncing the ball so that it does not hit anyone or anything with sufficient force to cause injury or damage. When dropping a Sad Ball from a high location, take care that it does not hit anything that can be damaged.

Disposal:

The glycerin and water solution may be rinsed down the drain with excess water according to Flinn Suggested Disposal Method #26b. Please consult your current *Flinn Chemical & Biological Catalog/Reference Manual* for proper disposal procedures.

Acknowledgment:

Special thanks to Mr. David A. Katz, Associate Professor of Chemistry, Community College of Philadelphia, who provided us with the instructions for this activity.

Materials for experiments with *Happy/Sad Balls* are available from Flinn Scientific, Inc.:

Catalog No.	Description	Price/Each
AP1971	Happy/Sad Balls	Consult Your Current *Flinn Catalog/Reference Manual.*
G0007	Glycerin, 500 mL	

42-P

Slime

(Polyvinyl Alcohol)

Materials:

- 4% polyvinyl alcohol (PVA) solution - 50 mL per group
- 4% sodium borate solution (borax)
- 5 oz. paper cup
- wooden craft stick
- food coloring
- plastic baggy

Safety:

- Lab aprons and safety glasses/goggles should be worn.
- The borax and the PVA will burn the eyes. Hands should be washed at the end of the lab.

Procedure:

Divide students into 5 groups. Assign each group one of the following "recipes":

Team	PVA	Sodium borate solution
1	50 mL	1 mL
2	50 mL	2 mL
3	50 mL	4 mL
4	50 mL	6 mL
5	50 mL	10 mL

1. Add PVA to paper cup.

2. Stir in food coloring if desired. (just a few drops)

3. Add sodium borate solution - stirring quickly making sure to scrape the sides and bottom using the wooden craft stick.

4. Pour entire contents of the cup into a plastic baggy and knead.

5. Take slime out of baggy and "investigate" properties.

6. Have groups compare properties of the different slimes:
    - bouncing
    - stretching slowly
    - stretching quickly
    - letting it "pour" from one hand to another
    - flow rate through a wide mouth funnel
    - etc......

Have the students record the appearance and characteristics of the PVA at each step. This method of doing the slime lab allows the students to work as teams and then causes the teams to interact to make comparisons. The students sometimes struggle to find the words to describe the slime in step #6 - encourage them to devise some sort of chart or graphic organizer to record their results/conclusions.

Notes:

By having different groups use different amounts of sodium borate solution, students should be able to more easily determine the effects of cross-linking on the properties of the polymer. The more sodium borate used, the more cross-linking that occurs. Each batch of slime is 96% water but they do not have the same viscosity. It should be emphasized that the students did not make polymer chains. The polymer chains are dissolved in the water in the PVA solution; they were already there. The sodium borate just "ties" the polymer chains together making it a more cohesive mass.

Polymer chains are formed by covalent bonds which are strong bonds. In making slime, individual polymer chains are "hooked" together by weak hydrogen bonds. It is evident that this cross-linking is weak because of the ease with which the slime pulls apart. It is sort of like "tying" together strong strands of string with limp strands of cooked spaghetti. Even though this cross-linking is weak, it does alter the properties of the polymer.

Have the students leave some of the slime stretched out on a counter overnight. The water will evaporate and the PVA will become a dry, brittle film that is mostly transparent. Also, pour some PVA solution that has **not** been cross-linked with borax on the counter. It will dry into a more flexible film much like the water soluble laundry bags used by hospitals. It is possible to mass a sample of each team's slime both before and after drying and calculate the percentage of water in each. This will provide evidence that each type of slime was indeed 96% water and that the difference in properties was not due to the amount of water but to the amount of cross-linking.

An observation that the students can make is how cool the slime feels. As the slime is stretched it has more surface area exposed to air and the evaporation rate of the water is increased. What they are feeling is the effect of evaporative cooling.

The PVA solution can be made using a stirrer hot plate. But it is much faster and easier to make it using a microwave oven. Do not let the solution boil whichever method you use. Boiling will alter the properties.

A beaker may be used to make the PVA solution. Add 4 grams of PVA powder to 96 mL of tap water and stir. The PVA will suspend briefly but will not dissolve until heated. To make larger amounts just multiply the amount of ingredients by the appropriate factor. Cover the beaker with microwaveable plastic wrap and stir between heating segments. Microwave for 2 - 3 minutes at a time depending on the amount of solution. Heat to 80°C. Microwave an additional minute at a time if needed. The prepared solution should be clear and somewhat viscous. The PVA solution will often still look slightly cloudy at this point but it will clear upon sitting. Do not heat above 80°C. The solution stores well in the refrigerator until needed.

The PVA solution is sticky. Have the students try to figure out a way to measure the required amount of PVA without putting it into a graduated cylinder. This is a quick, simple opportunity for them to problem solve. The students can measure 50 mL of water in a graduated cylinder, pour it into a cup, and then mark the fluid level. Pour out the water. Add PVA to the mark. Some students will usually figure this out for themselves. It really saves on clean-up. It is also helpful to store the PVA solution in PETE bottles (#1 recycling) with nipple-style caps. These are much easier to pour from and create less mess. Students often add too much food coloring. To avoid this problem, add the food coloring to the bottles of PVA solution prior to the lab.

GAK

An alternative to making PVA slime is to make gak. Gak uses Elmer's glue (either school glue or wood glue) which contains polyvinyl acetate instead of polyvinyl alcohol. The same principles apply and the same outcomes can be achieved. We do both labs for reinforcement. The gak is opaque whereas the slime is transparent; both can be dyed with food coloring. The gak will give more of a silly putty consistency.

With the PVA slime we have 5 different "recipes". With gak, we use 3 different "recipes" which are as follows:

#1
15 g glue
15 mL water
10 mL sodium borate solution

#2
15 g glue
30 mL water
10 mL sodium borate solution

#3
15 g glue
10 mL sodium borate solution

As in making slime, add food coloring to the glue and water before adding the sodium borate solution. The directions are basically the same for slime and gak. Have the students perform the same "tests" on the gak as they do on the slime.

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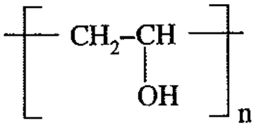
Polyvinyl Alcohol Activities

Catalog Nos.: P0209, P0210, P0211, P0203, P0153, P0154 Publication No.: 608.00C

Polyvinyl alcohol (PVA) is the world's largest volume, synthetic, water soluble plastic. PVA is nonhazardous and is used in many adhesives, films and elastomers. Its most popular use in schools is the preparation of "slime."

PVA is a polymer with a repeating vinyl alcohol unit and its molecular weight can range from 25,000 to 300,000 depending on its viscosity.



$$\left[-CH_2-\underset{OH}{\underset{|}{CH}}- \right]_n$$

Aqueous PVA solutions are relatively easy to make and two activities, *The Preparation of Slime* and *PVA Rope* are sure to be favorites with your students.

Preparation of a 4% Polyvinyl Alcohol Solution

There are two methods for preparing a 4% aqueous solution of polyvinyl alcohol, the conventional heating method and the microwave heating method. The microwave method is much easier. If you can find a microwave to use, your experience will be much more pleasant. Flinn Scientific also sells 4% polyvinyl alcohol solutions. Polyvinyl alcohol and its solutions are not considered toxic.

The 4% polyvinyl alcohol solution will last 6 to 8 weeks. (Flinn Scientific adds a preservative to its solutions). The solution will support bacterial growth and will act as a bacterial growth medium. You will be well served to keep your polyvinyl alcohol solution cool in a refrigerator if you wish to store it for a prolonged period of time. Distilled water is not required and not recommended. Polyvinyl alcohol solution made with distilled water will grow bacteria faster than polyvinyl alcohol solution made with tap water.

46-P 052695

Microwave Method:

Weigh 40 grams of polyvinyl alcohol into a 1-liter Pyrex® beaker. Fill the beaker to the 1 liter mark with hot tap water; stir. Cover with microwaveable plastic wrap. Microwave on high for about 3 minutes; stir and heat for an additional 3 minutes. Stir and heat for another 2 to 3 minutes. Repeat this process one more time, if necessary. Using short increments of time between stirring will produce the best results. Time will vary widely depending on the power of your microwave. With a clean spatula, remove the polyvinyl alcohol film lying on top of the solution. Allow the solution to cool before use.

Conventional Method:

It is not easy to make aqueous solutions of polyvinyl alcohol using the conventional method. Polymer behavior is tricky and preparing the solution requires patience.

Heat 1 liter of tap water to 88–90 °C (194 °F) or just under the boiling point of water. Once your water is heated, lightly sprinkle the polyvinyl alcohol into the water while stirring continuously (a magnetic stirrer/hot plate works beautifully to heat and stir the solution). It's important that the polyvinyl alcohol be added **lightly** and **slowly** since each grain of polyvinyl alcohol must be individually "wetted" for it to go into solution. For you cooks, it is a little like adding flour to your Thanksgiving Day gravy—you must not add the substance too rapidly. Remember, add the polyvinyl alcohol slowly while continuously stirring.

Failure to stir during the addition of the polyvinyl alcohol will result in a gooey mass of wet polymer that sticks together, settles out, clings to the wall of the vessel, and is, in general, less than cooperative with your efforts to bring it into solution.

Be careful to avoid overheating your solution. Why? Because overheating will cause water evaporation and a thick film will form on top of your solution. Secondly, very high heat may interfere with the hydrogen bonding interaction which is occurring between the polyvinyl alcohol and the water.

It will easily take 20 minutes to make the 1 liter solution, so please be patient. The completed polyvinyl alcohol solution should be clear, nearly colorless, and rather viscous (a semi-thick liquid).

You can get polyvinyl alcohol into solution without heating the water, but it takes absolutely too much time. You will be stirring and stirring for hours. We strongly recommend the use of heated water.

The Preparation of Slime

Slime your students with this fun but educational experiment. The preparation of slime is a popular activity done around Halloween or on the day before a vacation when students' minds may already be on vacation. This activity will surely be enjoyed by all. Slime is made from 4% aqueous solutions of polyvinyl alcohol and sodium borate.

Sodium borate ($Na_2B_4O_7 \cdot 10H_2O$), when dissolved in water, hydrolyzes to form a boric acid–borate ion with a pH of about 9.

$$\underset{\text{borate ion from sodium borate}}{B_4O_7^{-2}\,(aq)} + H_2O\,(1) \leftrightarrow \underset{\text{boric acid–borate ion}}{HB_4O_7^{-}\,(aq)} + OH^{-}\,(aq)$$

When the two solutions of polyvinyl alcohol and sodium borate are mixed, the borate ions ($B_4O_7^{-2}$) react with the hydroxyl (OH) groups of the polyvinyl alcohol. Weak crosslinking within the polymer occurs to produce the viscoelastic (viscous and elastic) gel. The high solubility in water suggests that extensive hydrogen bonding exists.

Materials Needed:

Polyvinyl alcohol, 4% solution (50 mL)

Sodium borate, 4% saturated solution, $Na_2B_4O_7 \cdot 10H_2O$ (5 mL)

- Disposable cup
- 10-mL Graduated cylinder
- Food coloring (optional)
- Wooden stick
- 50-mL Graduated cylinder

Procedure:

Place 50 mL of 4% polyvinyl alcohol solution into a disposable cup. Add a couple drops of food coloring, if desired, and stir with a wooden stick.

Pour 5 mL of saturated sodium borate solution (4%) into the cup while stirring (saturated sodium borate is about 4 g per 100 mL of water). The mixture will gel almost immediately but keep stirring until smooth.

To observe the properties of slime, knead it into a ball. Hold a small part of the ball and watch it stretch without breaking. Try stretching the slime quickly and see how it will break under these conditions. Slime will also pick up ink from paper. Have the students draw a picture or write their name backwards with a water soluble marker. Press the ball of slime onto the paper for only a split second. The design will be transfered to the slime. (The slime will stick to the paper if left on too long.)

