Welcome to Whacky Armor!

This is your guide for the virtual workshop experience. Follow along, make your silly putty, and test it out at home!

Big picture

Viscoelastic polymers are soft and somewhat fluid at rest. Some, like gloop or silly putty, will harden temporarily when struck with force. This behavior, called 'shear-thickening', makes them ideal for use in impact protective padding—we call it *Whacky Armor!*

Watch this!

Polymers Background Info: https://www.youtube.com/watch?v=UwRVj9rz2QQ

How to Make Silly Putty: https://www.youtube.com/watch?v=TISHX7CnXl0

Impact Drop Test: https://www.youtube.com/watch?v=q0-bgHkEiSE

Real World Uses: https://www.youtube.com/watch?v=vC4WwXqzSsU

What are polymers?

Before we make our viscoelastic polymer using glue and borax, let's demonstrate how it works.

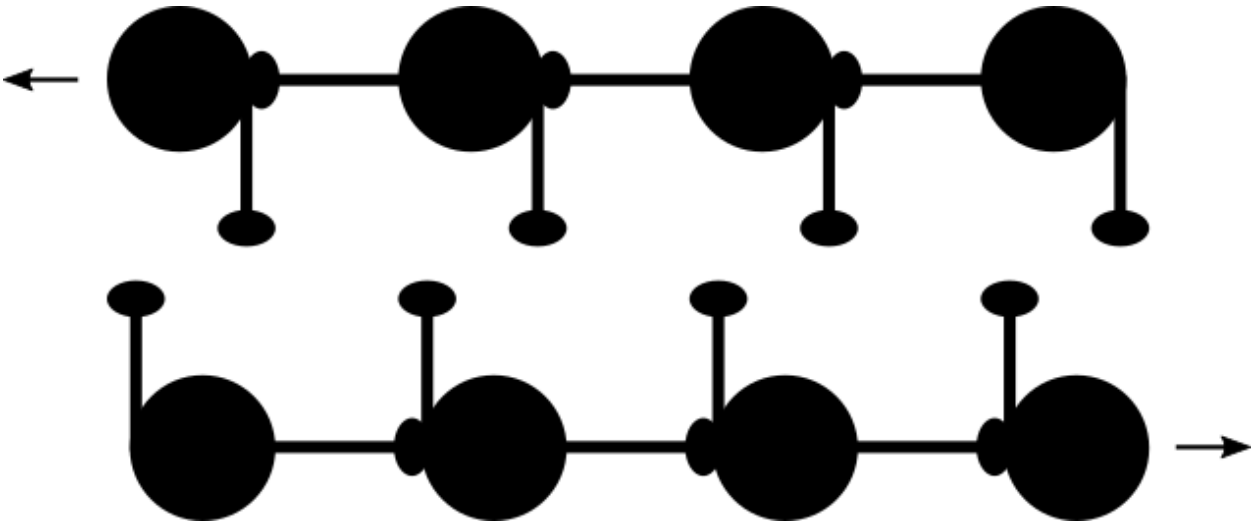
Silly putty is made from crosslinking polyvinyl acetate (glue) and sodium borate (Borax). Each polymer chain of glue is made from *monomers* of vinyl acetate.

VOCABULARY

Monomer: a single chemical unit. The monomer in glue is vinyl acetate.

Polymer: monomers linked together to form long chains. In glue, vinyl acetate monomers form chains of *poly*vinyl acetate, a single chemical unit.

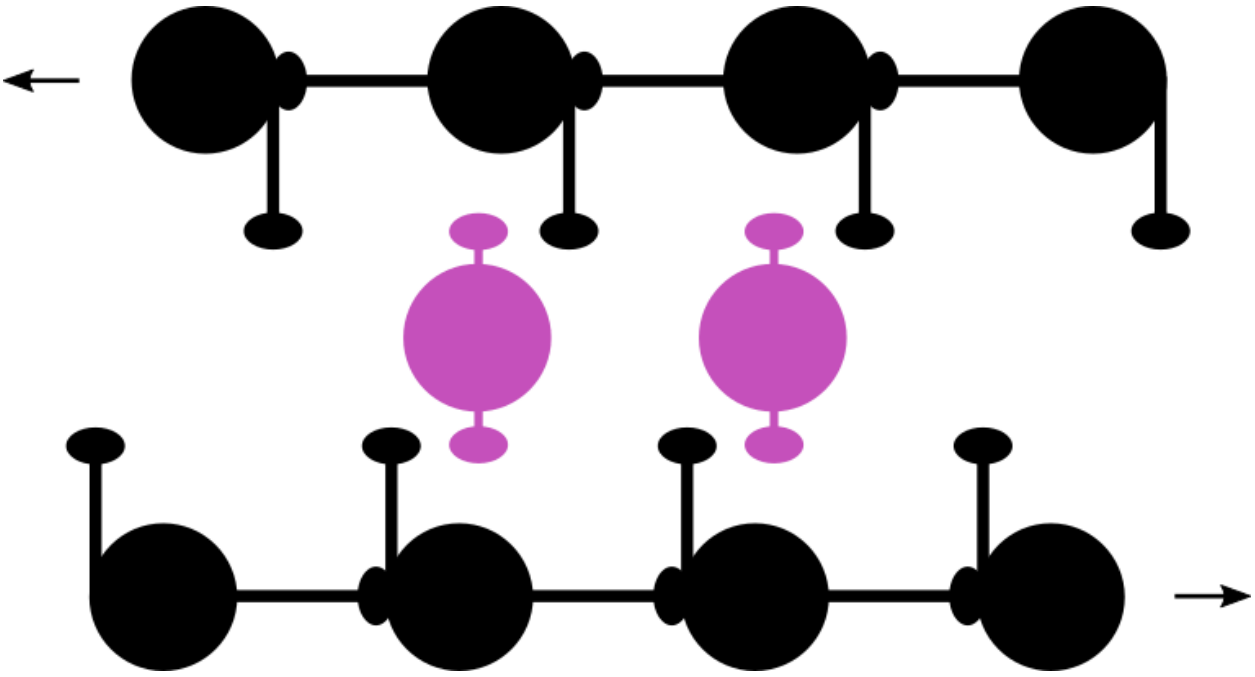
Every polymer is linked together along its "backbone". Some monomers are special and have additional chemical groups off the sides of the backbone, called functional groups. In the figure below, the polymer backbone is represented by the large black circles connected by bonds represented by the black lines. The functional groups are hanging off the sides of each monomer.



