A Comparison of Polymeric Liquids with Newtonian Liquids

Using Various Tests (Viscosity, Rod-Climbing, Elastic Recovery, and Creep)

Developers:

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Grade Levels:

6-12

Discipline:

Chemistry (matter, molecules, macromolecules)
Physics (liquid flow)
Environmental (plastics)
General Science (scientific process, testing)

Goals:

1. Students will be able to concretely illustrate and define a macromolecule.
2. Students will observe the unique behavior of polymers and relate to their knowledge of molecules.
3. Students will use the scientific process to determine the difference between Newtonian and non-Newtonian liquids.

Objectives:

- Students will understand the concepts of viscosity, elasticity and identify changes in behavior.
- Students will measure viscosity of liquids.
- Students will use tests and measuring as a means of making comparisons.
- Students will define crosslink and make crosslinked polymer solutions.

Lab I Materials:

Teacher will need to make solutions (4% by weight) of solid borax and poly (vinyl alcohol). Elmers glue is a good substitute for poly (vinyl alcohol). Students will need several 50-ml cups and sufficient amounts of solutions. Each group of students will need several craft sticks or dowels, graduated cylinders, pan balances or scales. If solutions are to be stored for another lab day, they can be kept for up to two weeks in baggies. However, containers with lids are ideal. See background for safety and disposal.

Procedures:

1. Gather materials necessary to make gluep.
2. Make several recipes of gluep following the directions given in Table I. It is not necessary to make all recipes for gluep.
3. Start all solutions with 15 mL of glue.
4. Add required water amount — mix well.
5. Continue to stir while adding the given amount of borax solution.
6. Observe the materials and notice the difference with amount of crosslinker (Borax) added. Record brief but descriptive observations in the table to be referred to later.
7. Clearly mark the various recipes A, B etc. on chart as well as on the containers.

Lab II Materials:

A. **Viscosity Test:** ring stand and clamp (optional), viscosity tester (sample design on last page), several disposable catch cups, various liquids (water, glycerine, catsup, honey or karo, glue, SPT oil, gluep), stop watch.

B. **Rod Climbing Test:** liquids in original containers, round cylindrical rods or wooden dowels.

C. **Creep Test:** Liquids being tested , some type of weight (marbles or metal balls work well) stop watch.

D. **Elastic Recovery Test:** Liquids being tested, wooden dowel, circle template with degree measurements: (sample on last page), arrow or marker to be placed at the top of the circle.

Procedures:

A. Viscosity Test

1. Gather the materials needed for the viscosity test.
2. The liquids you will use are: water, glycerine, honey, regular glue and recipes D, G and H.
3. Use a tall cylindrical plastic 50 – 100 mL container with a hole centered approximately 4 mm in diameter in the bottom (see figure on last page). About 1/2 the way down, mark line “B” with line “A” approximately 2 cm above it.
4. Use a ring stand and clamp to hold this cup in place for each liquid tested or a student could hold the cup.
5. Place catch cup under the viscosity tester to catch the liquid. Return each liquid to the original container for other tests. Use disposable catch cups to save time on cleaning. Wash tester after each liquid.
6. Hold the viscosity-tester in your hand with your finger over the hole.
7. Pour the liquid into the tester until the liquid covers line A of the tester,
8. When filled to mark, release your finger from the hole and hold the tester over the catch cup.
9. Time the flow of the liquid through the tester as it travels from line A to line B and record your reading in Data Table II.
10. Graph the results and draw your conclusions.

B. Rod Climbing Test

1. For the rod-climbing test you will need the same liquids and a dowel or cylindrical rod.
2. Place the rod in the center of the solution and turn the rod very quickly clockwise. Hold still for thirty seconds.
3. Observe the behavior of the liquid. Does it move toward the inside or outside of the container? Or does it climb up the rod moving toward the center? What would happen if your reversed the direction?
4. Record your observations on Data Table III.

C. Creep Test

1. To complete the creep test, make sure all liquids are settled and in original containers.
2. You will be timing this test over a period of thirty minutes.
3. Use a marble 10 mm in diameter or any other weight, but you must determine the diameter or height of weight.
4. Place weight on/in liquids and record how far weight sinks into the liquid.
5. Record data on Data Table IV and Graph II.

D. Elastic Recovery Test

1. To perform the elastic recovery test, you will need to remove marbles from the liquids and allow them to settle.
2. Cut out the circle template and arrow or marker found on last page.
3. Again, you will need a rod- or dowel-shaped stirrer.
4. Make the measuring device by placing the dowel in the center of the circle. Secure marker at the top of the dowel/stirrer. Place the entire measuring device on top of the container holding each liquid.
5. Align the marker so that you could make a 90° turn. Dowel should move freely.

6. Turn the dowel at least 90°, hold for 5 seconds, then release. What happens for Newtonian liquids?
7. Try the polymeric liquids a few times. How many degrees does the marker return?
8. Determine in degrees how much plastic recovery polymers have and which of those are most elastic.
9. Record your results in Data table V.
10. When all four tests are completed and data has been recorded and studied, answer the questions on the next page.