Your slime will last two days to a week. Store it in an air tight, plastic sandwich bag. When the slime starts to mold, dispose of it in a waste container.

Safety Precautions:

Students should be warned not to ingest the material and to use it only for the purposes is intended.

Do not allow slime to remain on clothing, uphostery, carpet, or wood surfaces. The slime will stain the surface. Clean up any slime as soon as possible.

Cleanup and Disposal:

Slime, polyvinyl alcohol solution, cups, and wooden sticks may be placed in the trash. Leftover sodium borate solution may be rinsed down the drain.

References:

Shakhashiri, B. Z. *Chemical Demonstrations;* University of Wisconsin: Madison, WI, 1989; Vol. 3, p 326.

Polyvinyl Alcohol Rope

Ropes of polyvinyl alcohol can be produced from aqueous solutions of polyvinyl alcohol and acetone. Polyvinyl alcohol is soluble in water but insoluble in acetone. Layering acetone over a 4% solution of polyvinyl alcohol creates a white interface of fibers which can be pulled upwards through the acetone to produce a polyvinyl alcohol rope. This demonstration is similar to the nylon demonstration but it is less expensive and uses less hazardous materials.

Materials Needed:

- Polyvinyl alcohol, 4% solution (50 mL)
- Acetone (30 mL)
- 150-mL Beaker
- Tweezers or forceps
- Aluminum foil, ~30 × 30 cm
- Paper towels (optional)

48-P

ocedure:

1. Pour 50 mL of 4% polyvinyl alcohol solution into a 150-mL beaker.
   Optional: Add a drop or two of food coloring (green will be a big hit!) and stir.
2. Carefully pour 30 to 40 mL of acetone on top of the polyvinyl alcohol solution. It helps if the beaker containing polyvinyl alcohol is slightly tipped and the acetone is poured along the side of the beaker from another beaker or graduated cylinder. A white interface of polyvinyl alcohol will immediately appear between the two liquids.
3. Using a pair of tweezers or forceps, pick up the interface layer and slowly pull it straight upwards from the beaker. A strand of polyvinyl alcohol rope, 30 to 40 cm in length, can easily be pulled out. Longer strands are possible if after 30 to 40 cm, a second pair of tweezers (or gloved hand) pinches the polyvinyl alcohol rope near the solution and continues to pull. The first section of polyvinyl alcohol rope can then be doubled over.
4. More ropes can be pulled out of the polyvinyl alcohol solution. Slightly stirring the polyvinyl alcohol solution helps. The first rope is usually the longest and most impressive.
5. Lay the ropes out on paper towels or aluminum foil in a fume hood overnight to dry.
6. After drying overnight, additional demonstrations of polyvinyl alcohol as a polymer are possible. For example, polyvinyl alcohol is flexible but inelastic when dry; however, if dipped briefly in water, it becomes elastic.
7. Alternative demonstration: Squirting aqueous polyvinyl alcohol solutions into acetone precipitates polyvinyl alcohol as a fibrous mass. These fiber balls can be removed with forceps and dried overnight.

afety Precautions:

Acetone is flammable and a dangerous fire risk; toxic by ingestion and inhalation: a skin and eye irritant. Due to the amount of acetone used, adequate ventilation is necessary and a fume hood is recommended. Wear chemical splash goggles and chemical-resistant gloves.

Disposal:

The acetone can be poured off the polyvinyl alcohol solution and evaporated in a fume hood. For additional directions, see Flinn Suggested Disposal Method #18A. Consult your current Flinn Chemical Catalog Reference Manual. The aqueous solutions can be flushed down the drain with excess water.

Reference:

Sherman, M. C. *J. Chem. Ed.*, **1992,** *69,* 883.

Chemicals for polyvinyl alcohol activities are available from Flinn Scientific, Inc.:

Catalog No.	Description	Price/Each
A0009	Acetone, 500 mL	Consult Your Current *Flinn Chemical Catalog/Reference Manual*
P0209	Polyvinyl alcohol solution, 500 mL	
P0210	Polyvinyl alcohol solution, 1 L	
P0203	Polyvinyl alcohol, 25 g	
P0153	Polyvinyl alcohol, 100 g	
P0154	Polyvinyl alcohol, 500 g	
S0334	Sodium borate, tetra, 100 g	
V0003	Food coloring, set of 4	

49-P

Educational Innovations, Inc.

MELT-A-WAY HOT WATER SOLUBLE POLYVINYL ALCOHOL BAGS

Polyvinyl alcohol laundry bags are used in hospitals to minimize the contact hospital workers have with contaminated clothing and bedding. Dirty items are put into these special bags which are then placed directly into the washing machine. Because polyvinyl alcohol is soluble in hot water, the bags are washed down the drain with the dirty water. At the completion of the washing cycle, the clean cloths are removed from the washing machine.

Polyvinyl alcohol (PVOH or PVA) laundry bags can be dissolved in hot water to make a polyvinyl alcohol solution. When combined with a *sodium tetraborate* (Borax) solution, the polyvinyl alcohol polymer is cross-linked to form a viscous fluid more commonly called GAK™ or Slime! Simply dissolve 1 bag in about 16-18 fluid ounces of water to make the 4% polyvinyl alcohol solution necessary to make slime. Refer to the procedure below.

Materials

- Polyvinyl alcohol (PVOH) laundry bag
- Borax (Sodium tetraborate, available from your local supermarket)
- 2 containers for mixing
- Utensils for mixing
- Water (hot & cold)
- Food coloring (optional)

SLIME TIME!

1. In a small container dissolve one (1) PVOH bag in 16-18 ounces of hot water (the hotter the water, the faster the bag will dissolve). Do not, however, *cook* the PVOH solution. Mix with a stick or spoon until the PVOH is dissolved. Set aside and allow to cool to room temperature.
   Hints:
   a. *You can dissolve more than one bag at once if you use more water!*
   b. *A few drops of food coloring may be added at this point to give your slime some color.*
   c. *If your bag does not dissolve completely, your water was probably not hot enough. You may continue even if there are still a few undissolved lumps remaining.*

2. In another cup or bowl make a saturated solution of Borax. Combine a small amount of Borax powder from the supermarket with water and stir. To make the solution saturated, continue to add Borax powder until there is a little on the bottom of the container that will not dissolve.

3. To make slime add the Borax solution to the PVOH solution dropwise while stirring. Continue adding the Borax solution until the PVOH solution is no longer a liquid. Knowing just how much Borax solution to add is the trick to this experiment. If you add too little, your slime will contain excess PVOH and it will be sticky. If you add too much, your slime will be excessively wet.
   Hints:
   If your slime feels sticky, try adding a little more Borax solution, if your slime feels very wet and slippery, remove it from the container and kneed it. In a few minutes the excess Borax solution will be absorbed.

4. Your slime is made of polyvinyl alcohol and if you leave it exposed to air for a long time (a few hours) it will begin to dry. Therefore, when you are not using it, you should store it in a plastic bag (ziplock bags work great).

5. As with any science experiment, your slime should not be consumed! Do not taste it or eat it and do not leave it where a pet or young child might have access without supervision. (If your slime should become moldy, throw it away.)

EXPLANATION

Polyvinyl alcohol consists of very long chain-like molecules called polymers. PVOH is viscous (thick) because all of these are tangled together just like a pot full of spaghetti. When the Borax is added, the borax molecules (sodium tetraborate) connect many of the PVOH molecules together. The result is a new substance which is even more viscous and has the physical properties of both a solid and a liquid.

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Guidelines for Writing Glue-up Lab Report

1. **Include a title** – should identify the material being tested and the characteristic of the material being investigated. (Ex. "An Experiment to Find a Glue-up With a Flow-Rate of 10g/min. From a Standard 16oz. Water Bottle Opening"

2. **State the Problem** – give a question that you're trying to answer or identify the problem you're trying to solve with the experiment that you're doing.

3. **Hypothesis** – Stated in "If …… then ….. because" format. Include a logical reason for choosing one combination of components for making the glue-up, over other combinations – base this on other experiments and class discussion.

4. **Background Information** – provide a paragraph of background information for all key concepts and processes involved. Your background information should cover the following elements –

   - What is viscosity?
   - What materials are being used to make Glue-up and how is each involved in increasing or decreasing the Glue-up's viscosity?
   - Summarize the experimental approach. (don't list the procedures, instead give a general idea of what you are doing and why you are doing it)

5. **Materials** – List all materials used. Provide an illustration of the experimental setup labeling how it is used to determine flow rate.

6. **Procedures** – List the procedures in a set of steps in the order necessary to complete the lab. Procedures should be clear and thorough enough that someone could use them to reproduce the same experiment. Use concise language, but be thorough. Do not use personal pronouns (he, she, them, they, etc.). At the end of your procedures list the **Manipulated Variable, Responding Variable and Control Variables.**

7. **Observations and Data:** All data from experiments are to be recorded first in your lab notebook in an organized data table showing appropriate units. This also includes any observations you make during the lab. For your formal reports, data tables must be well organized, labeled and done on a computer spreadsheet or table, or with a ruler. All quantities must include units and reflect the greatest precision available for the instruments used (2.0 grams not 2 grams) using our digital scales. If your data are qualitative observations, make sure that you are not recording inferences. Your data table should not include calculations that you have made with your data. That should be included in the next section. Be sure to record at least 30 trials of your material.

8. **Calculations/Data Analysis:** Show all of your calculations (including percent error- see back of this sheet) and give a narration with each step. What are you doing and why? If a method of calculation is repeated for multiple trials, you do not need to duplicate the explanation of the problem solving method. However, work still needs to be shown for all calculations. For each calculation, show the set-up for your calculation, cancellation of units if appropriate, and units for the answer. Make sure your answers are recorded to the correct number of significant digits (figures), and are boxed or shown in a chart. You should calculate an average (show the work for this and follow significant digit rules) for experiments involving multiple trials.

ERROR CALCULATIONS: When it is appropriate, you should accurately evaluate the validity of the results by calculating either the percent error or the percent yield as described below. You should show the set-up and all the work for the calculation. This calculation should be done once for the average calculated for experiments with multiple trials.

$$\% \text{ error} = \frac{\text{experimental value} - \text{expected (actual) value}}{\text{the expected (actual) value}} \times 100$$

Percent error is used when you know what the value should have been and you want to compare your value to it. A negative value simply shows how many percent too low your value was.

9. Conclusion/Error Discussion: This is the section where you tie everything together. Use the following examples. The conclusion should be written out in paragraph form and should include the following parts. Use the ***italicized*** words as guides to begin your statements.

1. *The purpose of this experiment was to ...* (Check your purpose)
2. *To achieve this goal we ...* (Describe the experimental approach. Be very brief)
3. *My experiment showed that ...(your results here- cite specific data)*
   (Use data and/or calculations from your experiment to justify your conclusions)
4. *Factors that affected our results are ...* (What is the error? What affect does this error have on your data? See error analysis explanation below. Keep in mind you may have more that one error but NO "could of's" or "should of's")
5. *Our results could be improved if we ...* (Suggestions for improvement on the lab, better equipment is not a valid suggestion).
6. *I could take this experiment further by...* (What would you like to investigate more?).

Error Analysis:

Discuss what your group may have done and show how it specifically caused your results to be as they are. For example: The density of iron should be 7.86 g/cm^3. If during a density experiment, your group found the density of iron to be 8.91 g/cm^3 instead, discuss errors which would cause your density calculations to be too high. *Make it clear how each error would have driven the density to be a higher value.* It is not appropriate to say "we must have misread the graduated cylinder or measured wrong". If you did this, your group should repeat the experiment!