VOCABULARY

Functional Group: a group of atoms capable of bonding with other functional groups. In Whacky Armor, the borate ions of the borax react with the polyvinyl acetate in the glue.

Borax also has functional groups that will react with the glue's functional groups. In the figure below, the Borax is represented by the purple circle with two functional groups available.



With silly putty, the Borax and glue will form *cross-links*, short-lived linkages that occur when the glue-borax mixture thickens.

VOCABULARY

Cross-linking: the formation of a chemical bond between two molecules.

When stress is applied to the silly putty, the cross-linking bonds cause the viscoelastic polymer (glue-borax) to harden (undergo *shear thickening*). When the stress is removed, the polymer returns to a more liquid state.

VOCABULARY

Shear thickening: the behavior of a fluid that thickens and hardens when shear stress (such as hitting) is applied but returns to its more liquid state with time or when the stress is removed.

Make Whacky Armor

1. Label two cups: #1 (Glue) and #2 (Borax).
2. Place 5 Tbsp. glue and 4 Tbsp. water into cup #1 and mix well.
3. Add a few drops of food coloring (optional).
4. In cup #2 dissolve 1 Tbsp. of borax in 2 Tbsp. warm water.
5. Pour the borax solution into the glue and water while stirring. Watch the way the two solutions interact while you count to ten. You are making a *colloid.* Stir until completely mixed to a putty-like consistency.
6. Pour the material onto a table covered in plastic wrap or wax paper, and knead until smooth. You've made *Whacky Armor*, a viscoelastic polymer with interesting *viscosity* properties!
7. Play with your *Whacky Armor* and observe how it behaves under these conditions: (Optional: record your observations on your handout.)
   - Shape it into a ball. Can it bounce?
   - Slowly poke your finger into the ball. What do you observe?
   - Squeeze the ball. How does it feel?
   - Lay the ball on the table and quickly tap it with the flat part of your hand. What happens?
   - Leave the ball untouched on the table and count to ten. Does it keep its shape?
   - Roll the putty into a rope about 6" long. Can you wrap it around your finger?
   - Pull the two ends. Does it stretch? Does it break?
8. Put on safety glasses.
9. Take wrapped hard candy and place it on the floor (ideally on a newspaper or other covering). Ask a partner to hold a ruler vertically next to your candy. Drop the 5 lb. kettlebell weight from a height of 12 inches, or the top of the ruler, onto the candy. Did the candy break or is it still intact?
10. Prepare a second piece of candy and lay it on the floor. Cover it with your *Whacky Armor*. Drop the 5 lb. kettlebell weight from a height of 12 inches as in Step 9. What happened? Did the candy break? Is the polymer still flexible? Do you think that Whacky Armor could protect your joints when playing sports?
11. Store the polymer in a resealable bag.

VOCABULARY

Colloid: molecules of one substance dispersed in a second substance. The dispersed particles do not settle, but remain in suspension.

Viscoelastic polymer: a polymer, whose viscosity is affected by shear stress such as squeezing, stirring, or hitting.

Viscosity: a fluid's resistance to flow. Water flows more easily than glue so glue has a higher viscosity than water.

Wrap it up

1. Discuss and compare observations from Step 7. Can you think of ways to use these unusual characteristics?
2. Discuss your observations in Steps 9-10. Explain how dropping a weight on the candy relates to the introductory "glue and borax" demonstration.
3. What are the advantages of using a viscoelastic polymer with shear-thickening properties for protective sports equipment rather than a hard shell?
    - **Answer:** It is light in weight and is flexible enough to conform to the body.
4. Can you think of other fluids that act the same way as the viscoelastic polymer that you made?
    - **Answer:** Quicksand is the made-for-movies example. The more the victim thrashes about the thicker the quicksand becomes and the harder it is to escape. If the victim relaxes, he/she will float because the body is less dense than the quicksand.
    - **Answer:** The synovial fluids in your elbow and knee joints become harder and stronger when mechanical stress is applied. They relax and become more liquid when the stress is removed. Thus, your usually flexible knees will resist impact (to some degree) when you fall while playing soccer.
5. Can I purchase protective gear that uses shear-thickening technology?
    - **Answer:** Yes, both sports and military equipment use shock-absorbing materials with shear-thickening behavior. In the 2006 Winter Olympics, the US and Canadian ski teams made history with their "soft armor." Vests, kneepads, elbow pads, shorts, pants and gloves are widely available.

Acknowledgements: This workshop was adapted from Style Engineers. For more information and additional Functional Apparel activities, follow the link: http://styleengineers.org/