nano@illinois

Research Experiences for Teachers (RET)

Properties of Polymers and Solubility

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**Description:**

In this module, students will be introduced to the exciting world of polymer chemistry by investigating the various unique properties of polymers. After an introductory activity in which students learn about the properties of polymers, a class discussion and a lecture will solidify their understanding of the material with a particular focus on how molecular structure influences macroscopic properties. As an assessment, students will relate the properties of these polymers to their molecular structure, and use their new knowledge of polymers and their properties to choose the best solvent for a variety of laboratory tasks. The students will also understand the important roles polymers play in the field of nanotechnology.

**Learning objectives:**

* Student will be able to:
  + Describe the general structures of synthetic polymers.
  + Describe the general properties of synthetic polymers.
  + Predict the solubility of various polymers in various solvents and justify their choices using the structures of each molecule.
  + Apply their knowledge of polymer properties to a real-life problem.

**Prerequisite knowledge/skills:**

* Atoms, Molecules, and Compounds
* Chemical and Physical Properties
* Lewis (Electron-Dot) Structures for Molecules
* Intermolecular Forces of Attraction
* Basic science lab techniques
* Basic science safety procedures
* Reviewing structural formulas of organic molecules is recommended.

**Duration:** 126-168 minutes (3-4 42-minute class periods)

**Target grade level(s):** 9-12

**Target subject(s):** Chemistry (Multiple Levels)

**Alignment with Next Generation Science Standards:**

* HS-PS1-1.
  + Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
* HS-PS1-3
  + Matter and Its Interactions  
    Students who demonstrate understanding can: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

**Background:**

Synthetic polymers play important roles in the field of nanotechnology. An understanding of their basic chemistry and properties will assist with a wide variety of laboratory techniques. For example, engineers will often use a polymer coating such as PPC to coat a silicon chip. That coating will later need to be completely removed – every last speck. Removing the polymer is done by dissolving it in a variety of solvents; solvent efficacy varies based on the solvent type and polymer type. This solubility depends on the structure of the polymer subunits. Following the general idea that “like dissolves like,” molecules with more polar groups will dissolve more easily in polar solvents such as water and isopropyl alcohol. Polymers with less polar groups will require a less polar solvent. The dipole-dipole and induced dipole attractions between the polymer and solvent molecules vary based on the electrostatic attractions between the molecules. In this module, students will practice relating solubility to the polarity of a molecule and make predictions about solubility based on polarity.

Synthetic polymers are a very broad class of molecules, and as such, it is difficult to make sweeping generalizations about their properties. This module attempts to introduce students to some general properties (such as behavior under various temperatures) as well as some more specific and interesting properties.

This module concludes with a laboratory challenge where students will need to remove an anti-reflective coating from a plastic lens. This mimics the removal of a polymer coating from a silicon chip. Students will be able to choose from a variety of solvents to experiment with and assess the solubility of the anti-reflective coating, and will use their observations to make predictions about the nature of the coating. Anti-reflective coatings on glasses may vary in their composition, and not all coatings may be made strictly of polymers- but students will still gain the valuable experience of scientific experimentation and model the process of polymer removal using a solvent. As an optional extension, the teacher may choose to investigate the optical properties of the lens before and after the removal of the anti-reflective coating.

**Preparation time:**

* For the station activity: 30 minutes
* For the laboratory assessment: 60-75 minutes depending on the number of students

**Preparation notes for materials and chemicals:**

*For the stations activity:*

* Prepare three different distinct stations by setting out the materials at each station in advance. The following provide enough materials for 10 groups of 3 students plus a little extra just in case.
  + Station 1: White glue (300 mL), water source, 2 graduated cylinders, 10 paper cups, 75 mL borax, hair dryer, stirring rod with rubber policeman
  + Station 2: Teflon tape (pre-cut into 3-4 cm strips so students do not waste it); cling wrap (pre-cut into 3-4 cm2 squares), Parafilm (pre-cut into 1 in2 squares), scissors, metric ruler
  + Station 3: 20-25 paper clips (any size)