Miscellaneous:

Type your report. Double space between sections, single space within a section.
Use the headings listed above for each section.
Edit / Proof-read your work.
Always turn in a neat, well organized report – on time.

Peer Edit for Glue-up Lab

Name of Editor: ______________________________

Format: Each section is clearly labeled with bold type and/or larger font headings. Name, period and date are clearly indicated on the front page of the document.

1. Title: title indicates the material being worked on and the target flow rate

2. Statement of Problem: the problem statement is specific to the experiment with enough detail to identify the goal of the experiment.

If no, what seems to be missing from the problem statement?

3. Background:
All key terms are correctly defined

A list of materials is given and a description of the effect that each has on the flow characteristics of the material is provided with significant detail. Illustrations are provided that enhance the concepts of cross-linking between the Borax molecules and Glue polymer molecules.

A summary of the experimental approach is provided so that the reader has a clear understanding of the goal of the experiment.

4. Materials / Illustration: Materials are listed in one or more vertical lists

The list is specific: (ex. Amount of Borax Solution, Water and Glue are given)

The list is complete – if there are items listed in the procedures, but not in the materials – What are they?

Is an illustration included that adds to the understanding of the experimental design / set-up? Is this illustration labeled so that it is clear what is being shown?

5. Variables: Did the student include manipulated, responding and controlled variables, clearly labeled?

Are there variables that you feel are missing or misidentified?

6. Procedure: the procedure is written in 3rd person (no use of "I", "we", "you", etc.)

Put a check next to each item from the materials list as it appears in the procedure. Is there anything on the list that is not specifically mentioned in the procedure? If yes – identify.

The procedure is extremely detailed and it is very clear exactly how to carry out each step.

Identify steps that are not detailed enough, or are confusing to you.

7. Observations and Data:
The student has included detailed observations for the experiment.

Each piece of data is clearly labeled as to what it represents.

The data is organized in a table showing appropriate units and precision (correct number of decimal places).

Only RAW data is included in the data table (no calculated or derived quantities).

8. Calculations / Data Analysis:
For each of the calculations, did the student **give a narration** (not just a label) explaining what they are doing and why?

Use your calculator to compute all of their calculations. Identify any mistakes that you find.

For each calculation, did the student show the set-up for their calculation? (i.e. equation for percent error)

Units are included, not just in the answers, but in each number used in the calculation (when appropriate). Cancellation of units is shown when appropriate.

The answer is shown using the correct number of significant digits (figures).

Identify any calculations that are missing.

9. Conclusions / Error Discussion
The student has reiterated the purpose of the experiment.

The student has described the experimental approach used to solve the problem (they have not given a step-by-step rehash of their procedure).

The student has shared their results using their calculations to justify their conclulsions.

The student has identified potential sources of error.
Examples:

For each source of error identified, the student has described specifically how the error(s) would have influenced the results. (Would it have increased or decreased the percent error, and WHY?) Very Important!

Is the connection between error and the affect on the results clear and well-explained?

The student has offered suggestions for improvement of experimental design.
Example(s):

The student has identified unanswered questions or suggestions for future research.

55-P

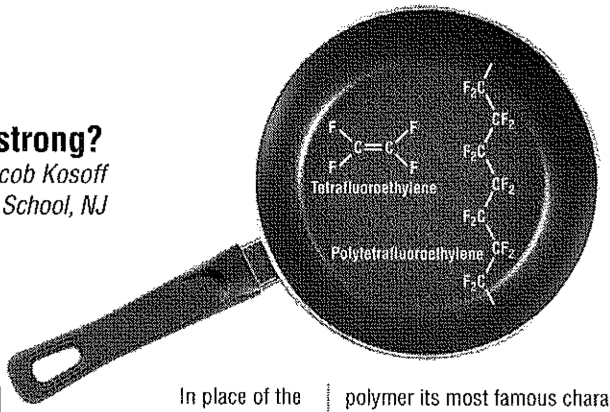
9 F Fluorine

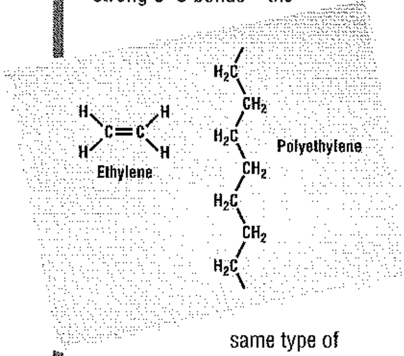
As a Matter of Fact

By Robert Becker

Q. Why is Teflon® so strong?

Jacob Kosoff
Burlington Township High School, NJ





A. The secret to Teflon's strength lies within its highly stable covalent bonds. A polymer, Teflon contains long chains of strong C–C bonds—the same type of covalent bonds that makes a diamond so tough. But the story gets a bit more complicated. Polyethylene is another polymer containing long carbon chains, and, surprisingly, it's almost as strong as Teflon. When we think about the number of uses for polymers, we usually associate polythylene with plastic bags and Teflon with the surface of sturdy frying pans.

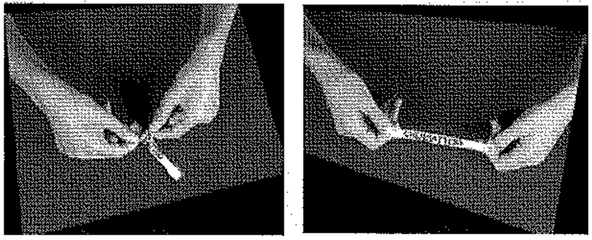
Let's look at the two polymers and compare another one of their properties. Polyethylene, as the name implies, is polymerized from ethylene, and Teflon is polymerized from tetrafluoroethylene. In place of the C–H bonds in polyethylene, Teflon's carbon chains are surrounded by a coating of much stronger C–F bonds. This C–F coating makes Teflon very resistant to chemical attack, even at high temperatures, and it gives the polymer its most famous characteristic—its capacity to resist forming bonds with other compounds. In fact, *The Guiness Book of World Records* lists Teflon as the slipperiest material in the world! This property makes Teflon—not the more reactive polyethylene—ideally suited for nonstick coatings on cookware.

If nothing sticks to Teflon, how can Teflon stick to a pan? DuPont uses a technique called stratification in which various coatings are applied to the metal and baked at around 420 °C for a set period of time. At this high temperature, the binders attach themselves to the pan, and the fluoropolymers rise to the top. The result is a nonstick surface that stays in place. ▲

TRY THIS! TRY THIS! TRY THIS! TRY THIS!

Plumbers are familiar with a product known as Teflon tape (PTFE tape, available in most hardware stores). It is used to make a water-tight seal between threaded iron pipes.

1. **Cut a 15- to 20-cm length of this tape and try stretching it just a little bit lengthwise. Make sure you have a firm grip of the entire ends, not just the corners. What do you observe?**
2. **Now try to stretch it just a little bit widthwise (not too far). What do you observe?**
3. **Try to stretch it again lengthwise. (Repeat steps 2 & 3, if you like.)**
4. **Next, try to break it slowly lengthwise. Use as much force as you need.**
5. **Now try to break it slowly widthwise. Use as much force as you need. What do you observe?**
6. **Now for some fun! Cut a new length of Teflon tape and use a permanent marker to write a secret message on the tape. It is a little tricky to keep the tape from bunching up; it helps to have a partner hold it taut while you write on it very lightly. When the message is finished, fold a small piece of clear tape around each end as shown.**



7. **Stretch the tape widthwise in a few places to distort the message beyond recognition. (Careful not to stretch it too far!)**
8. **Hand it to a friend, and have that person pull the two ends apart to unscramble the distorted message. See what happens. Redistort the message and try it again.**
9. **Think about the properties of Teflon tape that allowed you to do this activity. Does it work with other kinds of flexible tapes?**

PHOTOS BY MIKE CIESIELSKI

CHEMMATTERS
1155 Sixteenth Street, NW
Washington, DC 20036-4800

Reach Us on the Web at:
www.acs.org/education/curriculum/chemmatt.html

Polymer Stations

1. **Latex Ball** - directions on handout in notebook - page 59-P. Please do not use graduated cylinders to measure out latex.

2. **Expandable Polyurethane Foam** - Rigid and Flexible - directions in notebook on page 60-P and in the Battelle Handbook page 7.7

Rigid Foam - Blue Cans

- Equal parts A and B by mass - measure out into separate cups.
- May add food coloring to one of the cups.
- Combine and stir for approximately 50 seconds while scraping the sides and bottom. Allow to set-up. Do NOT touch while still tacky.
- Use Fantastic or acetone to clean up any spills or messes.

Flexible Foam - Pink Cans

- 1 Part A to 3 parts B by mass - measure out into separate cups.
- May add food coloring to one of the cups.
- Combine and mix for approximately 10 seconds while scraping the sides and bottom. Allow to set-up. Do NOT touch while still tacky.
- Use Fantastic or acetone to clean up any spills or messes.

3. **Expanded Polystyrene Beads**
   - Spray mold with release agent - Camie 980.
   - Measure out approximately 60 grams of beads for the football mold or 22 grams for the die mold.
   - Add coloring (powder) if desired.
   - Place in boiling water for 30-35 minutes. Turn at least once during heating.
   - Quench to cool.

4. **Polyurethane Resin Cast (Eurocast) -** Battelle Handbook page 7.18 **BUT** follow the directions below for the clip mold. Also in the notebook on page 61-P.
   - Measure out 2 ½ fluid ounces of Part A and 2 ½ fluid ounces of Part B into separate cups. (18 drams of each will also work and has less waste.)
   - Add a couple of drops of dye to each cup.
   - Pour both into a larger cup and stir for 30 seconds. Mix thoroughly!!
   - Fill molds to edge but do not let run over.
   - Let sit for 10 minutes or until cool and remove from mold.
   - Rough edges may be sanded or filed.
   - Carefully assemble with spring.

5. **Polydensity Tubes** – directions on handout in notebook – page 62-P. Use the shortened version.

6. **Shrinking and Expanding Plastics**
   - Use toaster oven to shrink polystyrene (#6 recycling code) - handout in notebook – Shrink to Fit – page 69-P.
   - Use heat gun to soften the sides of a HDPE container (#2 recycling code) until almost transparent and "wobbly". Gently blow into opening.
   - Use heat gun to shrink a PETE bottle (#1 recycling code).

Latex Rubber Ball

Wear safety goggles and lab apron.

1. Measure 15 mL of latex into a paper cup. (Do not pout latex into a graduated cylinder.)
2. Feel texture of latex. Immediately wash your hands.
3. Add 15 mL of water to cup. Stir
4. Add 15 mL of vinegar to the cup while stirring.
5. Place the polymer lump under running water.
6. Gently pull the lump of rubber from the stick. Squeeze the lump into a ball while under water. Squeeze the ball several times to remove unused or trapped chemical.
7. Squeeze the ball dry in paper towels.
8. Record observations.

You can order latex from either Flinn Scientific or IASCO. The IASCO website is: http://www.iasco-tesco.com/cat55/index.htm

This lab demonstrates a natural polymer and the formation of an elastomer.

http://www.gloves.com.my/vulcanization.htm

Comparing Rigid and Flexible Urethane Foam

Purpose: To gain an understanding of the preparation and properties of two types of Urethane Foam

Part 1 - Preparing Rigid Urethane Foam

Materials - Rigid Urethane Foam

Molding Foam (Urethane) - "Blue" - Parts A and B
Small Paper Cups (2)
Craft Stick
Balance

Procedures:

1. Set balance to read zero when paper cup is placed on it.
2. Measure out 10 grams of Part A into cup and set this aside.
3. Place a second paper cup on the balance and set balance to read zero.
4. Place 10 grams of Part B into cup.
5. Mix Part A into Part B - total mixing time should be about 30 seconds.
6. Let the mixture sit and allow foam to form.

