Poly-Ox with a Twist

Properties of Polymers

FLINN SCIENTIFIC CHEM FAX!

Introduction

In this gravity-defying demonstration, a super-duper polymer gel will climb up the side of a beaker. And there is an interesting twist—shine an ultraviolet light on the gel and see an electrifying fluorescent green glow!

Concepts

- Polymers
- Fluorescence
- Viscosity

Materials

Polyethylene oxide, 3–3.5 g	Beakers, 600-mL, 2
Methyl alcohol, 25 mL	Graduated cylinder, 25-mL
Fluorescein, a few crystals	Stirring rod
Tap water, 300–350 mL	Ultraviolet light

Safety Precautions

Methyl alcohol is extremely flammable and toxic by ingestion and inhalation. Fluorescein dye is irritating to skin, eyes, and mucous membranes. Avoid all body tissue contact. Polyethylene oxide has a very low level of toxicity. Due to its high molecular weight, it is poorly absorbed in the gastrointestinal tract and is completely and rapidly eliminated. The resin is neither a skin irritant, a sensitizer, nor does it cause eye irritation as the dry powder or as aqueous solution. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Pour approximately 25 mL of methyl alcohol in a clean, dry 600-mL beaker. Add a few crystals of fluorescein indicator dye to the alcohol and swirl to disperse.
2. Add 3–3.5 g of polyethylene oxide to the beaker. Swirl the mixture to completely wet the resin with alcohol. The polymer will not dissolve, but will be a free-flowing slurry (see tip #2).
3. Add 300–350 mL of tap water to the alcohol-polymer mixture "in one pour." Use a stirring rod to stir the mixture until all the polymer has disappeared and the solution is homogeneous and thick.
4. Pour the gel into a second 600-mL beaker and then pour back and forth between the two beakers to finish mixing the gel.
5. The polyethylene oxide can be made to siphon "uphill" out of the beaker and against gravity. To start the process, raise the beaker with the gel above the empty beaker. 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. This siphoning process can be repeated indefinitely by switching the raised and lowered beakers.
6. Darken the room and illuminate the fluorescent polymer gel with an ultraviolet light.
7. Choose a volunteer from the class to hold an ultraviolet light vertically next to the polymer. Pour the gel back and forth between the two beakers. Notice the striking effect from the addition of the fluorescent dye.
8. Turn the room lights back on. Pour all of the gel into one of the beakers. Add 100 mL of tap water to the empty beaker and coat its sides with the fresh water by swirling.
9. Pour the gel into the water and then back into the original beaker. The siphoning process speeds up considerably, pulling the gel quickly out of the upper beaker. See how small of a strand you can get to start the siphoning process. (*Caution:* Even small strands on the outside of the beaker can start the siphoning process, emptying the beaker unexpectedly.)

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10. After the demonstration, either save the gel for later use, or pour the gel down the drain with plenty of water. Rinse the beakers with tap water.

Disposal

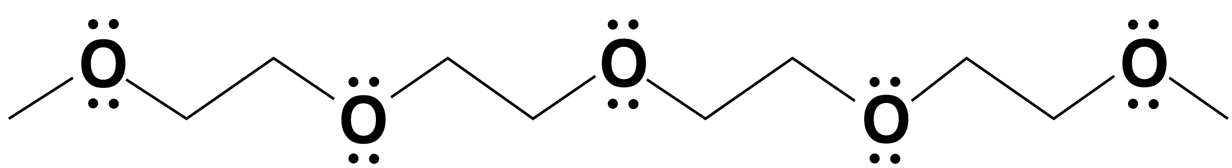
Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The gel can be disposed of down the drain with plenty of water according to Flinn Suggested Disposal Method #26b.

Tips

- Although the properties of Poly-Ox are intriguing, we do not recommend touching any chemical with bare hands.
- The alcohol acts as a dispersant to separate the polymer particles and to inhibit the formation of large, insoluble lumps.
- Distilled or deionized water is unnecessary since, being nonionic, polyethylene oxide gel is not affected by the minerals in ordinary tap water.
- The polyethylene oxide polymer gel will become slightly thicker and smoother with time. Cover the gel when not per forming the demonstration.
- Other fluorescent dyes can be added to the gel in place of fluorescein such as rhodamine B or eosin Y. Food dye may also be used to color the poly-ox, if desired.
- Avoid pouring the polyethylene oxide over carpeting or getting the gel on clothing as it is difficult to clean out of fibers.

