Super Duper Polymer Gel

Properties of Polymers

FLINN SCIENTIFIC CHEM FAX!

Introduction

A super duper polymer gel will climb up and out the side of the beaker against the force of gravity in this demonstration of polymer properties and hydrogen bonding.

Concepts

- Polymers
- Viscosity
- Hydrogen bonding
- Bond lengths and bond angles

Materials

Methyl or ethyl alcohol, 25 mL

Polyethylene oxide, 3–4 g

Fluorescent dye, fluorescein or rhodamine B (optional)

Graduated cylinder, 25-mL

Beaker, 600-mL, 2

Stirring rod

Food dye (optional)

Safety Precautions

Methyl alcohol is a flammable solvent and dangerous fire risk. It is toxic by ingestion. Keep away from flames and other sources of ignition. Polyethylene oxide has very low toxicity—it is actually used as a food additive. The high molecular weight of the polymer ensures that it is poorly absorbed in the gastrointestinal tract and will be completely and rapidly eliminated. Wear chemical splash goggles and chemical-resistant gloves and apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Mix 20–25 mL of an anhydrous alcohol such as methyl or ethyl alcohol with 3–4 grams of polyethylene oxide in a clean, dry 600-mL beaker. Swirl the mixture to completely wet the resin with alcohol. The polymer will not dissolve, but will be a free-flowing slurry.
2. Add 350–400 mL of tap water into the alcohol–polymer mixture "in one pour." Use a stirring rod to stir the mixture until the polymer has dissolved and the solution is homogeneous and thick.
3. Pour the gel into a second 600-mL beaker and then pour back and forth between the two beakers to finish mixing the gel.
4. The polyethylene oxide can be made to siphon "uphill" out of a beaker and against gravity. To start the process, raise the beaker containing the gel and begin to pour the gel into an empty beaker beneath it. Once the gel starts to pour, turn the raised beaker upright again. The gel will move up the sides of the raised beaker as a thin film and then form thick strands as it falls into the lower beaker. This siphoning process can be repeated indefinitely by switching the raised and lowered beakers.
5. (Optional) Add a few crystals of a fluorescent dye such as fluorescein or rhodamine B to the alcohol before adding the polyethylene oxide. The gel can then be illuminated with a fluorescent lamp in a darkened room, creating a striking effect. Food coloring may also be used—add food dyes directly to the water in Step 2.

Disposal

Consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The polymer gel is 99% water and can be disposed of in the trash according to Flinn Suggested Disposal Method #26a.

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Tips

- The alcohol acts as a dispersant to separate the polymer particles and inhibit the formation of large, insoluble lumps. Any water-soluble alcohol can be used as long as it is dry. In addition to methyl or ethyl alcohol, isopropyl alcohol, ethylene glycol, propylene glycol, and acetone may also be used as a dispersant.
- It is not necessary to use deionized or distilled water in this demonstration. The polyethylene oxide gel is nonionic and is not affected by the minerals in tap water.

Discussion

Polyethylene oxide is a nonionic, water-soluble, high molecular weight polymer. It is a polyether—every third atom in the polymer chain is an oxygen atom. The large number of oxygen atoms in the polymer chain leads to extensive hydrogen bonding with water molecules. The hydrogen bonding allows the polymer to dissolve in water despite its very high molecular weight (about 4,000,000).

The combination of being water soluble and having a high molecular weight gives polyethylene oxide many interesting properties and useful applications. Most unique is its ability to "thicken" water. The long polymer chains become intertwined like spaghetti and are heavily hydrogen-bonded to surrounding water molecules. The result is a "viscoelastic" gel. The high viscosity is due to the large number of hydrogen bonds between the polymer molecules and water, which create a molasses-like gel. The high elasticity is due to the ability of the very long polymer chains to straighten out when stretched and to slide past each other.

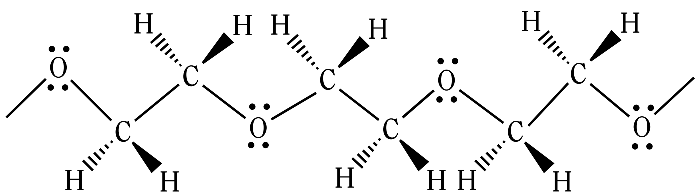


Figure 1. Structure of Polyethylene Oxide.

Polyethylene oxide is used to thicken and add a "soft and silky feel" to shampoos, hair conditioners, cold creams, and lotions. It is also used in inks, latex paints, cleaning solutions, and detergents.

Polyethylene oxide is a "straight-chain" polymer. Challenge your students to estimate the total length of a polyethylene oxide molecule having a molecular weight of 4,000,000.