Challenge:

Create a polymer product using the gluep recipes or variations of those recipes. To be correct your product must do what you claim it does and you must have exact recipe so that it can be duplicated.

Product S	a super ball
Product T	a wall climber
Product U	cement or adhesive
Product V	transfer printing material
Product W	your own invention

Good Luck!!

Extension:

How do these liquids behave when temperature is increased? decreased?

Table I/Gluep:
All solutions are to be begin with 15 mL of glue or 15 mL of poly (vinyl alcohol) (pva).

Borax	No Water	5 mL Water	15 mL Water	30 mL Water
3 mL	A	B	C	D
10 mL	E	F	G	H
15 mL	I	J	K	L

Data Table II/Viscosity Test

Liquid	Prediction	Time of flow from Line A to Line B

Graph I Viscosity Test

Data Table III/Rod Climbing Test

Liquid	Observations

Data Table IV/Creep Test

Liquid	Prediction	Distance Weight Moved Into Liquid					
		30s	1 min	2 min	5 min	10 min	30 min

Graph II/Creep Test

Data Table V / Elastic Recovery Test

Material	Prediction

Questions:

Which of the liquids tested are Newtonian (i.e.: show only viscous behavior)?

Which of the liquids are polymeric? What makes them different from other liquids?

Could you draw or illustrate a macromolecule such as polyethylene?

What happened to the gluep solutions with less water added and with more water added?

What did the borax solution do to the gluep?

What happens to the molecules of the gluep solution when the borax molecules are added?

Define Viscosity.

Which of the Newtonian liquids is most viscous? How do you know?

Which of the polymeric liquids tested is most viscous?

Which would flow more quickly glue or honey? Justify your answer.

Define inertia. In the rod-climbing test what happens to the Newtonian liquids as the dowel is turned?

What happens to the polymeric liquids?

How does this relate to their molecular structure?

Based on your results of the creep test, define and explain crosslinking.

Can you draw or illustrate your product using the molecular diagram given?

Define elasticity.

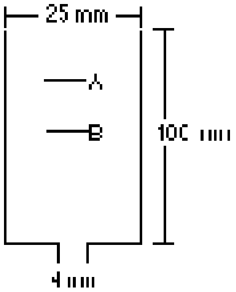
Which recipe of the gluep is most elastic and why?

Why are polymers unique?

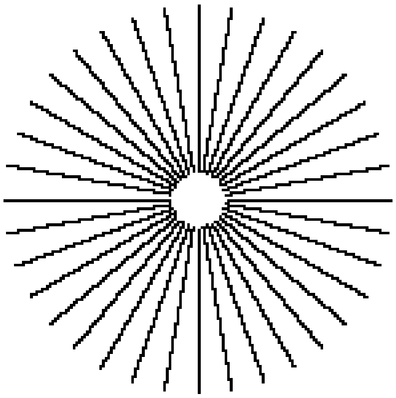
What are some versatile characteristics of polymers that make them so important to industry today?

Are there any other interesting ideas you developed from these labs?

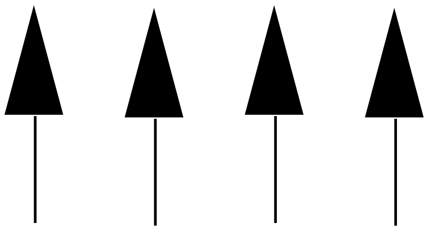
What are some other concepts from this lab you would like to learn more about?



Viscosity Tester



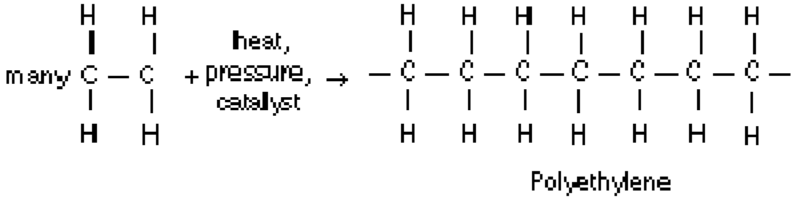
Elasticity-recovery circle



Elasticity- recovery arrow

Background Information:

Polymers are huge chain-like molecules containing many small molecules called monomers. The branch of science which studies the deformation of polymers is called Rheology. Many polymers are found in nature. Proteins, starch, cellulose, DNA, latex from rubber trees and tortoise shells are examples of natural polymers. Synthetic polymers are those such as plastics, polystyrene, synthetic rubber (polyisoprene), Teflon, acrylic latex, nylon, and polyesters made by man. All plastics are polymers but not all polymers are plastics. Polymers are so useful because of their great variety. Scientists and engineers have been able to develop polymers with many different properties. Polymers may be flexible or rigid, transparent or opaque, heat resistant or not, waterproof or water soluble, hard or soft, insulators or conductors, elastic or stiff, etc. Not only can polymers be made from many different monomers but they can be put together in many different ways. Polyethylene is a polymer made by bonding together many monomers called ethylene. Polyethylene molecules are much larger than shown.