*For the laboratory assessment:*

* After reviewing each student’s or group’s procedure, I suggest assembling the required reagents and equipment for the student in a small plastic box (such as shoebox) for students to keep themselves organized during the lab (and to prevent their lab materials from getting mixed up with that of another group).
* Acetone, isopropyl alcohol, and ethanol do not require special preparation, but students should be given limited quantities of these reagents. Acetone, isopropyl alcohol, and ethanol should be stored in containers with lids that close tightly; otherwise, the solvents will evaporate.
* Students will find that rubbing alcohol is the best solvent for removing the anti-reflective coating. Students may experiment with various concentrations and combinations to determine the optimal concentration for their particular polymer.
* Depending on the type of anti-reflective coating on the lenses, student results may vary widely. Inexpensive plastic lenses with anti-reflective coating from a drugstore will have a less expensive coating that is typically easier to remove. To this end, you may find it more appropriate to evaluate students on the soundness of their procedure and scientific methodology rather than their success with removing the polymer.

**Safety:**

* Students should wear protective eyewear throughout the laboratory activities.
* Students should wear protective eyewear, gloves, and a chemical splash apron when working with acids, bases, and chemical solvents.
* Students should work in a fume hood when using volatile solvents such as acetone and isopropyl alcohol.
* All standard laboratory safety practices should be followed and students should be supervised by an adult at all times.

**Waste disposal:**

* Acetone, isopropyl alcohol, and ethanol may be collected in a single waste beaker and stored in the fume hood for disposal following your state and federal guidelines.

**Materials/supplies/equipment needed with example source listed/pricing/CAS # and contact information**

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|  | Example Source | Link | Price |
| Borax | Amazon | <https://www.amazon.com/Borax-Laundry-Booster-Powder-Pounds/dp/B018HUUK40/ref=sr_1_3?s=industrial&ie=UTF8&qid=1520018115&sr=1-3&keywords=borax> | $11.23/ 4 lbs |
| White Glue | Amazon | <https://www.amazon.com/Colorations-Washable-White-School-Glue/dp/B01HZMNSHC/ref=sr_1_1_sspa?s=industrial&ie=UTF8&qid=1520018068&sr=1-1-spons&keywords=white+glue&psc=1> | $18.99/gallon |
| Polyethylene Wash Bottle, 250 mL | Flinn | <https://www.flinnsci.com/bottles-washing-polyethylene/> | $4.50 each |
| Paper Clips | Amazon | <https://www.amazon.com/AmazonBasics-Paper-Clips-Nonskid-10-Pack/dp/B074K6BRXS/ref=sr_1_1_sspa?s=industrial&ie=UTF8&qid=1520017816&sr=1-1-spons&keywords=paper+clips&psc=1> | $7.99 for 1,000 |
| Paper Cups | Amazon | <https://www.amazon.com/oz-White-Paper-Cups-Pack/dp/B074KL2RWF/ref=sr_1_1?s=industrial&ie=UTF8&qid=1520017833&sr=1-1&keywords=paper+cups&dpID=41DG7kNQAJL&preST=_SY300_QL70_&dpSrc=srch> | $12.99 for 100 |
| Acetone, laboratory grade | Flinn | <https://www.flinnsci.com/acetone/> | $33/4L plus hazardous shipping charge |
| Isopropyl alcohol, 95% or 70%, laboratory grade | Flinn | <https://www.flinnsci.com/isopropyl-alcohol-laboratory-grade/> | $37/4L plus hazardous shipping charge |
| Ethanol, 95% Solution | Flinn | <https://www.flinnsci.com/ethyl-alcohol-95/> | $28/4L plus hazardous shipping charge |
| Teflon® Tape | Amazon | <https://www.amazon.com/Teflon-Thread-Seal-Tape-Sealing/dp/B06WW6M7F9/ref=sr_1_1_sspa?ie=UTF8&qid=1520017671&sr=8-1-spons&keywords=teflon+tape&psc=1> | $9.99 |
| Parafilm ® | Flinn | <https://www.flinnsci.com/parafilm-m-rolls/> | $27.25/250 ft |
| Hair Dryer | Amazon | <https://www.amazon.com/Conair-Keeper-Folding-Handle-Retractable/dp/B009ZPMPGI/ref=sr_1_1_sspa?s=industrial&ie=UTF8&qid=1520017884&sr=1-1-spons&keywords=hair+dryer&psc=1> | $11 |
| Stirring rod with rubber policeman | Flinn | <https://www.flinnsci.com/rubber-policeman-angle-shaped/ap1650/> | $0.86/ea |
| Scissors | Amazon | <https://www.amazon.com/CCR-Scissors-Comfort-Grip-Handles-Titanium/dp/B071768FQ3/ref=sr_1_1_sspa?s=industrial&ie=UTF8&qid=1520017902&sr=1-1-spons&keywords=scissors&psc=1> | $10.00 for 10 scissors |
| Metric Rulers | Amazon | <https://www.amazon.com/School-Smart-Through-Flexible-Inches/dp/B003U6OV9C/ref=sr_1_9?s=industrial&ie=UTF8&qid=1520017917&sr=1-9&keywords=metric+ruler> | $4.50 each |
| Plastic Wrap | Amazon | <https://www.amazon.com/Glad-ClingWrap-Plastic-Food-Wrap/dp/B0014CZ0TE/ref=sr_1_4_a_it?ie=UTF8&qid=1520018551&sr=8-4&keywords=plastic+wrap> | $2.50/roll |
| Anti-reflective coated glasses lenses | Amazon | <https://www.amazon.com/Computer-Glasses-Polycarbonate-Anti-reflective-Protection/dp/B00ABTTJS4/ref=sr_1_3?s=industrial&ie=UTF8&qid=1520017942&sr=1-3&keywords=anti+reflective+coating+glasses&dpID=41YwGix1g4L&preST=_SY300_QL70_&dpSrc=srch> | $15.60 for two lenses |
| Light Microscope | Flinn | <https://www.flinnsci.com/flinn-basic-microscope/ms1130/> | $93/ each |