Observation / Analysis Questions: (Answer these questions in your journal in complete sentences)

1. Record observations after about 3 minutes. What does it look like? Feel like? Smell like?
2. How has the mixture changed? Describe the characteristics of the material that was made, before and after the reaction.
3. What applications do you see this product being used for? For example, do you think it's an insulator or a conductor?

Part 2 - Preparing Flexible Urethane Foam

Materials - Flexible Urethane Foam

Flexible Urethane Foam - "Pink" - Parts A and B
Small Paper Cups (2)
Craft Stick
Balance

Procedures:

1\. Set balance to read zero when paper cup is placed on it.
2\. Measure out 5 grams of Part A into cup and set this aside.
4\. Place a second paper cup on the balance and set balance to read zero.
5\. Place 15 grams of Part B into cup.
6\. Mix Part A into Part B - total mixing time should be about 30 seconds.
7\. Let the mixture sit and allow foam to form.

Observation / Analysis Questions: (Answer these questions in your journal in complete sentences)

1. Record observations after about 3 minutes. What does it look like? Feel like? Smell like?
2. How has the mixture changed? Describe the characteristics of the material that was made, before and after the reaction.
3. What applications do you see this product being used for? For example, do you think it's an insulator or a conductor?

Final Analysis: (Answer this question in your journal using a complete sentence)

Compare and contrast the two types of Urethane foam. How are they similar? How are they different?

Polyurethane Resin Cast
(Eurocast - Clip Mold)

1. Measure out 2 fluid ounces of Part A and 2 fluid ounces of Part B into separate cups. (Or 18 drams of each to make sure the mold is filled.)
2. Add several drops of dye to each cup.
3. Pour both parts into a larger cup and stir for 30 seconds.
4. Fill molds to edge but do not let run over.
5. Let sit for 10 minutes or until cool enough to handle and remove from mold.
6. Rough edges may be sanded, filed, or trimmed with a razor blade.
7. Carefully assemble with spring.

Website with ordering information and complete directions:

http://www.iasco-tesco.com/cat55/index.htm - page 83

List of websites with background information on different types of polyurethanes:

http://www.azom.com/details.asp?ArticleID=218

http://www.csuchico.edu/~jpgreene/m247/m247_ch02/

http://chem-eng.utoronto.ca/~woodhouse/PUchemistry.htm

http://www.polyurethane.org/s_api/index.asp

http://www.epoxyproducts.com/chemistry.html

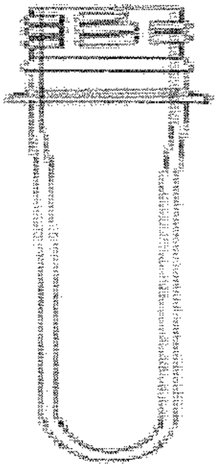
POLYDENSITY TUBES®:

Serious fun with a dense subject

→START HERE: Your "tube" already has two kinds of plastic pellets.
One color is pieces of POLYETHYLENE TEREPHTHLATE [PET] recycle code #1.
The other color is POLYPROPYLENE [PP] recycle code #5, or LOW DENSITY POLYETHLYENE, [LDPE] #4, or HIGH DENSITY POLYETHYLENE [HDPE] #2.

NOW, DO THIS:

1. Pour in rubbing alcohol until the preform is just over HALF full.
   Cap and shake the mixture.



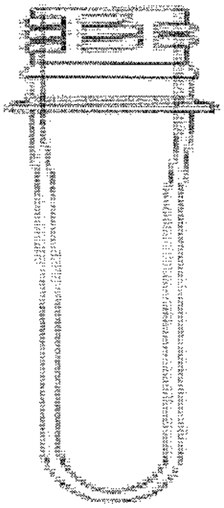
2. Stop shaking, observe, sketch, speculate . . .

least dense component ________________

middle density component ________________

most dense component ________________

3. Add water until the preform is >3/4 full.
   Shake, Observe. Sketch. . .



least dense component ________________

middle density component ________________

most dense component ________________

Use the information on the back to come up with an explanation.
AFTER you've finished this page, get the next page. .

Household plastics, from least dense to most dense:

Recycle code	Density in g/mL	Symbol	Name
isopropyl alcohol	0.86	C_3H_7OH	2-propanol
rubbing alcohol	0.88	water in alcohol	70% isopropyl alcohol
5	0.90-0.91	PP	polypropylene
corn oil	0.92-0.93		Not a plastic
4	0.92-0.94	LDPE	low density polyethylene
2	0.95-0.97	HDPE	high density polyethylene
water	1.00	H_2O	Not a plastic
6	1.05-1.07	PS	polystyrene
salt water	~1.2	NaCl(aq)	saturated salt solution
3	1.16-1.35	PVC	polyvinyl chloride [in film form]
1	1.38-1.39	PET(E)	polyethylene terephthalate

I---------“Floaters”-----------I I-------”Sinkers”-------I

5PP-4LDPE-2HDPE—water---6PS-3PVC-1PET

Thanks to AMCOR for preforms and PET pellets and to EQUISTAR for PP and PE pellets.

63-P

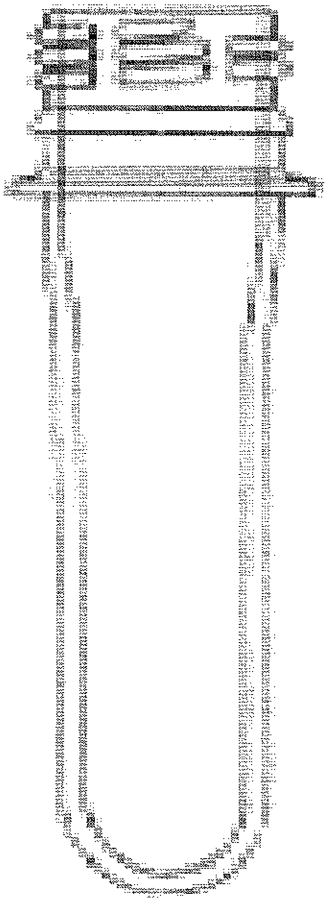
POLYDENSITY TUBES®:

Serious fun with a dense subject

NOW, THE FUN PART . . .

4. Measure about 5 g (1 teaspoon) of canning salt.
    Pour ALL of it into the preform. Cap and shake.
        Shake some more.
            And more. It may take several minutes to dissolve.

5. Observe . . . Keep watching . . .Patience



6. SKETCH the layers you see.

least dense component __________ (l)

middle density components _______ (s)

and ______________ (l)

most dense component __________ (s)

HEY, how come those plastics are "floating" in the middle?

HYPOTHESIZE <u>before</u> you look at the explanation on the back.

64-P

HERE'S WHY: Propanol (Rubbing alcohol is 70% propanol in water.) dissolves easily in water. Because of "hydrogen bonding" between the very polar water molecules and the somewhat polar 2-propanol molecules, the alcohol is soluble in water in all proportions. Propanol and water are "miscible" in each other.

HOWEVER, 2-propanol is NOT soluble in a NaCl solution.

WHY? Salt, sodium chloride, is an ionic compound. In water, it dissociates into sodium cations + and chloride anions ---.

These ions are strongly attracted to the oppositely charged regions of the polar water molecule: MORE STRONGLY attracted than the alcohol molecules are.

SO, those --chloride ions and +sodium ions sort of "elbow" the alcohol molecules: They push and shove them out of the way.

IN OTHER WORDS, when you add salt to the mixture, the propanol and salt water no longer dissolve in each other. They are "immiscible", and separate into two layers.

The alcohol is less dense than the salt solution, so the alcohol will float on top of the salt-water.

Solids, such as HDPE, LDPE, PP, and PS, which are less dense than salt-water, but more dense than propanol, will float BETWEEN the alcohol and the salt solution.

Because both the liquids are colorless, the interface is difficult to see. It appears that the plastic pieces are "flinking" in the middle of a test tube full of water. BUT THEY AREN'T: Look carefully and you can see a faint white cloudiness at the interface where the alcohol and salt-water meet.

☺ ✈ ❀ ✈ ☺ ☻ ☺ ❀ ✎ ✈ ☺ ☹ ☻ ✎ ✈ ☺ ❀

THANK YOU to Barbara Walker and to Dr Chang of Iowa State for the explanation of the "salting out" of alcohol by salt. It's a technique used by generations of biochemists. .

POLYDENSITY TUBES®

TEACHER NOTES

I can't tell you strongly enough to try this with the EXACT components you plan to use. You may be the person to find a polypropylene which floats in propanol. Or some other plastic which doesn't do what you expected.

Use pellets from a Hands on Plastic kit which can be orderd free of charge or obligation from the American Plastics Council website at http://www.teachingplastics.org. OR, Try various kinds of plastic beads from a craft store. I've had interesting results with the "pony" style beads. Also try the ultraviolet detecting beads from **Educational Innovations. http//www.teachersource.com** OR, Punch circles or cut small chips from plastic bottles, containers and lids until you have a good mix of pieces of plastic.

The clear plastic "preforms" can be bought at **Educational Innovations**, or ask a local soft-drink bottler.

Try coloring the liquid layers with various dyes, stains and food colors. Most McCormick® food colors will tint both layers. Except for yellow food coloring, which tints mostly the water layer. Fluorescein does the same. To tint the alcohol layer, I've had good luck with liquid Yaley® brand candle dyes from a large craft store or http://www.yaley.com/candles/candle_dye.html

EARTH SCIENCE students can model the five major layers of the earth.

CRUST==cut out crustal plates from styrofoam food trays
UPPER MANTLE == 2-propanol
LOWER MANTLE == small pieces of HDPE, LDPE, PS or PP
OUTER CORE == salt-water layer, tinted brown with tea
INNER CORE == dark sand

SEVEN LAYER BOTTLE
Many cooking oils have a density between that of the alcohol and the salt-water layers. By choosing plastics with the appropriate density, you can create a POLYDENSITY bottle with seven layers. The oil and alcohol are very close in density and in polarity. They may take from an hour to a week to separate.

***Discourage observers from shaking this bottle*.**

For example, try;

styrofoam pieces
rubbing alcohol
polypropylene pieces
Mazola corn oil
LDPE or HDPE pellets
saturated salt water
PETE pieces or pellets

I recommend that you begin by mixing just water, alcohol, and salt. Shake it up and allow those two layers to separate.

NEXT, add the pieces of different plastics.

LAST, gently add the Mazola

ENJOY !

(A “less inquiry” version)

POLYDENSITY TUBES®

1. Fill the “tube” about 1/4 full of various plastic pieces.
2. Pour in rubbing alcohol to just over half full. Swirl.
3. Observe, sketch: Note which solids float or sink.
4. Add water until the tube is a little over 3/4 full.
5. Put on the lid and shake the tube.
6. Observe, sketch, speculate . . .
7. Remove lid and add about 5 g (1tsp) of salt.
8. Put on lid and shake the tube, LOTS. It might take a minute for most of the salt to dissolve.
9. Keep watching . . . Keep on watching.

10 Observe, diagram, hypothesize . . .

WHAT’S HAPPENING? This method of separating propanol and water is known as “salting out”. The sodium and chloride ions from salt interfere with the hydrogen bonding between the alcohol and water molecules. Bonding between ions from salt and water is stronger and more favorable than the hydrogen bonding between alcohol and water. As a student observed, “Water will rather hang with the salt ions than with the alcohol.”

TEACHER NOTES for POLYDENSITY TUBES®

The clear plastic "preforms" can be purchased at **Educational Innovations at 1.888.912.7474 or http//www.teachersource.com**

Pellets are from a Hands On Plastics® kit which can be ordered free of charge at the American Plastics Council website at http://www.teachingplastics.org/hands_on_plastics/order/index.asp.

