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Educational Resources: Polymers

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Polymers

This document contains 3 polymer-based activities demonstrating different properties of polymers – the physical characteristics, possible absorbency, and elasticity. These activities can be abbreviated and used in rotating stations, planned over multiple days, or you can pick one that fits best with the classroom environment.

Relevant Indiana state standards

Note: Polymers are never mentioned as a specific topic in any standards, although they are an important concept.

- 5.PS.2 Demonstrate that regardless of how parts of an object are assembled the mass of the whole object is identical to the sum of the mass of the parts; however, the volume can differ from the sum of the volumes. (Law of Conservation of Mass)
- Fits with “Super-Absorbent Polymers”
- 6-8.E.4 Develop a prototype to generate data for repeated investigations and modify a proposed object, tool, or process such that an optimal design can be achieved.
- Fits with “Rubber Bouncy Balls”
- 7.ESS.6 Research common synthetic materials (i.e. plastics, composites, polyester, and alloys) to gain an understanding that synthetic materials do come from natural resources and have an impact on society.
- 8.PS.6 Compare and contrast physical change vs. chemical change. Analyze the properties of substances before and after substances interact to determine if a chemical reaction has occurred.
- Fits with “Super Absorbent Polymers”

What are polymers and what can they do?

This is meant to demonstrate the wide range of what polymers can do and their properties.

Supplies

- Paperclips (a single paperclip and a chain of 6+ for each person/group)
- PFTE tape
 - Also known as Teflon tape or thread seal tape
 - PFTE stands for polytetrafluoroethylene, a polymer
 - It's a white tape that will stretch along the width but not the length
 - Around 1-2 inches long per person.
- Pen/permanent marker (for writing on PFTE tape)
- Newspaper sheets (1/4 sheet)
- Plastic grocery sack pieces
 - Each student needs around a 4 inch square. Just enough to recognize what it is and stretch it.
- Other polymer materials
 - A rubber band, plastic toy brick, cotton yarn (natural polymer), clear plastic cup, and/or a rubber eraser
 - These shouldn't be destroyed every time, but depending on how destructive the students are, some pieces may sustain damage.

Pre-activity questions

- Can you think of any similarities between a rubber eraser, plastic brick, and pop bottle?
 - Could talk about how they are manmade, plastic, or can be the same color?
- Look around and pick an object. Describe 3 physical properties.

- Physical properties include color, hardness, melting point, texture, crystal structure, and more. This does not include the current shape. For example, physical properties of a wooden table include that it's brown, solid, and not super hard (can be scratched relatively easily).

Discussion topics/topics to know

- Polymers and polymer chains (section 1, Paperclip Polymers)
 - Polymers are made from a long chain of monomers.
 - Monomers are smaller repeating pieces of covalently bonded atoms.
 - Because polymers are long chains, they are heavier and larger molecules.
 - Their size and length gives them different properties.
- Natural and synthetic polymers
 - Polymers appear in nature, like cellulose (wood), cotton, natural rubber, and silk.
 - We also have a lot of synthetic polymers.
 - Plastics, nylons, Teflon, and acrylic are all manmade polymers.
 - Synthetic polymers are normally created or used for specific properties.
 - For example, Teflon is used to coat non-stick pans
- Direction of polymers
 - Polymer molecules align in different directions in substances. This partially informs what the properties and shape of a polymer is.
 - They can be tangled together or all in a line.
- Physical properties
 - Physical properties are properties that can be observed without chemically changing a substance and are consistent.
 - These include color, melting point, boiling point, hardness, and plasticity.
- Common properties of polymers/definitions
 - Ductile: An object is ductile if it bends when you apply a force
 - Brittle: An object is brittle if it breaks when you apply a force
 - Plasticity: How ductile or brittle an object is
 - Tension: stretching

Instructions

This has 3 different sub-sections. The first section uses paperclips to show the difference between molecules and polymers. The second section talks about the alignment of polymer chains in different polymers. And finally, the third section lets students describe and compare the properties of a variety of polymers.

Depending on the quantity of materials and class time you have, these 3 sections could also be set up as stations around the classroom with some minor modifications.

Paperclip Polymers

1. Give each student/group a paperclip chain and a single paperclip.
2. Have students try to bend the single paperclip as far as they can. It should break at some point and not bend easily.
3. Now have students try to bend the entire paperclip chain. Because it's a chain, it should bend pretty easily in any direction.
 - a. Paperclips are not made of polymers, but they work well for a physical representation.
 - b. The single paperclip represents a small molecule, which can't bend very well or have a lot of flexibility.