Discussion

Polyethylene oxide is a water soluble, nonionic, high molecular weight polymer. It is a polyether containing an oxygen as every third atom in the chain (see structure below). This large number of oxygen atoms and the two pairs of nonbonded electrons leads to extensive hydrogen bonding when the polymer is in an aqueous solution. Polyethylene oxide has a very high molecular weight (~ 4,000,000), but the hydrogen bonding allows it to be soluble in water.

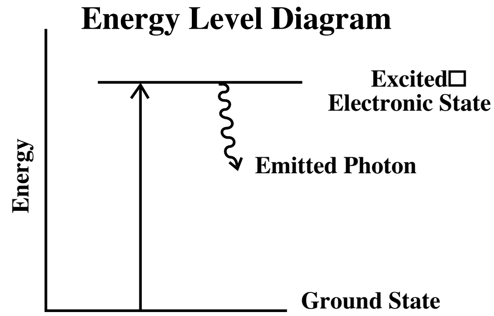


The combination of being water soluble and having a high molecular weight leads to many interesting properties and useful applications. Most unique is its ability to “thicken” water. This is due to the long polymer chains that are intertwined like spaghetti and heavily hydrogen-bonded to surrounding water molecules. The result is a “viscoelastic” gel. The high viscosity results from the large number of hydrogen bonds between the polymer molecules and water, causing a “molasses-like” gel to form. The high elasticity is due to the ability of these very long molecules to both straighten out when stretched and slide past each other, forming fresh hydrogen bonds as they move.

Polyethylene oxide is used to both thicken and to add a “soft and silky feel” to many shampoos, hair conditioners, cold creams, lotions, inks, latex paints, cleaning solutions, and detergents.

Fluorescein, a fluorescent dye, is added to the polyethylene oxide polymer gel. In the presence of ultraviolet radiation, fluorescence occurs. The high-energy light from the ultraviolet light is absorbed by the fluorescent dye and re-emitted as light in the visible region of the spectrum, being observed as a green glow.

In fluorescence, when a light source is shined on a material, a photon is absorbed. The energy from the photon is transferred to an electron that makes a transition to an excited electronic state. From this excited electronic state, the electron naturally wants to relax back down to the ground state. When it relaxes back down, it emits a photon (symbolized by the squiggly arrow in the diagram below).



If the emitted photon's wavelength is in the visible portion of the spectrum, a colorful, glowing effect is observed. Emission of this form is termed fluorescence. This process is practically instantaneous so the fluorescence is observed as soon as the exciting source is present, and it disappears as soon as the exciting source is removed.

Additional Activities

Polyethylene oxide is a straight chain (no branching or side chains), high molecular weight polymer that lends itself to some fun and fascinating mathematical calculations. Challenge your students to estimate the following value.

1. The length of a polymer chain of polyethylene oxide with a molecular weight of 4,000,000.
2. The total length (in meters and/or miles) of all polyethylene oxide polymer chains in one drop of solution. Assume a molecular weight of 4,000,000, a drop volume of 0.05 mL, and a concentration of 1 g resin in 100 mL solution.

Provide as much information to the students as you deem appropriate. To determine the length of the polymer, the length of the monomers must be calculated first. Answers will vary depending on the bond length and bond angle values used and their procedure. Some geometry and trigonometry is required to calculate the length of the monomer.

The following procedure and values is one possible approach to solving the problem.

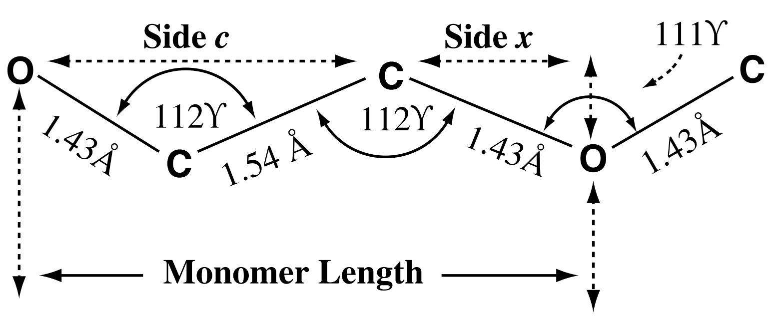
Part 1. Length of the Monomer

Use the following values:

• Normal Bond Length:	C—C	1.54 Å
	C—O	1.43 Å
• Estimated Bond Angles:	C—CH_2—O	112°
	C—O—C	111°

C—CH_2—O and C—O—C are not true tetrahedral structures (109.5°) due to the differences in size of a hydrogen or electron pair and a carbon atom.