OR, Punch circles or cut small chips from plastic bottles, containers and lids until you have a good mix of pieces of plastic.

OR, Try various kinds and sizes of plastic beads from a craft store. Also try the ultraviolet detecting beads from **Educational Innovations. http//www.teachersource.com**

Kosher salt or canning salt and distilled water can be found in most large supermarkets. [Regular table salt has additives that cause the water layer to be cloudy.]

PROCEDURE:
Fill the preform less than a quarter full of plastic pieces.
Add rubbing alcohol to just over the half full point.
Then add water until the container is barely over 3/4 full.
Start with a teaspoon of salt. Add. Cap the container and shake.
It may take several minutes for the salt to dissolve.
For larger containers, add more salt. You need a saturated salt solution.
There should be just a little bit of undissolved salt at the bottom.

Shrink To Fit
(Polystyrene)

This is used as a two day lab. The first day, the students experiment in groups with percent reduction of polystyrene using different geometric shapes. Next they design individual projects and calculate what the preheated dimensions need to be using what they learned the first day.

Materials:

- scissors
- rulers
- balance
- permanent markers
- polystyrene - PS - (recyclable #6) plastic: salad trays, bakery boxes, etc.
- tray covered with aluminum foil
- spatula
- toaster oven
- pot holder
- hole punch
- two ceramic tiles (optional)

Advance Preparation:

- Collect enough items made of recyclable plastic #6 for each student to have one.
- Preheat the toaster oven to approximately 300° F. (Will vary from oven to oven.)

Activity:

1. Draw the following geometric shapes on the board: circle, square, rectangle, triangle, and a rhombus. Have the students provide the formulas for calculating the area of each shape. Divide the students into 5 teams and assign each team one of the shapes. Each team is to cut out the largest shape possible from their piece of plastic. They are to measure the dimensions, calculate the area, and find the mass of their geometric shape and record all data on the board for all students to copy into their journals. Students should make observations about the plastic in their journals (color, thickness, rigidity, etc.).

2. Shrink each shape using the preheated toaster oven. Place the piece of polystyrene on an aluminum foil covered tray and place it in the oven. It should take about a minute. It will sometimes curl up as it heats. Once it has uncurled, it can be removed from the oven. Watch it carefully. Sometimes it will curl up and "stick" to itself. You can usually "undo" it by manipulating it with forks if it doesn't harden too quickly. Use the spatula to flatten it while it is still hot if still slightly curled. Pressing the piece between two ceramic tiles works very well.

3. Have the students measure the dimensions, calculate the area, and measure the mass of their geometric shapes again. They should record the "after heating" data on the board for all students to copy into their journals. Once again, have them make observations about the plastic in their journals.

4. Have students calculate the percent reduction and the percentage of plastic area remaining.

5. On the second day, the students design individual projects (key chains, pendants, earrings, Christmas ornaments, luggage tags, etc.). They draw the design in their journals showing the dimensions they wish their final project to have. Using the information gathered in the team activity, they determine what the original dimensions of their plastic will need to be. Have them make the object and compare the size of the completed project with their original drawing. Permanent markers may be used to add color and create designs. A hole punch can be used to make key chains luggage tags. Hint: You might want to demonstrate this for them. One punch shrinks too much to fit most key rings so usually multiple over-lapping punches are needed. Be sure to punch the holes before the shrinking process.

Concepts:
The plastic used in this activity (polystyrene) is easy to work with when heated. While hot, polystyrene can be stretched into any shape required. Normally, the polymer chains in a piece of polystyrene are jumbled together in an almost random way (think of wet spaghetti noodles dumped on a plate). When heated, the strands can be stretched into a more ordered pattern and "frozen" in place. If the polystyrene is reheated, it returns to its original shape (a type of "memory polymer".) A plastic that softens upon heating and can be reshaped is known as a thermoplastic. Thermoplastics can be melted or softened to make new products and thus are recyclable. They include polyethylene, polypropylene, polyvinyl chloride (PVC), and polystyrene (PS). Products and packaging made from one of these thermoplastics are stamped with the recycling symbol - a triangle of arrows with a number (1 - 7) inside.

Polystyrene is not the only plastic that behaves this way with heat. Soda bottles are also made from plastic with similar qualities (recyclable #1 - PETE). Soda bottles are transported as "pre-forms". A pre-form is a rigid piece of plastic the size and shape of a large test tube. When it gets to the bottling plant, it is heated and expanded by blow molding into the desired size.

High density polyethylene (HDPE) bottles help to demonstrate the concept of thermoplastics. HDPE is recyclable #2. Sunny Delight bottles and half gallon or one gallon juice, milk, and distilled water jugs are usually #2. Heat the side of a clean #2 bottle with a heat gun until it softens and becomes more transparent. Then gently blow into the opening and watch it expand. It is a simplified demonstration of blow-molding.

This activity can help illustrate the Law of Conservation of Matter (mass).

Comments:
Students may also measure thickness (both before and after heating) with calipers. This will allow them to calculate the percent change in thickness and also compare volumes. More math calculations!!!!!!

This activity was performed after comparing the solubility of natural (starch) and synthetic (foamed polystyrene) packing materials in water and acetone. Thus the monomer and formation of polystyrene had already discussed. Also, a burn test was done on both foamed and non-foamed PS. Of course the students wanted to try shrinking a Styrofoam cup. It works very well. The kids are amazed by how hard and brittle it becomes. (Have plenty of cups on hand because they will want to try it more than once - right-side-up, up-side-down, on its side, etc.). The clear polystyrene drinking cups found in some motel rooms also work well. They shrink into nice little Frisbees. Dollar stores often have packages of 5 oz. drinking cups made out of polystyrene. They shrink into flat circles and are very inexpensive. They make great backpack tags, luggage tags, etc.

Have plenty of PS collected because the students will end up wanting to make more than one project. They love watching it shrink - they describe it as "looking like slugs when you pour salt on them".

On the average, between 80% and 90% reduction in area occurs.

If the students make key chains, the holes need to be large and away from the edge. Otherwise they will not be big enough or they will break from the weight of the keys.

The students love this activity (despite all the math calculations) and don't want to stop. It is a great activity to do at the end of school or before a holiday. Not a single problem with discipline or keeping the students on task (other than fighting over the PS if the supply runs low).

Websites where sheets of polystyrene can be purchased:

http://www.unitednow.com/detail.asp?PRODUCT_ID=GAS-13682
http://www.dickblick.com/zz614/12/products.asp?ig_id=6829
http://www.ellison.com/shop/?p=product_detail&itemnum=17912
http://www.misterart.com/store/view/003/group_id/7371/GRAFIX-Shrink-Film.htm

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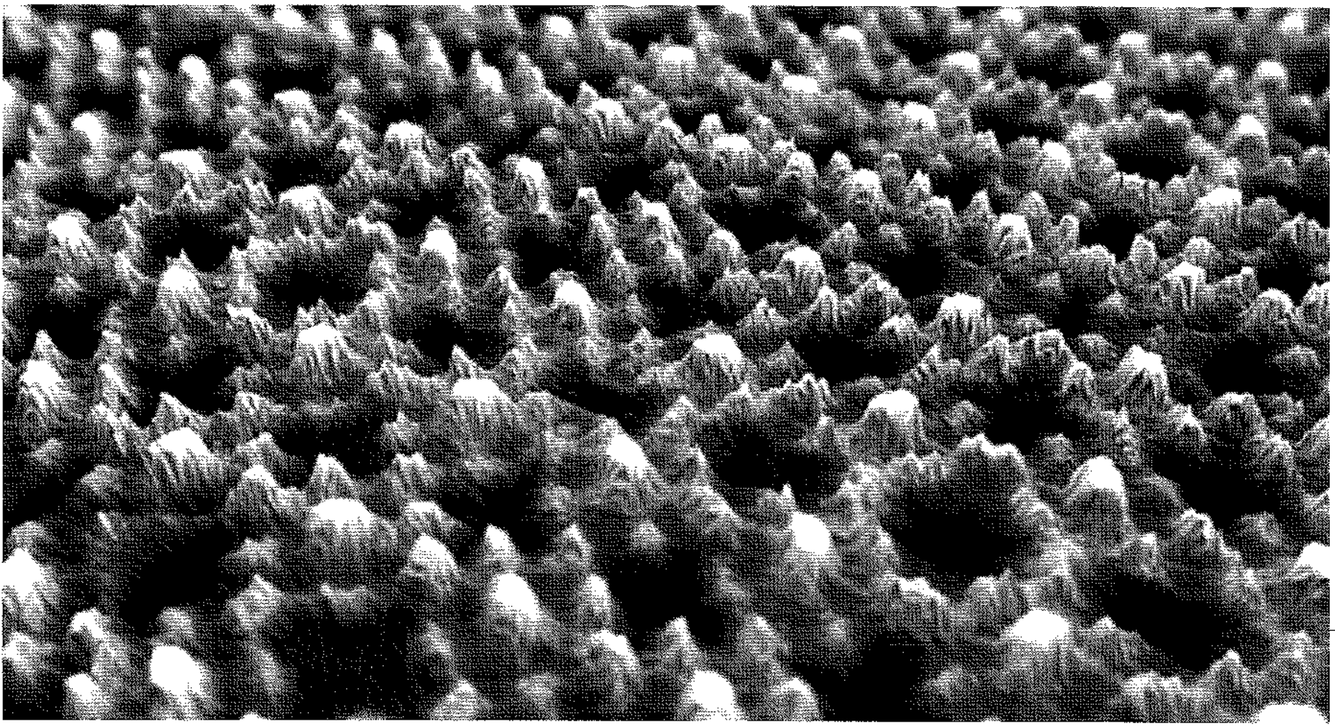
POLYMER
AMBASSADORS

Biomimetic Nanotechnology

Researchers mimic biology to form nanoscale devices

by Eric J. Lerner



Center for Nanobiotechnology, University of Natural Resources and Applied Life Sciences, Vienna, Austria/Friedrich Schiller

Figure 1. Scanning-force-microscope surface-relief reconstruction of a crystalline protein S-layer from *Bacillus sphaericus* CCM2177 with a center-to-center spacing of 13.1 nm.

Nanotechnology involves the creation and manipulation of complex structures on the scale of nanometers—something organisms have done for about 3.8 billion years. Using DNA, RNA, and a huge variety of proteins, living cells build complex molecules and nanoscale organelles, and create nonliving materials, such as tooth enamel, with nanoscale structures. So it is logical for nanotechnologists to seek to duplicate organisms' own techniques to try to create new nanomachines from the bottom up.

Although biomimetic nanotechnology is in its infancy, with no applications yet reaching commercialization, the barriers in some cases lie mainly in scaling up production processes to industrial levels. In others, researchers must make significant basic breakthroughs to bridge the gap between laboratory experiments and usefulness.

Imitating nature

Researchers are exploring several ways to imitate biology at the submicrometer level. One approach tries to inorganically duplicate biological materials that have extraordinary properties. A recent successful example of this comes from a study of geckos at the University of Manchester's Centre for Mesoscience and Nanotechnology in England. The little lizards have a remarkable ability to cling to almost any surface, no matter how smooth, even when they are upside down (Figure 2).

To imitate nature, one must first understand it. Not until 2000 did researchers determine that the gecko's sticking abilities stemmed from the 200-nm-wide keratin hairs that coated the soles of their feet. Capillary forces cause hairs with that diameter to stick to films of water or wet surfaces. Equally strong van der Waals forces enable them to attach to dry surfaces as well. Each hair exerts only 10^{-7} N of force, but they are densely packed enough to collectively have an adhesive force of 10 N/cm^2—enough to suspend a 100-kg mass from a patch 10 cm on each side.