- c. The paperclip chain represents a polymer. The paperclips are all similar to monomers. The long chain has different applications than a bunch of individual paperclips.

Directionally Challenged Polymers

1. Every student or group needs a quarter sheet of newspaper, part of a plastic grocery sack, and a piece of PTFE tape.
2. Have half the class hold the newspaper normally with the text readable and the other half hold the newspaper piece rotated 90 degrees so all the text is sideways.
3. Everyone now should try to rip it from top to bottom.
 - a. People holding the newspaper normally should have it rip nicely down the middle.
 - b. Those holding it rotated will have a weird/small rip.
 - c. The cellulose in the paper (a polymer) is all aligned vertically, so ripping with the polymer works, but ripping against it is tough.
4. Next up is comparing how 2 polymers react to stretching. (the grocery bag and PTFE tape)
5. Have students write or draw something on the grocery sack and the PTFE tape.
6. Now stretch the tape and the sack
 - a. The tape should be stretched width-wise
 - b. This should deform all the writing
7. And stretch in the other direction (so, for the PTFE tape, length-wise)
 - a. The writing on the PTFE tape is back to normal, while the grocery sack looks worse.
 - b. This is because the polymers in PTFE tape all run parallel with the tape and don't stretch, but just shift around a little.
 - c. Plastic grocery bags are also made of polymers, but their molecules are just in a giant tangle, so when they stretch, it stays that way.

Polymer Diversity

1. Give every student multiple samples of various polymer-based objects (suggestions in the "**Supplies**" section)
 - a. If you don't have enough for an entire class set, have students get in groups and pass the samples around.
2. Students need to compare and contrast the properties of these polymers, including color, plasticity (ductile vs brittle), and reaction to tension (stretching).

Post-activity questions

- A scientist just created a synthetic polymer in the lab. It's transparent, doesn't stretch, can bend without breaking (ductile), and is water resistant. What could this new polymer be used for?
 - It's up to student's creativity. Maybe some sort of window, bowl, dishwashing piece, or something else.
- Why do scientists want to create materials that have different strengths?
 - We use plastic bags, rubber bands, and Teflon-coated pans. Specific properties give every substance a specific role to play.
- All of the objects here (except the paperclips) were made of polymers. What is one advantage of scientists learning more about polymers?

- Scientists can do more/create more/understand more of how polymers might interact.

Optional Extensions

- To add to Directionally Challenged Polymers, you can make a larger demo piece using sticks and string
 - Make a bunch of parallel lengths of string between two sticks (similar to the warp threads when weaving). If you want, add a design in Sharpie on the string that's visible when the string is pulled taut.
 - Holding the sticks apart, have a student take ahold of the strings at the top and bottom and pull them apart.
 - It creates a similar shape to the misshapen PTFE tape.
 - Now have the student slowly relax while you pull on the sticks
 - Everything is now back in order
 - This shows on a macro scale how the polymer molecules in Teflon are aligned and why that works
- Another small demonstration involves string and bags
 - Have 1 bag with short (approx. 1 foot) pieces of string, one with medium (1 yard), and 1 with just one long piece.
 - Invite students to come up and pull a piece of string out of each bag. The short one will be the simplest, and the long the hardest.
 - This once again connects to how the length of polymers changes their properties. Long molecules can wrap around themselves and hold different bonds based on shape.

Super-Absorbent Polymers

Supplies

- Diapers (or straight sodium polyacrylate)
 - Gardening stores sometimes have small bags of sodium polyacrylate, as it's also used to retain water in soil
- Cups/beakers for students
- Water
- Small paper cups or 100 mL beakers
- Sodium Chloride (table salt)
- Balances accessible for students (optional, only if this is also being used to demonstrate how the total mass does not change)
- 10 mL graduated cylinders or tablespoons (1 tablespoon is around 14-15 mL of water)
 - Plastic dosage cups also measure mL
- Optional: Some other product such as Instant Snow to compare the two polymers

Warnings/Hazards

- Do not rinse the polymer down the sink, as it may clog the drain. The sodium polyacrylate can be thrown away in the trash
- Do not get sodium polyacrylate in your eyes.
- Do not ingest sodium polyacrylate. Make sure to wash your hands after use.

Pre-activity questions

- How do you think diapers work?