Teflon looks like polyethylene except that each hydrogen is replaced by a fluorine (F). Poly(vinyl chloride) (PVC) is similar except that every other hydrogen on one side of the chain is replaced by a chlorine (Cl). Each is made from a single type of monomer $CF_2 = CF_2$ in the case of Teflon and $CH_2 = CHCl$ in the case of PVC.

Other polymers such as Poly(ethylene terephthalate) (PET) may involve two or more different monomers. The most common pattern, and the one found in PET, is -X-Y-X-Y-X-Y-X-Y-X-Y where X and Y are two different monomers. Some natural polymers involve more different monomers and different patterns. For example, proteins contain 20 different monomers (amino acids) in a wide variety of different, seemingly random patterns. Additional materials such as crosslinkers alter the properties and uses of various polymers. We will investigate this process in our lab activities also. A crosslink is a cross-bond between the molecules which results in a complex, interconnected network. This crosslink likewise affects the behavior of the polymer.

Use of polymers has increased in this country so that now plastics make up about 7% of municipal solid waste by weight and 20% by volume. The plastics industry recognizes this problem and is currently working on efforts of recycling, biodegradation, source reduction, and more. We can and must aid in recycling plastics as well as all other recyclables. Man-made polymers are becoming more and more a part of our daily lives. Students encounter these substances constantly in everything from plastic soda bottles to foamed polysytrene cups to disposable diapers. Chemists are able to design polymers to have specific properties. In this activity, students combine common household materials in various proportions and thus crosslink a polymer. They will find that the properties of the polymer, gluep, will vary considerably. It is their “job” to find what they consider to be the “perfect” combinations of ingredients. An alternate activity for younger students is to make gluep as directed and observe the interesting properties of this polymer.

Like Silly Putty® and Slime®, gluep is a non-Newtonian fluid. That is, it has some properties of a liquid (for example, it flows) and some properties of a solid (for example, it shatters). Like Slime®, it is a crosslinked polymer. Polymer is a compound word: “poly” means “Many” and “mer” means “unit. The glue solution is poly(vinyl acetate) which has been dissolved in water. The poly(vinyl acetate) chains are so long that they interfere with each other, causing the glue to be rather thick and to pour more slowly than water. Gluep forms when the solution of borax (sodium borate) is added to the glue solution. The borax crosslinks the polymer chains, binding them together and producing a gel-like material that is more viscous than the glue solution and has a variety of interesting properties. In these labs we will be investigating our gluep solutions and some other Newtonian liquids.

Safety:

There is little danger in handling gluep. Do not give gluep to children younger than five years of age. They may try to taste it and while it is nontoxic, it could get stuck in a child's throat. Some people have an allergic reaction to dry borax. You should use adequate ventilation when preparing the solution and wash your hands after contact with the solid. We used Material Safety Data Sheets from Fisher Scientific Chem. Division, 1 Reagent Lane, Fair Lawn, NJ 07410 on all materials used in these labs.

Disposal:

Discard gluep in a waste can, not down the drain. Do not set gluep on natural wood furniture as it will leave a water mark. It may stick to other materials.

Special Notes:

If a teacher chooses to use poly(vinyl alcohol) you must mix it at least one month in advance.

Anticipatory Set Ideas:

1. Ask for 8 volunteers, telling them that they will be holding hands. Each volunteer represents a monomer, one unit. Form two polymer chains of 4 monomers each by having the students join hands. Poly means many so a polymer is many units.

2. Have each polymer move around the room with hands still linked. Point out that they can move relatively freely just like the polymer [poly(vinyl acetate)] molecules in white glue.

3. Explain that the borax solution contains a molecule called a cross-linker which links these polymer chains together. Show how a crosslinker (yourself) works by holding the arm of a monomer in the middle of each of the polymer chains.

4. Have the polymers move around as before. It will be clear that, while some movement is still possible, it will be much more difficult than before the cross-linker was added.

You could give students several pieces of string 10 cm in length. Lump them together and let them see if they can untangle them. Then do the same thing to several pieces 30 cm long. The longer "chains" are "entangled" and are more difficult to get apart. Compare to polymer molecule.

Natural Polymers

Name	**Sample Uses**
Proteins	Amino Acids - building blocks of protein
Starch	white powdery substance in green plants foods, energy source for many animals.
Cellulose	Main part of plant cell walls many uses - wood - paper
DNA	genetic molecule carries traits from parent to off-spring
Latex	milky juice given off by trees used to make rubber balls etc.
Tortoise Shell	Protective covering of amphibious creatures used in objects for ornamentation

Synthetic Polymers

Poly(vinyl chloride) (PVC)	pipes, house siding appliances, autos, oil, cosmetic bottles, credit cards, food packaging
Polyethylene (PE)	plastic bags, milk bottles, squeeze bottles, packaging.
Polystyrene (PS)	styrofoam cups, insulation, construction, lighting signs
Polyisoprene	gutta percha (natural rubber)
Rubber	tires, etc
Teflon	cooking utensils, bearings, paints
Acrylic latex	paints
Nylon	string, thread
Polyesters	fabrics
Poly(ethylene terepthalate) (PET)	fibers, fabrics, soda bottles

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