Inspired by these findings, the Manchester team attempted to reproduce the gecko hairs as an array of plastic fibers. These rigid fibers, however, did not work because only a few of them would make contact with an uneven surface, and the fibers lacked sufficient strength to resist breaking when the adhesive was pulled away from the surface. So the team tried a polyimide plastic film and patterned the fibers using electron beam lithography.

They found that if the fibers were too close together, they stuck to each other, which reduced their stickiness to the surface. The optimum geometry proved to be a spacing of 1.6 μm, a diameter of 500 nm, and a length of 2 μm. With a flexible backing applied to the fibers—so that they could more easily accommodate irregular surfaces—the team achieved an adhesion of 3 N/cm^2, almost 30% that of the real gecko. This adhesion strength would be sufficient to suspend a man with just adhesive gloves covering his palms.

Although the experimental version of gecko tape lasted through several cycles of attachment and detachment, the team contemplates making future versions based on hydrophobic materials, such as the gecko's keratin. In concept, these materials would not stick to each other and would last longer. Of course, researchers must develop less expensive techniques than electron lithography to mass-produce such tape.

Building with proteins

Dropping in scale from hundreds of nanometers to 10 nm brings researchers to the realm of large molecules. Organisms build structures with proteins, so a second major biomimetic approach uses natural or newly designed proteins to create nanostructures. For one thing, natural proteins can form repetitive, crystalline structures to serve as substrates for arrays of nanomachines or for nanoelectronics.

Bacteria form a one-molecule-thick layer of crystalline proteins on their exteriors, called S-layers, which repeat on a 10-nm crystalline grid. A number of groups, including Uwe Sleytr and colleagues at the Center for Nanobiotechnology, University of Natural Resources and Applied Life Sciences, in Vienna, Austria, seek to use bacterial S-layers as superstructures for artificial arrays. This effort involves first chemically removing the S-layer from the bacteria and breaking it up into individual molecular subunits. The subunits, when placed in solution, reassemble into ordered arrays on solid supports, such as silicon wafers, metal electrodes, or synthetic polymers (Figure 1).

Once an S-layer attaches to a substrate, specific sensor molecules can be attached to the molecular array to form a bioanalytical sensor. For example, Sleytr's group made a glucose sensor by binding glucose oxidase molecules to the S-layer and measuring the current passing through the electrodes as the oxidase reacted with the glucose.

Another application under development uses S-layers as photoresists in conventional lithography. Exposure to UV light destroys the S-layer proteins in the same way that exposure to radiation changes a conventional photoresist. However, S-layers are only 5–10 nm thick, much thinner than conventional photoresists, which makes possible the replication of narrower features.

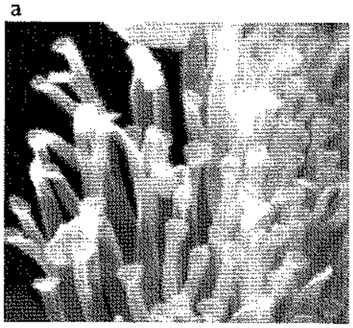
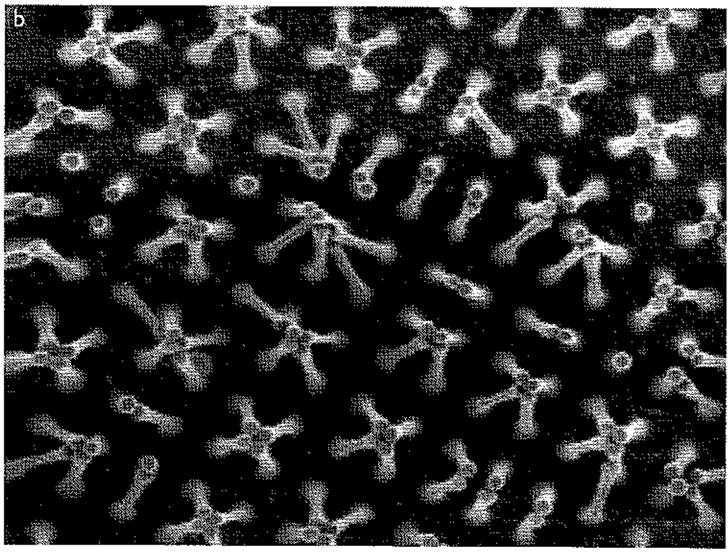


Figure 2. Geckos can cling even to smooth surfaces when upside down because of capillary and van der Waals forces between the surface and densely packed 200-nm-wide keratin hairs on the soles of their feet (a). Fibers patterned with electron beam lithography from a plastic film (b) achieved an adhesion almost 30% as good.



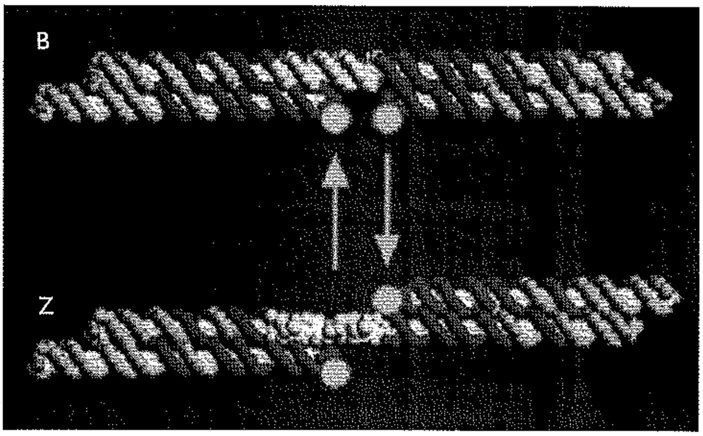
Centre for Mesoscience and Nanotechnology, University of Manchester, U.K.

Binding proteins

Other researchers are experimenting with proteins in a far more complex way—using their ability to specifically bind with each other and with inorganic materials as a way to build new materials. One of the characteristics of biologically produced nonliving materials, such as abalone shell and spider silk, is a hierarchical structure. That is, structures exist not just at the macroscopic level and the crystalline level, but at many scales in between. This structuring often imparts remarkable characteristics to a material, such as silk's great strength. If researchers can design appropriate new proteins, they could be used to produce similarly complex artificial materials in an industrial process.

However, scientists as yet cannot predict the shape of proteins or their binding properties just from the sequences of their constituent amino acids, because protein-folding simulations have not advanced that far. An alternative approach selects proteins with the desired binding properties from a large number of randomly generated molecules. This can be done by the genetic engineering of bacteriophage viruses—viruses that infect bacteria—an approach pioneered by Angela M. Belcher, associate professor of materials science at the Massachusetts Institute of Technology (MIT), and other researchers.

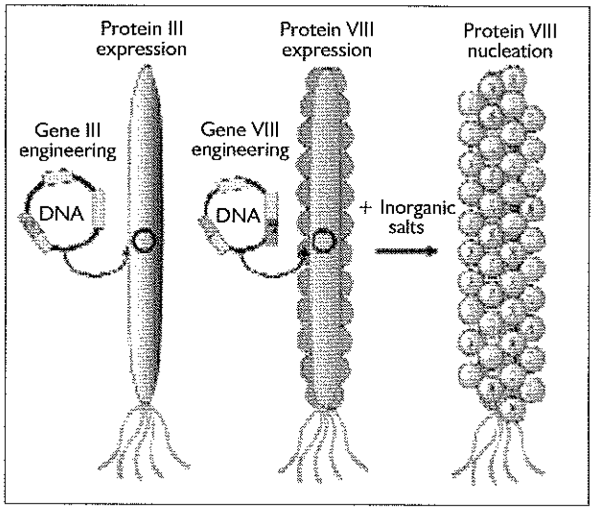
In the first step, DNA fragments with random sequences coding for many different proteins are incorporated into the DNA of bacteriophages in such a way that one of the proteins forms on the exterior of a virus. The viruses replicate and are placed in a solution in contact with the material to which they are supposed to bind. After washing away the viruses that do not bind, the few that do attach are chemically freed from the target and allowed to repli-



Department of Chemistry, New York University

Figure 3. Two double-crossover molecules (red and blue) connected by a bridge element (yellow) that can be converted from B-DNA (top) to Z-DNA (bottom) by the addition of hexaaminecobalt(III) chloride (and converted back again by its removal) form the basis of a DNA nanomechanical device. The change is monitored by attached fluorescent dyes represented by the stippled circles.

cate again. The sequence is repeated until only the protein with the strongest binding remains. That protein can then be sequenced for future use. In this manner, researchers at various laboratories are creating a library of proteins that bind to specific elements and inorganic compounds, including gold, platinum, silver, zinc oxide, gallium arsenide, and iron oxide.



MIT

Figure 4. DNA fragments coding for proteins are incorporated into bacteriophage viruses such that one of the proteins forms on the exterior. The viruses replicate, bind to a target substance such as zinc sulfide, and form wires from which the viruses may be removed by heating.

One possible application of such inorganic-binding proteins (also referred to as genetically engineered polypeptides for inorganics, or GEPIs) is in the assembly of nanoparticles into specific nanoscale devices, such as quantum dots. Because protein-binding reactions occur at or near room temperature in solutions, they could be considerably less expensive than conventional vacuum techniques, such as molecular-beam epitaxy. In addition, such proteins could prove useful in creating smaller devices.

A separate approach to creating nanostructures uses viruses as part of the structure itself, not just to produce the right proteins. In joint work by Belcher's MIT group and researchers at the University of Texas at Austin, genetically engineered bacteriophages align themselves into long filaments. Their outer proteins bind with inorganic materials, such as zinc sulfide and cadmium sulfide, to form long nanowires up to 600 nm long and only 20 nm across. Heating the resulting wires to 350 °C removes the virus, leaving only the metallic wire behind.

The viruses used consist of only six proteins, two of which bind with the selected inorganic material. The researchers hope to modify some or all of the remaining proteins to produce more-complex self-assembled structures than wires (Figure 4).

Structuring DNA

Producing the proteins needed for nanostructures involves DNA, of course, because it is the DNA in the virus that codes for the amino acid sequence in the proteins. But another biomimetic approach uses the DNA itself as the structural element, not proteins. The idea—developed by Nadrian C. Seeman, professor of chemistry at New York University, among others—is to unravel the two intertwined helixes at the end of DNA molecules and then stick them together with the matched ends of two other DNA molecules. Because the specific sequence of nucleic acids in a given DNA strand will only match with the corresponding sequence in another DNA strand, specific molecules can be fit together like a jigsaw puzzle, with only one possible structure at each point where one DNA strand attaches to two others.

The process of joining one DNA molecule to two others occurs in organisms during meiosis, the cell-division process that produces germ cells (egg and sperm) and temporarily forms X-shaped structures called Holliday junctions. However, with appropriately designed DNA sequences, a molecule can have Holliday junctions at both ends, thus allowing them to form two- and even three-dimensional arrays.

Normal DNA molecules are too flexible to form rigid scaffolding. In chromosomes, DNA is twisted into densely packed hierarchies of helixes, not a rigid array. But if two DNA molecules attach to each other twice at crossover points, the resulting double-crossover DNA (DX DNA) is stiff. By 2000, Seeman was able to use these molecules to produce two-dimensional arrays of DNA molecules.

However, progress toward the practical application of these DNA arrays has been modest. Three possible applications have been discussed. One would use the arrays, eventually elaborated into three-dimensional arrays, as scaffolding for nanoelectronic components. Specific components, attached to DNA sequences, would bind to the matching sequence in the right place in the array.

A second application, perhaps closer to realization, would use the arrays to bind large biological molecules into an artificial crystal for X-ray crystallography studies. Conventionally, such studies rely on the molecules forming crystals on their own, but in many cases, natural crystallization does not occur. Putting large numbers of molecules into identical spaces in a regular array would form an artificial crystal, making crystallography studies possible.