Discussion topics/topics to know

- Polymers/monomers
 - “poly” means “many”, so polymers are many small molecules (monomers)
- Absorbency
- Compare the super-absorbent polymer to a sponge
- Changes in volume vs changes in mass
- Chemical vs physical changes
 - Water + polymer is a physical change
- Super-absorbent polymers have a variety of uses beyond diapers.
 - Used to clean up and absorb oil spills
 - Used in soil to provide water for plants

Instructions

- Before the day of, prepare getting super-absorbent polymer by tearing apart the diapers and shaking out the polymer crystals.
 - The main method we have used is just cutting the diaper in half with a guillotine paper cutter, then turning the cut end upside-down over a beaker and rolling the edges back and forth/pulling the two parts apart. It's a good idea to pick any larger cotton fiber pieces out.
 - Test and see what method works for you, as practically every set of instructions has a different method.
 - You can also let students get the polymer crystals out of the diapers. Each student needs around half a diaper's worth.
- Give every student a cup/beaker and the portioned amount of polymer. Make sure everyone has easy access to water, whether that's through giving everyone an additional cup with water, jugs for tables, or if there are enough sinks around the classroom.
 - Each student will also need access to salt later.
- Start in the front of the classroom/somewhere students can see that has a bucket or tray, or just over a sink. Pour around 50 mL of water into a clean container and flip it upside down. All the water will pour out.
 - This is just intended to show students what happens without the polymer.
- Have students weigh the cup + polymer and record it.
- Students now should pour 50-100mL of water (10 mL at a time) into their cup with the polymer crystals.
 - For weighing, student can either weigh the water before adding it, or just assume 1 gram per milliliter of water.
 - Have them add until the polymer appears to be almost liquid
 - If the polymer jiggles and has a closer consistency to jello without being able to fully slosh like a liquid, it should be close to capacity
- Now (with caution and over a table just in case a student added too much water), have students flip their cups over.
 - Hopefully, the polymer should stay in the cup
- Once everyone is done observing the polymer with water, have students weigh and add salt.
 - Adding salt causes the polymer to become soupy again due to the addition of sodium cations. This process takes around a minute and is easier to observe with polymer that has slightly under maximum capacity of water.

- If you have time, another extension can be to leave a cup of the polymer and water out for a few days to allow the water to evaporate. Once the water is gone, the polymer will appear practically the same as the beginning, showing that the addition was just a physical change.

Post-activity questions

- Did the mass of the water, polymer, or cup change during this experiment?
- Did the volume of the polymer and water change during this experiment?
- How much water can 1 diaper absorb?
- How much water can 1 gram of polymer absorb?
- What are other possible uses for super-absorbent polymers?

Clean up notes

- If any wet crystals ended up on the floor/tables, first clean up as much as possible, then wait for them to dry, before finally sweeping with a dry cloth. Attempting to clean up jelly-like absorbent crystals with a wet paper towel is a frustrating experience.
- If glassware needs cleaned, start by taking out as much as possible when originally wet. Then, wait for it to dry and scrape out as much as possible again. Finally, fill the glassware with water and let it sit, then scrape off any leftover gel.

Homemade “Rubber” Bouncing Balls (2)

White glue contains the polymer polyvinyl acetate, or PVA. PVA reacts with Borax to form slime, or, with the addition of cornstarch, can form a solid bouncing ball. This is because Borax creates crosslinking in the polymer, and the cornstarch adds the structure.

Supplies

- Borax
 - The borax will need to be dissolved in warm water in order to get the proper concentration. The water does not need to be boiling hot, but room temperature water cannot dissolve the required volume of borax.
 - Each ball needs around a half tablespoon of borax (5 grams)
- Cornstarch
 - 2 teaspoons (5 grams) per ball
- Elmer's white glue
 - We also had success with Elmer's wood glue and clear glue
 - Wood glue forms a stable ball that smooths out easily, but doesn't bounce quite as well as others
 - Clear glue stays more separated and has a tendency to crumble/shatter if dried out at all
 - White glue makes a looser ball that holds together better after a few minutes of drying time
 - 5-10 mL of glue per ball
- Warm water
 - 25 mL per ball
 - 1 tablespoon is a little under 15 mL, so if you don't have metric measuring containers on hand, 1 2/3 tablespoons (aka 5 teaspoons) also works.
- A stirring rod, stick or spoon
- A beaker or disposable cup

- Even when using wood glue, I didn't have any issues cleaning out the container. However, it's sometimes easier and safer to just plan on throwing the cups away.
- Optional: rubber gloves
 - For handling the mixture. It's non-toxic, but you do get a lot of cornstarch on your hands.
- Some sort of measuring stick/yardstick/tape measure

Pre-activity questions

- What is glue normally like when you pour it out?
- Why do balls bounce?