**Procedure/activity:**

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Polymer Station Activity

Student Guide

In this activity, you will investigate a variety of interesting properties of synthetic polymers.

Station 1. Viscoelastic Properties of Polymers

Background: *Viscosity* is a substances’ resistance to flow. *Elastic materials* stretch with pulling but return to their original position when the force is released. Many polymers, such as the polyvinylacrylate in white glue, have interesting *viscoelastic* properties.

Materials: White glue, water, 2 graduated cylinders, paper cup, borax, hair dryer, stirring rod with rubber policeman

Directions: Measure 25 mL of white glue into a paper cup.

Make some observations about the glue. Is it viscous? How about elastic?

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Measure 10 mL of water in a graduated cylinder and add to the paper cup. Measure 5 mL of borax solution and stir or knead well. Observe how the properties of the mixture have changed. Is it viscous? How about elastic?

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Shape the mixture into a ball and dry it with the hair dryer to “cure” the ball. Test out its bounciness! Does it bounce?

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Station 2: How do polymers behave under different stressors?

Teflon ® is the brand name for polytetrafluoroethylene, abbreviated PTFE. This polymer has a large number of C-F covalent bonds, which are incredibly strong. Teflon is one of the most nonreactive chemicals on the planet because it requires a large amount of energy to break the C-F bonds. Teflon is used for a variety of applications, most famously as the non-stick coating on cookware.

Plastic cling wrap may be made from a variety of synthetic polymers, the most common being polyvinyl chloride (PVC).

Parafilm ® is not a polymer, but is made largely from Paraffin wax, which is a mixture of nonpolar hydrocarbons.

Materials: Teflon tape, plastic cling wrap, Parafilm, scissors, ruler

Observe the Teflon tape. What does it look like? Feel like?

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Observe the plastic cling wrap. What does it look like? Feel like?

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Observe the Parafilm. What does it look like? Feel like?

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Cut a strip of each film approximately 1 inch in length. Carefully stretch each film lengthwise until the strip breaks. Use your ruler to measure the length the strip stretches before it breaks. Record your observations as the tape stretches.

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How did the properties of the two polymers compare to the Parafilm, which was not a polymer?

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Station 3. How do polymers behave at different temperatures?

At this station, you will model the behavior of a polymer under various temperatures using a linked chain of paperclips to represent a polymer chain.