DNA arrays also could form the basis for nanomachines. In one effort in this direction, Seeman and colleagues developed a DNA structure that could be rotated back and forth between two positions. To do this, they connected two DX molecules with a DNA "shaft" that can be converted from right-handed B-DNA to left-handed Z-DNA by the addition of $Co(NH_3)_6Cl_3$ (Figure 3).

Significant obstacles stand in the way of practical applications of DNA structures, which remain in the early research phase. For one thing, DNA nanomachines would appear slow, taking a relatively long time—seconds or at least milliseconds—for chemical messengers to reach a machine and change its state. Perhaps more fundamentally, researchers have not figured out how to replicate DNA structures on a large scale. In organisms, DNA molecules replicate with the aid of enzymes that unzip and rezip them. But such replication appears difficult in the complexly branched structures of DNA constructs. Clever topological tricks could possibly overcome this problem, but they have not been worked out yet in practice.

Prospects

Although DNA structures are not a near-term technology, other approaches seem closer to realization. At the mesoscale—the gecko tape, for example, where existing fabrication technology could produce structures imitating biological ones—obstacles to commercialization involve the usual challenges of scaling up a laboratory-created item to an industrial product and improving durability.

Protein-based techniques are at an intermediate stage—neither entirely a pure research subject, nor one verging on commercial application. For the most part, these techniques aim at using biologically based processes to produce artificial structures that could, in principle, be built by entirely inorganic means. For example, many groups working with nanotubes are also looking at ways to form regular arrays that incorporate appropriate metals and other materials. One key question that remains unresolved is whether protein-based methods can come on-line faster or less expensively than nanotube-based methods.

75-P

Serendipity: Accidental Discoveries in Science
by Royston M. Roberts
ISBN: 0-471-60203-5

16

CELLULOID and Rayon: Artificial Ivory and Silk

Celluloid

The first successful synthetic plastic was celluloid, which was developed to replace ivory in billiard balls. In 1863 there was a shortage of ivory, the material of choice for billiard balls, because of depletion of the herds of wild elephants in Africa. (Isn't it surprising to learn that what is a serious problem today was also of concern over a hundred years ago!) A major manufacturer of billiard balls offered a prize for an ivory substitute that could be used to make billiard balls.

A New Jersey printer named John Wesley Hyatt and his brother Isaiah began experimenting with various materials. One of these was a mixture of sawdust and paper bonded together with glue. When John Hyatt cut his finger while engaged in this work, he went to a cupboard to get some collodion to protect the wound. (Collodion, a form of cellulose nitrate dissolved in ether and alcohol, was popular for this purpose at that time. Alfred Nobel's similar experience, one that led him to the invention of blasting gelatin, is described in Chapter 15.) To his surprise, he found that the bottle of collodion had overturned, spilling the contents; the solvent had evaporated, leaving a hardened sheet of cellulose

nitrate on the shelf. Hyatt realized that this material might make a better binder for his sawdust and paper mixture than the glue he was using.

After some experimentation, Hyatt and his brother found that cellulose nitrate and camphor, mixed with alcohol and heated under pressure, made a plastic apparently suitable for billiard balls. Nobel made blasting gelatin from cellulose nitrate combined with nitroglycerin. The camphor must have modified the explosive nature of the cellulose nitrate considerably; however, billiard balls made of celluloid did explode occasionally!

▼ *An advertisement for celluloid collars, around 1875*

Hyatt and his brother did not win the prize for an ersatz billiard ball, perhaps because the balls they made tended to explode. But they did patent their plastic made of cellulose nitrate and camphor in 1870 under the name "Celluloid," and it became popular for other applications. In the late nineteenth century, it was used for collars and cuffs of men's shirts. It was molded for dental plates, knife handles, dice, buttons, and fountain pens. More modern plastics have largely replaced it, but I remember as a boy identifying it as the material from which small pocket calendar cards were made—by its odor of camphor.

Rayon

Spilling a bottle of collodion also provided the idea for the first successful substitute for silk. When Pasteur was trying to save the French silk industry from a disastrous epidemic among silkworms, a young chemist named Hilaire de Chardonnet assisted him. From his experience with the silkworm problem, Chardonnet became convinced that an artificial substitute for silk was highly desirable. While working in his darkroom with photographic plates in 1878, he spilled a bottle of collodion. He did not immediately clean up the spill, and when he did, he found a tacky viscous liquid left by partial evaporation of the solvent, which produced long thin strands of fiber as he wiped it up. These fibers resembled silk enough to encourage Chardonnet to experiment further with the collodion.

Within six years after the accidental spill, Chardonnet produced an artificial silk. He derived the collodion from a pulp of mulberry leaves, (the natural food of silkworms!) dissolved in ether and alcohol, drew out filaments of the fiber, and coagulated them in heated air. Cloth made from the new synthetic fiber was displayed so successfully at the Paris Exposition in 1891 that financial backing was obtained immediately. The new fiber was called "artificial silk" until about 1924 when the name *rayon* was first used.

▼ POSTSCRIPT

Chardonnet's rayon was highly flammable. Other processes were later invented to convert cotton into silk-like fibers that were not flammable. Cellulose nitrate, the original rayon, is no longer used as a textile fiber. Cellulose nitrate was also once used for photographic film, both ordinary still film and commercial movie film. Its flammability was responsible for

several disastrous fires in movie theaters; if a projector malfunctioned so that the film remained stationary in the path of the intense light for more than a few seconds, it would catch fire. The "safety film" that replaced it many years ago was cellulose acetate.

The fundamental difference in appearance of cotton and silk textiles lies in the filaments from which each is woven. The filaments of cotton are fuzzy, whereas the filaments of silk are smooth, just as they come from the silkworms. These smooth filaments give the silky sheen to silk. Chardonnet's rayon simulated silk because the cellulose (cotton or wood fiber) was converted into a chemically different form (cellulose nitrate) that could be dissolved in ether and alcohol, and smooth filaments could then be pulled or extruded from the viscous solution.

The most successful newer rayons are xanthate rayon and acetate rayon. Xanthate rayon takes its name from a process in which cellulose is converted into a chemically different and soluble form (cellulose xanthate). The viscous solution of cellulose xanthate is extruded through fine holes as smooth filaments into a chemical bath that converts the cellulose xanthate back into cellulose. The overall effect is to change the physical shape of fuzzy cellulose fibers into smooth silk-like fibers, and this rayon is actually regenerated cellulose.

Acetate rayon is more like the original Chardonnet rayon. Cellulose is converted into the acetate ester, which, like the nitrate ester, is soluble and can be extruded into smooth filaments. However, in contrast to cellulose nitrate, the cellulose acetate is not flammable. The textile industry now uses the generic term *acetate* for acetate rayon to prevent confusion with the other major type of rayon, xanthate rayon. If the label says simply "rayon," the material is probably xanthate rayon. It may be appropriate to mention a caution for anyone who may work in a laboratory where organic solvents like acetone may be used. "Acetate" is somewhat soluble in these solvents, and clothing made of it should not be worn in environments where contact with them is possible. Ordinary "rayon" (xanthate rayon) is chemically identical with cotton, and thus is impervious to organic solvents.

Various synthetic fibers have since been developed that are more like silk than rayon. They may even be superior to silk in some ways. The nylon that Wallace Carothers and his group at Du Pont developed in the 1930s is one of these fibers. New generations of nylon and other synthetic fibers, such as the polyesters, have been developed and have displaced rayon for many textile uses. (Chapter 25 describes the discovery of nylon and also mentions the polyesters Terylene and Dacron.) But Chardonnet's artificial silk started attempts to duplicate or improve on nature's silky textile.

They All Laughed...
by: Ira Flatow
ISBN: 0-06-092415-2

14

Teflon: The Top-Secret Discovery

The lowest coefficient of static and dynamic friction of any solid.

—*Guinness Book of World Records*, describing Teflon

Roy J. Plunkett didn't know he had invented Teflon. Teflon appeared totally by surprise to the young chemist. Just two years earlier he had graduated with his Ph.D. from Ohio State University. And now, on April 6, 1938, as a chemist for Du Pont, Plunkett had unknowingly invented a compound that would change the world.

Plunkett had been assigned a project: Come up with a nontoxic refrigerant. Jack Rebok, Plunkett's lab assistant at Du Pont's Jackson Laboratory in New Jersey, had just cracked the valve on a bottle of special Freon gas that Plunkett had concocted. But no gas came whistling out. Scratching his head, Rebok turned to Plunkett.

"Hey doc, did you use all this stuff up last night?"

"No. I don't think so," replied a perplexed Plunkett.

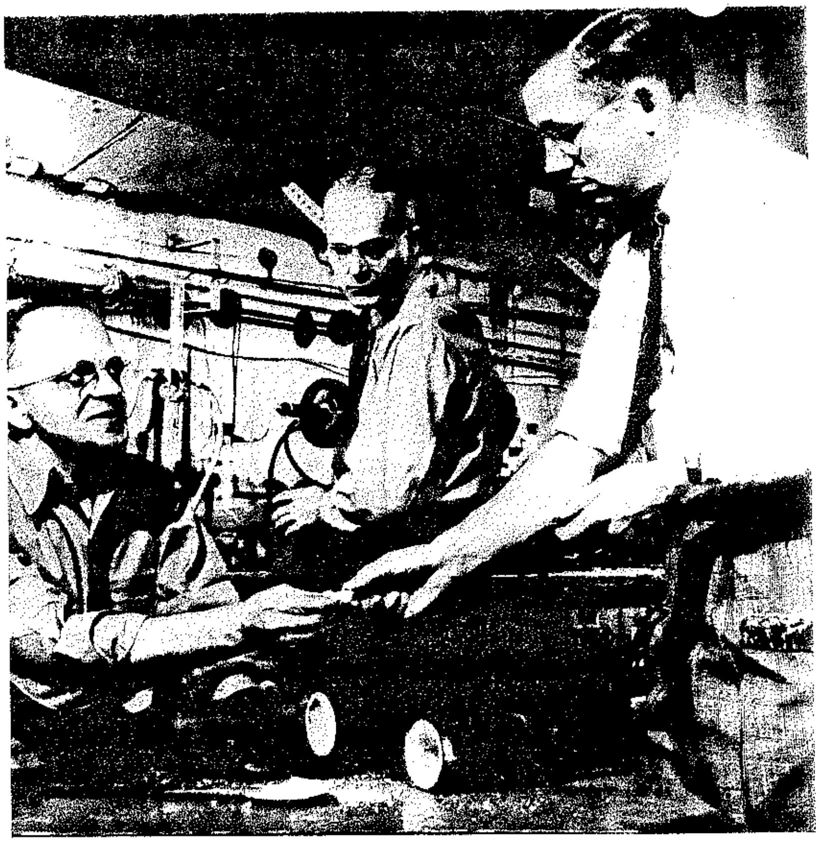
"Well, there's nothing coming out," said Rebok as he examined the opened valve.

"Well that's odd. Let's check it out."

Trying to understand where the gas had gone, Plunkett suggested they weigh the cylinder. "It weighed what we expected it to, so we knew something was in there."

Perhaps the valve was stuck? Running a wire through the valve showed it to be open. The only thing left to do was open her up. Sawing open the cylinder, Plunkett dumped out its contents. "I was flabbergasted," he said. "Gee whiz, it's gone wrong."

And sure enough, out of the innards of the cylinder came not a gas but instead a greasy white powder. What was this stuff?