Figure of Monomer:



1A. Calculate side *c*

$$\text{side } c = a^2 + b^2 - [2ab \bullet \cos \angle c]$$
$$= (1.43 \text{ Å})^2 + (1.54 \text{ Å})^2 - [2(1.43 \text{ Å})(1.54 \text{ Å}) \bullet \cos 112°]$$
$$= 2.04 + 2.37 + 1.65$$
$$= 2.46 \text{ Å}$$

1B. Calculate side *x*

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin 90°}{1.43} = \frac{\sin (111°/2)}{x}$$

$$\frac{1}{1.43} = \frac{82}{x} \quad \text{therefore} \quad x = 1.18 \text{ Å}$$

1C. Length of monomer

$$\text{side } c + \text{side } x = 2.46 \text{ Å} + 1.18 \text{ Å} = 3.64 \text{ Å}$$

Note: If a typical tetrahedral bond angle of 109.5° is used for both C—C—O and C—O—C bond angles, then the following length of monomer is obtained:

$$\text{side } c + \text{side } x = 2.42 \text{ Å} + 1.17 \text{ Å} = 3.59 \text{ Å}$$

Part 2. Length of a Polymer Chain

Polymer M.W. = 4,000,000 g/mol

Monomer M.W. = 44 g/mol

$$\frac{4{,}000{,}000 \text{ g/mol}}{44 \text{ g/mol}} = \text{~}90{,}900 \text{ monomer units/molecule}$$

$$90{,}900 \text{ monomer units} \bullet 3.64 \text{ Å/unit} \bullet 1 \times 10^{-10} \text{ m/Å} = 3.31 \times 10^{-5} \text{ meters}$$

Note: If your students used a bond angle of 109.5°, then the length of a molecule is 3.26×10^{-5} meters.

Part 3. Total Length of All Polymer Chains in One Drop of Resin Solution

Assume 3.5 grams of resin in 350 mL of solution.

$$\frac{3.5 \text{ g resin}}{4{,}000{,}000 \text{ g/mol}} = 8.8 \times 10^{-7} \text{ moles of resin in beaker}$$

$$8.8 \times 10^{-7} \text{ moles resin} \times 6.02 \times 10^{23} \text{ molecules/moles} = 5.3 \times 10^{17} \text{ molecules in the beaker}$$

$$\frac{5.3 \times 10^{17} \text{ molecules}}{350 \text{ mL}} = 1.5 \times 10^{15} \text{ molecules/mL} \times \frac{1 \text{ mL}}{20 \text{ drops}} = 7.6 \times 10^{13} \text{ molecules/drop}$$

$$7.6 \times 10^{13} \text{ molecules/drop} \times 3.3 \times 10^{-5} \text{ meters/molecule} = 2.5 \times 10^{9} \text{ meters of resin/drop}$$

$$\frac{2.5 \times 10^{9} \text{ meters of resin/drop}}{1600 \text{ meters/mile}} = 1{,}560{,}000 \text{ miles of resin/drop}$$

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, transfer of energy
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, interactions of energy and 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. 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?

   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. Fluorescence occurs when a substance absorbs a photon from a light source. The energy from that photon causes an electron to move to an "excited" state (higher energy level). As that electron returns to its ground it releases another photon with a particular wavelength. Explain how this relates to the "colorful glow" you see when a substance fluoresces.

   The glow is caused by the energy that is released by the electron relaxing from a high energy level to a low energy level. If the photon that is released at this time has a wavelength that is within the visible spectrum, then we can see the colorful glow it causes.

Acknowledgment

Special thanks to Walter Rohr, retired chemistry teacher, Eastchester High School, Eastchester, NY, for supplying us with this activity.

References

http://sprott.physics.wisc.edu/demobook/intro.htm, Demonstration 6.10, "Fluorescence".

Myerly, Richard C. *J. Chem. Ed.*, **1980**, *57*, 437–8.

Union Carbide product literature.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Poly-Ox with a Twist* activity, presented by John Mauch, is available in *Properties of Polymers* and in *Fluorescence*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Poly-Ox with a Twist* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Poly-Ox with a Twist—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP5931	Poly-ox with a Twist—Chemical Demonstration Kit
AP9030	Ultraviolet Light
F0043	Fluorescein, 25 g
M0054	Methyl Alcohol, Reagent, 500 mL

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

Poly-Ox with a Twist Demonstration 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?

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