1. Lay the paper clip chain, completely stretched out, on the lab bench top. Observe the angles at which the paper clips lie.
2. Taking care not to hit the paper clips, hit the surface of the lab bench top with the palms of your hands with the force you might use when giving a high-five. Observe the behavior of the paperclip chain- how does it respond to the vibrations of the table?

3. Reset the paperclips to their original setup, then repeat the previous step but with more force.

*Remembering that temperature is directly related to the molecular motion of particles, describe the behavior of polymers under high temperatures as compared to lower temperatures.*

Polymers and Intermolecular Forces Laboratory Assessment

Over the past few days, you have learned quite a bit about polymers, their properties, and intermolecular forces. Now, you will have an opportunity to apply your knowledge to solve a problem.

Your tasks:

* identify a suitable solvent (or sequence of solvents) that may be used remove the polymer without damaging the plastic lenses underneath
* predict the likely structure of the unknown polymer based on its solubility

Materials available for your use:

* Four anti-reflective coated lenses (three are to practice on, one will be evaluated for your final assessment).
* Standard chemistry laboratory equipment including: Beakers, Erlenmeyer and volumetric flasks, graduated cylinders, stirring rods, label tape, sharpie markers, Parafilm, hot plates, wash bottles, chemical scoops, scales, weighing trays, light microscopes

Chemicals available for your use:

* Acetone
* Isopropyl Alcohol
* Ethanol
* Distilled or deionized water
* Tap water
* Dish soap
* Other chemicals may be available to you- check with your instructor for approval if you would like to use something not listed here.

Safety:

* Acetone washes should be conducted in a fume hood.
* Personal protective equipment including goggles, gloves, and an apron should be worn when working with all chemicals listed above.
* Acetone, isopropyl alcohol and ethanol are all volatile; take care to avoid breathing in their vapors.

Waste Disposal:

* Acetone, isopropyl alcohol, and ethanol may be collected in a single waste beaker and stored in the fume hood.

Deliverables:

* You will return for evaluation at least one of your lenses with the anti-reflective coating removed to the best of your ability.
* You will submit a one or two paragraph summary of your polymer’s solubility in various solvents supported by your observations.

Evaluation

This rubric may be used to evaluate the student’s work.

Part 1: Lens Clarity

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Exceeds expectations | Meets expectations | Approaching expectations | Does not meet expectations |
| Removal of Anti-reflective coating | All of the anti-reflective coating has been removed using chemical means. | At least 75% but less than 100% of the anti-reflective coating has been removed using chemical means. | At least 50% but less than 75% of the anti-reflective coating has been removed using chemical means. | Less than 50% of the anti-reflective coating has been removed or the student. |
| Integrity of Plastic Lens | The plastic lens is undamaged. | The plastic lens has a small amount of damage, but the damage does not impair the function of the lens. | The plastic lens has moderate damage that impacts the function of the lens. | The plastic lens has moderate damage and the lens is no longer usable. |

Part 2: Paragraph

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Exceeds expectations | Meets expectations | Approaching expectations | Does not meet expectations |
| Collection of Data | Student describes polymer behavior under 3-5 solvents. | Student describes polymer behavior under 2-3 solvents. | Student describes polymer behavior under 1-2 solvents. | Student does not report the results of sufficient trials, or the trials do not accurately address the solubility of the polymer. |
| Analysis of Data | Student draws a conclusion regarding the solubility of his/her polymer that is supported by his/her data, and ranks the relative solubility under different solvents accurately. | Student draws a conclusion regarding the solubility of his/her polymer that is supported by his/her data. | Student draws a conclusion that is only partially supported by the student’s data. | Student draws a conclusion that is contradicted by the data, or the student fails to draw an appropriate conclusion. |

**Presentation talking points:**

Slide 1: Synthetic polymers have a large diversity of practical uses in everday life. Your coffee cup, lunch bag, and even your clothing are likely to be made from polymers. Your athetic equipment and clothing almost certainly contain a number of polymers. So what exactly is a polymer?

Slide 2: A useful analogy for polymers and monomers is that a monomer is like a bead and a polymer is a string of beads. We won’t cover organic (naturally occurring) polymers here, but rather artificially synthesized synthetic polymers.