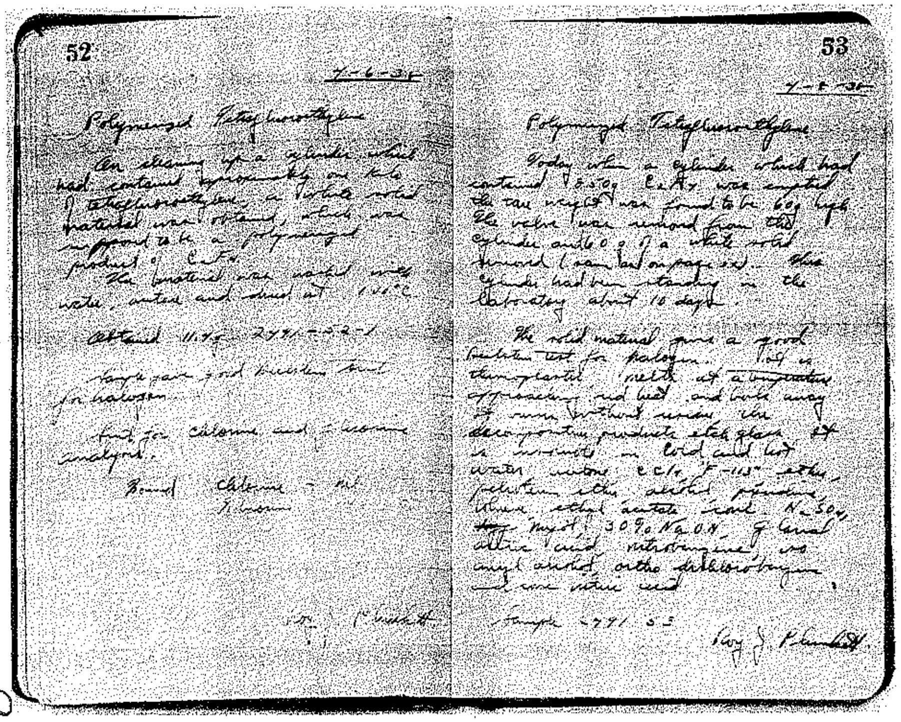
Serendipity in Action. Dr. Roy Plunkett (right) reenacts the discovery of Teflon in his lab. Plunkett shows his assistant, Jack Rebok (left), the white powdery material he scraped from inside the cylinder they curiously sawed open after a "failed" experiment with refrigeration gases. Bob McHarness looks on during this reenactment of the 1938 discovery.

SERENDIPITY IN A BOTTLE

Plunkett had been looking for a new kind of refrigerant, the gas used in air conditioners and refrigerators to suck out the heat. He thought he was mixing together a batch of tetrafluoroethylene—Freon—a little-used substance that might have refrigerating potential. But now, instead of finding the gas in his bottle as expected, he came face to face with a mysterious white powder.

If Plunkett had been a highly focused inventor like Edison with his light bulb, he might have just tossed the stuff out and written the whole thing off as "mysterious dirt in collecting cylinder" as Edison had written of the Edison effect. "But that's the thing about a discovery," Plunkett would say later, "even though it [the experiment] did go wrong you go ahead and find out what you got." Being the curious scientist that he was, Plunkett gave it the usual preliminary tests: Rub it with your finger, taste it, sniff it, see if it burns, drop some acid on it.

Nonstick Pages. Two pages from the 1938 laboratory notebook of Roy Plunkett, ushering in the age of nonstick coatings. Based on the work begun on these pages, Plunkett, holder of the original patent for Teflon, was invited to join Thomas Edison and the Wright Brothers in the National Inventors Hall of Fame.



What neither Plunkett nor anyone else realized on that day, April 6, 1938, was that he had accidentally invented Teflon,* a material so revolutionary and valuable that its discovery would remain a military secret until after World War II. Inside the tank the molecules of the gas had formed into a long chain (polymerized) so that they now became a solid. More precisely, a plastic. One of the first ever invented.†

Plunkett soon discovered that Teflon was truly unique. It was an inert substance. It was absolutely stable; nothing reacted with it. Neither heat nor electricity nor acids nor solvents could affect it. It was corrosion-proof. And to top it all, Teflon was the most slippery substance on earth. More slippery than the slipperiest substance in nature: wet ice against wet ice.

A MILITARY SECRET

A few months later, Teflon was put to the test. Scientists working on the first nuclear bomb—the Manhattan Project—needed to make gaskets that could resist the terribly corrosive uranium hexaflouride used in making U-235, the chief ingredient in the bomb. They turned to Du Pont.

When told that the experimental new plastic was very expensive, General Leslie R. Groves, the army's ranking officer on the project, said that money was no object. Secretly, Du Pont made more of the white powder during the war and supplied it to the military. While Teflon and nylon were both invented in the same year, Teflon was not known to the public until after the war, 1946.

One of the first postwar customers was a gasket company in

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* The name Teflon is derived by combining the chemists' nickname for tetrafluoroethylene—*tef*—with an arbitrary suffix—*lon*—that Du Pont likes to choose for its products, as in nylon, Orlon, and so forth.

† Plunkett and Du Pont refer to Teflon as being "discovered." To be precise, Teflon *was* discovered when the bottle was opened. But Teflon does not occur in nature so I prefer to call it an invention. The National Inventors Hall of Fame agrees: It inducted Plunkett into its hallowed halls in 1985.

Members of the Polymer Family

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

Thermoplastics

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

Thermosets

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

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

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

Polymer Processing

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

Injection Molding

Injection molding is a very common process for forming plastics, which involves four steps:

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

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Advantages of injection molding include rapid processing, little waste, and easy automation.

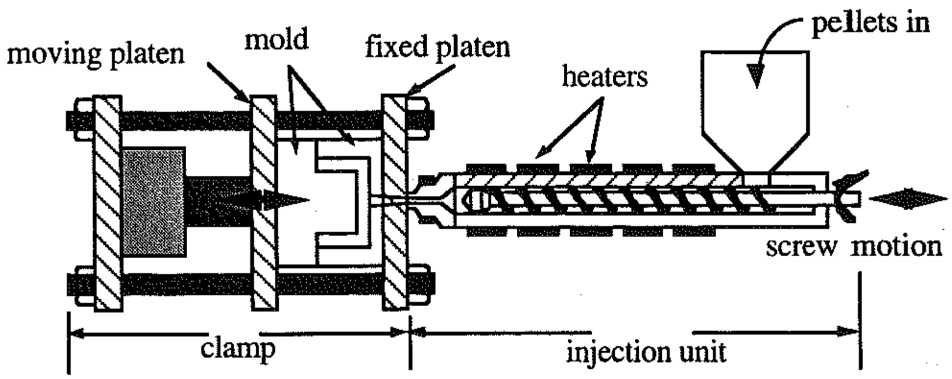

Figure 3: *Diagram of injection molding.*

Compression Molding

Compression molding was among the first methods used to form plastics. It involves four steps:

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

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

Transfer Molding

Transfer Molding is a modified form of compression molding. It is used primarily to produce thermosetting plastics. It involves five steps:

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

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

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Blow Molding

Blow molding involves three basic steps:

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

This process is rapid and relatively inexpensive.

Extrusion

Extrusion is ideally suited for parts of constant cross section like pipes and rods. It involves four steps:

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

An extruder has a hopper to feed the polymer and additives, a barrel with a continuous feed screw, a heating element, and a die holder. • ••

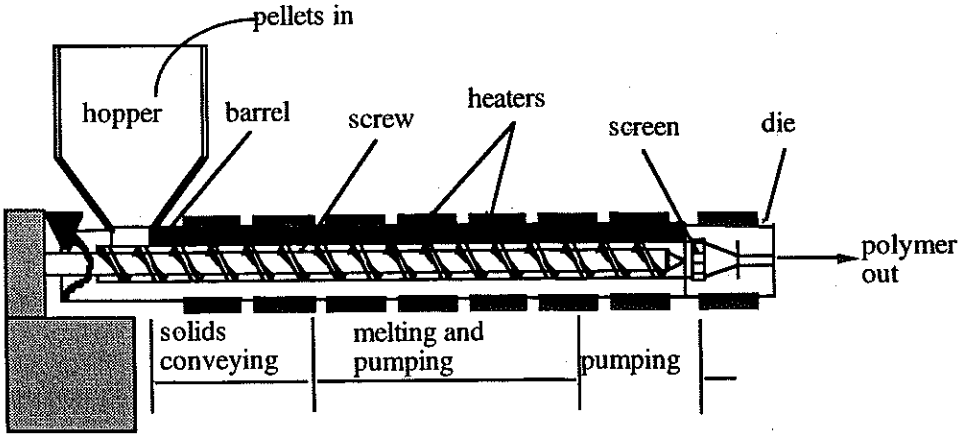

Figure 4: Diagram of an extruder.

•Molten ploymer, which is forced through the die, must be carefully cooled to avoid deformation (or slumping) upon exiting the die

••In addition, plastic bags and films can be formed by extrusion by fitting an adaptor at the end which blows air through an orifice into the hot polymers extruded through a ring die.

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

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

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Glossary

Abbreviations:

HDPE: high density polyethylene

LDPE: low density polyethylene

PET: polyethylene terephthalate

PP: polypropylene

PS: polystyrene

PVA: polyvinyl alcohol

PVC: polyvinyl chloride

addition polymerization: a chemical reaction in which simple molecules are linked together to form long chain molecules.

amorphous: non-crystalline polymer or non-crystalline areas in a polymer.

Bakelite: a polymer produced by the condensation of phenol and formaldehyde.

branched polymer: polymer having smaller chains attached to the polymer backbone.

cellulose: a natural polymer found in wood and other plant material.

composite polymer: a filled or reinforced plastic.

condensation polymer: one in which two or more molecules combine resulting in elimination of water or other simple molecules, with the process being repeated to form a long chain molecule.

configuration: related chemical structure produced by the making and breaking of primary valence bonds.

copolymer: a macromolecule consisting of more than one type of building unit.

creep: cold flow of a polymer.

cross-linking: occurs when primary valence bonds are formed between separate polymer molecules.

crystalline polymer: polymer with a regular order or pattern of molecular arrangement and a sharp melting point.

dimer: a polymer containing two monomers.

domains: sequences or regions in block copolymers.

elastomer: a type of polymer that exhibits rubber-like qualities.

Ekonol: a moldable, high temperature polymer.

end group: functional group at the end of a chain in polymers, e.g. carboxylic group.

extrusion: a fabrication process in which a heat-softened polymer is forced continually by a screw through a die.

filler: a relatively inert material used as the discontinuous phase of a polymer composite.

free radical: A chemical component that contains a free electron which covalently bonds with a free electron on another molecule.

homopolymer: a macromolecule consisting of only one type of building unit.

initiation: the start of a chain reaction with a source such as free radicals, peroxides, etc.

kevlar: a high strength polymer which can withstand high temperatures.

linear: polymers made up of one long continuous chain, without any excess appendages or attachments.

macromolecule: a polymer.

material: a substance useful for structural purposes.

monomer: smallest repeating unit of a polymer.

nylon: a polymer used commonly in the textiles industry.

oligomer: a low molecular weight polymer in which the number of repeating units is approximately between two and ten.

polyethylene: the most extensively produced polymer.

polyester: a polymer with a COOR repeating unit.

polymer: a high molecular weight macromolecule made up of multiple repeating units.

polymerization: the chemical reaction in which high molecular mass molecules are formed from monomers.

polystyrene: a polymer commonly used in packaging.

propagation: the continuous successive chain extension in a polymer chain reaction.

T_g: glass transition temperature below which a polymer is a hard glassy material.

thermoplastic: a polymer which may be softened by heat and hardened by cooling in a reversible physical process.

thermoset: a network polymer obtained by cross-linking a linear polymer to make it infusible or insoluble.

T_m: melting temperature.

van der Waals forces: intermolecular attractions.

viscosity: the resistance to flow as applied to a solution or a molten solid.

vinyl chloride: the monomer used in PVC production.

vulcanization: cross-linking with heat and sulfur to toughen a polymer.

Source: Seymour and Carraher POLYMER CHEMISTRY Dekker 1993

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