Discussion topics/topics to know

- Crosslinking polymers
 - Polymers create bonds between each other to hold together more
 - This often changes their properties
 - It's a specific property of polymers
- Related to the slime trend – it still involves borax + glue crosslinking, but also uses cornstarch to add more solids

Instructions

For creating each ball:

- Dissolve $\frac{1}{2}$ tablespoon (or $1\frac{1}{2}$ teaspoons) Borax into around 25 mL warm water by stirring
 - All the Borax won't dissolve unless your water is close to boiling, but it's fine.
 - For the first set, the Borax and cornstarch can be premeasured in separate cups to speed up the process.
- Add 2 teaspoons cornstarch and stir until fully combined
 - There will be some slight resistance to stirring immediately after adding the cornstarch because of its tendency to form ooblek, but once it fully combines, it's fine.
 - (As a note, Ooblek is the general term for the non-Newtonian solid made of a specific balance of cornstarch and water. When sudden pressure is applied, the liquid becomes solid, so hitting with a hammer can cause it to shatter but it can drip from your hand. Look it up – it's pretty fun)
- Pour 5-10 mL of glue into the mixture and let it sit for 30 seconds.
- Mix around until the glue piece seems fully rubbery.
 - Squish the glue piece along the side sometimes if possible, as only the outside of the glue piece will react, so pockets of not-rubbery glue exist in the middle
- After it all seems solid, take the glue piece out and squish it around in your hands, starting to shape it into a ball.
 - If parts are still extremely squishy/there's still non-rubbery glue, put it back in the borax/cornstarch mixture and stir again.
 - Because of the mess of the cornstarch/borax/water, the glue piece can be patted dry gently with paper towel before shaping.
- Once it's rolled into a relatively smooth ball, let it sit 30 seconds to dry out a little bit.
- Roll it around in your hands again to fix the flat spot that formed while sitting out and drop it from a specified height. Record the bounce height.
 - Warning about bouncing: It's hard to get an even ball shape, so sometimes the ball will just bounce in a random direction. Be prepared.

Have students repeat the process once more, adjusting the amount of cornstarch, Borax, or water to see how that changes the end result.
Compare everyone's results on the second ball and see who had the highest bounce!

Different Recipe Notes

- Using no Borax will keep the glue from pulling together.
- Half the original amount of Borax makes a looser ball that is a little stickier, but still bounces well.
- Double the original amount of Borax makes a tight ball that bounces well.
- Using no cornstarch will lead to less structure for the glue, just forming a semi-solid sticky gel mass.
- Half the original amount of cornstarch makes the ball much stickier and more slime-like, but once it dries it'll still bounce.
- Double the original amount of cornstarch is the messiest option. The water just turns into a thin slime and the resulting ball is covered in cornstarch and doesn't bounce well without extra drying time.
- Don't add the Borax and the cornstarch at the same time – the borax won't dissolve well at all.

Post-activity questions

- (if the class tried multiple recipes) Which ball bounced the highest?
- What properties changed in the glue to create the ball?

Possible Extensions

- Have students try different glues when creating the new ball
- For a physical demonstration:
 - Have students stand in 2 lines and try to move around.
 - They are 2 separate polymer molecules that are not crosslinked.
 - Now have students on the ends grab hands and crosslink. Have the students attempt to shift around as 2 separate lines.
 - Because they are crosslinked, they are much more solid and can only flex a little – similar to the change in the rubber ball.

Other Polymer Activities/Extensions

Most of these activities were compiled from the November 14, 2017 edition of the Journal of Chemical Education (Volume 94, Issue 11), the same location as some of the above activities. This issue was a special issue on polymer concepts, containing ideas for connecting polymer activities in elementary through undergraduate chemistry.

Tie Dye (3)

- This activity is more suitable for a high school setting
- Students use the process of tie dyeing and diagrams of the chemistry involved to learn more about polymers and dyes through a physical example

Simple assembly activities (4)

- Once again more suited to a high school audience, the Polymer Day activities include tie ins for epoxy mixing and polyurethane creation.

8 – Polymers Full Activity/Key

- They have instructions and academic ideas in the article/supplementary materials

Sources

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3. Tie-Dye! An Engaging Activity To Introduce Polymers and Polymerization to Beginning Chemistry Students

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