Slide 3: Engineers select polymers based on the desired functions and characteristics of the end product.

Slide 4: The instructor might consider bringing in several examples of everyday objects made of these polymers, perhaps labeled, for students to handle. The instructor might ask: how do these objects compare? How are they different? (Most moderately flexible; many are translucent; some are designed to be waterproof, or retain heat).

Slide 5: It is helpful for students to recognize that polar molecules tend to be asymmetrical. Electron pairs are not always pictured in the Lewis structures, so the instructor might explicitly point out that there are two electron pairs on the oxygen atom in the water molecule. Students may require an explanation (or review) of structural notation for organic molecules. Try to avoid the use of the phrase “like dissolves like” as a justification- it is a mnemonic, not an explanation. Polar molecules are miscible in other polar molecules because they are attracted to one another; polar molecules are not attracted to nonpolar molecules and thus the two are not miscible.

Slide 6: Here are a variety of solvents used to dissolve polymers in nanotechnology labs. Most of these solvents are far too volatile, carcinogenic, or both for use in high school labs, but it is useful to inspect their structures. They are useful for emphasizing that polarity of molecules exists on a spectrum, and that molecules are not simply “polar” or “nonpolar”; for example, NMP is polar but not as polar as GBL. Volatility is a consideration because it affects how quickly a molecule evaporates.

Slide 7: Here, students are shown two very common polymers (PVC and PTFE) in typical polymer notation. PTFE is expected to be more dense- although Cl has a heavier atomic mass than F, there are more F atoms than Cl atoms in a single unit of PTFE. Hydrogen has an very light molar mass. The instructor might point out that we would expect the spacing of the monomer subunits to be similar in the two molecules, otherwise it would be difficult to compare the densities.

Slide 8: Here, we would expect vinyl chloride, which is polar (negative pole around the chlorine), to be more soluble in water than tetrafluoroethyne, which is nonpolar (symmetric distribution of charge). As a follow up question, the instructor might ask which of the two molecules would be more soluble in a clearly nonpolar solvent such as benzene.

**Links to the research articles and other resources:**

[1] Fritz, N., Dao, H., Allen, S. A. B., & Kohl, P. A. (2012). Polycarbonates as temporary adhesives. *International Journal of Adhesion and Adhesives*, *38*, 45-49.

[2] Li, H., Wu, J., Huang, X., Yin, Z., Liu, J., & Zhang, H. (2014). A universal, rapid method for clean transfer of nanostructures onto various substrates. *ACS nano*, *8*(7), 6563-6570.

[3] Berger, M. (2014, July 8). A universal and rapid method for transferring nanostructures. Retrieved July 18, 2017, from <http://www.nanowerk.com/spotlight/spotid=36430.php>

[4] “Plastics.” *The Basics: Polymer Definition and Properties*, plastics.americanchemistry.com/plastics/The-Basics/.

[5] “Structure and Properties of Polymers.” *Flinn Scientific.*

For the Bouncy Ball recipe used in the Stations Activity:

[6] “Level Chemistry Events.” CHEMATHON, University of Maryland, 2017. <http://blog.umd.edu/chemathon/level-i-chemistry-events/>.

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The *nano@illinois* Research Experience for Teachers (RET) at the University of Illinois at Urbana-Champaign (from 2014-2017) exposes a diverse set of in-service and pre-service science, technology, engineering, and mathematics (STEM) teachers and community college faculty from across the nation to cutting-edge research in nanotechnology. The RET focuses on recruiting underrepresented minority populations (focused on ethnicity, geography, disability, and veteran status) including women and will target teachers from high-need areas, including inner city, rural, low-income, and those with significant URM students. Participants conduct research over 6 weeks in world-class labs with 4 follow-up sessions during the school year.

Teacher professional development opportunities includes teacher-focused lectures, mentoring, networking, poster sessions, ethics seminars, hands-on modules, STEM education issues, career choices, and resources for implementing a nano lab and curriculum. Teachers will develop modules to be disseminated widely and present their results. High-quality follow-up sessions and evaluation will be infused.

The nano@illinois Research Experiences for Teachers (RET) is managed by the University of Illinois Center for Nanoscale Science Technology.

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