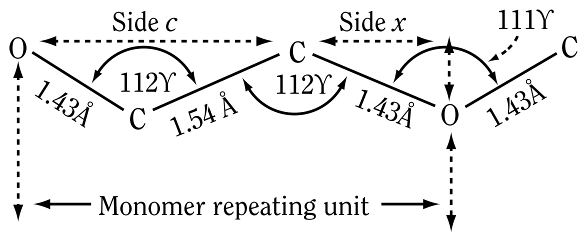
To determine the length of the polymer chain, the length of the monomer repeating unit in polyethylene oxide must first be calculated. Answers will vary depending on the bond length and bond angle values used in the calculations. Some knowledge of geometry and trigonometry is required. The procedure illustrates one possible approach to this problem.

Length of the Monomer Repeating Unit

Average Bond Lengths:	C—C	1.54 Å
(1 Å = 10^{-10} m)	C—O	1.43 Å
Estimated Bond Angles:	C—C—O	112°
	C—O—C	111°

Notice that the C—C—O and C—O—C bond angles deviate slightly from true tetrahedral bond angles (109.5°).

Repeating unit in polymer chain:



Length of side c = $a^2 + b^2 - [2ab \bullet \cos \angle C]$

= $(1.43\ Å)^2 + (1.54\ Å)^2 - [2(1.43\ Å)(1.54\ Å) \bullet \cos 112°]$

= $2.04 + 2.37 + 1.65$

= $2.46\ Å$

Length of side x: $\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$

$\frac{\sin 90°}{1.43\ Å} = \frac{\sin (111°/2)}{x}$

$\frac{1}{1.43\ Å} = \frac{.82}{x}$

side $x = 1.18\ Å$

Length of monomer repeating unit = side c + side x = 2.46 Å + 1.18 Å = 3.64 Å

Length of a Polymer Chain

Polymer molecular weight = 4,000,000 g/mol

Monomer molecular weight = 44 g/mol

$\frac{4{,}000{,}000 \text{ g/mol}}{44 \text{ g/mol}} = \approx 90{,}000$ monomer units/polymer molecule

(90,000 monomer units) (3.64 Å/unit) $(1 \times 10^{-10}$ m/Å$) = 3 \times 10^{-5}$ meters

Note: Results are rounded to one significant figure.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Do not "play" with the polyethylene oxide over carpeting—it is difficult to clean out of fibers. The gel can be disposed of in the wastepaper basket (it's 99% water). The glassware can be rinsed with plenty of tap water and dried.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
- Evidence, models, and explanation
- Form and function

Content Standards: Grades 5–8
- Content Standard B: Physical Science, properties and changes of properties in matter

Content Standards: Grades 9–12
- Content Standard B: Physical Science, structure and properties of matter

Answers to Worksheet Questions

1. Describe the appearance and behavior of the polyethylene oxide.

   The polyethylene oxide is a thick gel. When poured from one beaker to another, it can siphon up the side of the first beaker, working against gravity, and then form a thick strand that falls to the beaker waiting below.

2. The long polymer chains in polyethylene oxide, which are already extensively bonded to each other, will form even more hydrogen bonds with surrounding water molecules. In this state it resembles intertwined spaghetti. How do you think this contributes to its gel-like appearance and self-siphoning behavior?

   The large number of hydrogen bonds among the polymer chains and between the chains and water molecules causes it to form a thick gel rather than a free-flowing liquid. And since these long chain molecules are interconnected, they can stretch out and form more hydrogen bonds with each other, allowing them to be pulled together against gravity.

3. What is a polymer?

   A polymer is a large molecule, usually in the shape of a chain, composed of many smaller molecules called monomers.

4. Research two commercial products that polyethylene oxide is used in. What purpose does it serve?

   Two commercial products polyethylene oxide is used in are shampoos and lotions. The polymer is responsible for the soft, silky feel of these products.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Super Duper Polymer Gel* activity, presented by Irene Cesa, is available in *Properties of Polymers*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Super Duper Polymer Gel* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP4556	Polyethylene Oxide
E0007	Ethyl Alcohol, 500 mL
M0054	Methyl Alcohol, 500 mL
F0043	Fluorescein
R0008	Rhodamine B
V0003	Vegetable Dye Set

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Super Duper Polymer Gel Worksheet

Discussion Questions

1. Describe the appearance and behavior of the polyethylene oxide.

2. When polyethylene oxide is combined with water, the long polymer chains, which are already extensively bonded to each other, will form even more hydrogen bonds with surrounding water molecules. In this state it resembles intertwined spaghetti. How do you think this contributes to its gel-like appearance and self-siphoning behavior?

3. What is a polymer?

4. Research two commercial products that polyethylene oxide is used in. What purpose does it serve?