Polymer Lesson

Yellow highlight = required component

Subject Area(s) **Physica, Science and Technology**

Associated Unit

Lesson Title **“Unusual Behavior of Polymers”**

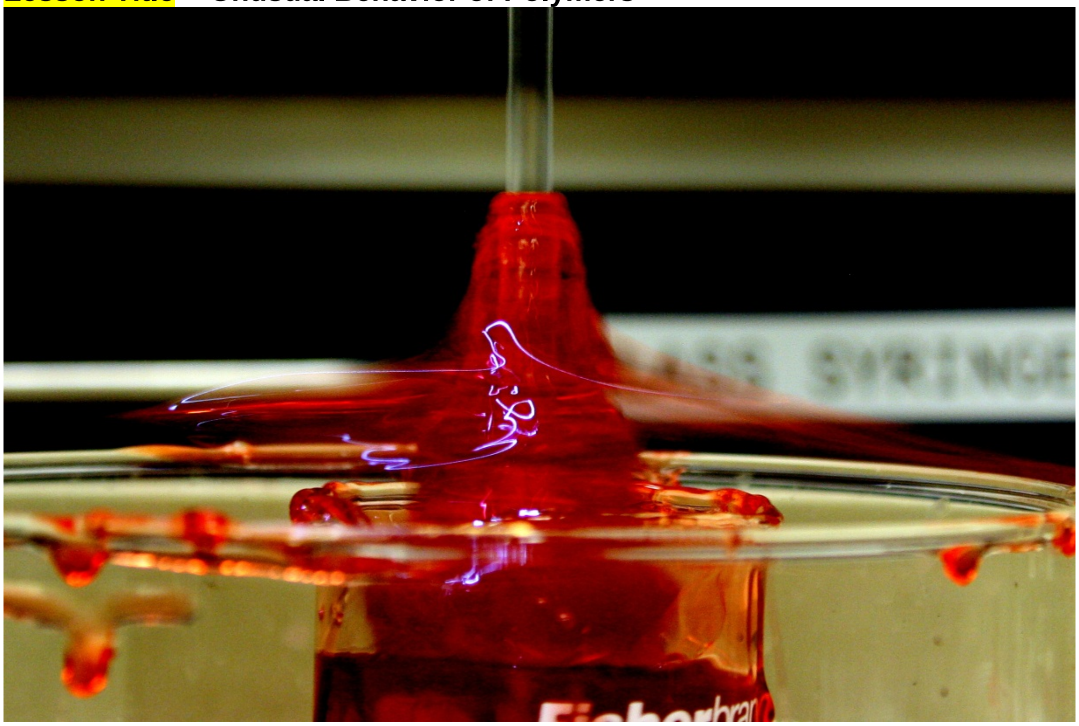

Image 1
Image file: __Weissenberg.jpeg_?
ADA Description: _This is my personal photo__?
Source/Rights: Copyright © ___?
Caption: _Photo of the Weissenberg Effect in action_?

Grade Level (10-12)

Lesson # __ of __

Lesson Dependency

Time Required **50 – 80 minutes**

Summary

Students will be introduced to the world of polymer science. After discussing what constitutes a polymer, the behavior of polymeric materials will be contrasted with simpler materials by discussing Newtonian and Non-newtonian fluids. Macroscopic behavior is linked back to phenomenon on the molecular level. Concepts such as entropy and enthalpy will be explored in detailed to explain some of the unusual behavior of polymers. Four different effects will be covered; Weissenberg, Barus, Kaye, and a defying gravity experiment. Students will then have

an opportunity to make their own polymer that exhibits elastic properties in a short lab. This lab can be accompanied by a discussion in elasticity if desired

Engineering Connection

In the modern age with technology all around us, sometimes we fail to realize how one particular type of material has completely shaped our lives. The seat that you rest on, the panels that make up your car, the shampoo that you washed you hair with, even the oil the helps your engine run contains this special material. Polymers. But what are polymers and how do you take advantage of their unusual properties?

Engineering Category = ***#1 Relating science and/or math concept(s) to engineering***

Choose the category that best describes this lesson's amount/depth of engineering content:
1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

Keywords

Newtonian, Non-Newtonian, Polymer, Polymer Chemistry, Polymer Physics, Viscosity

Vocabulary / Definitions

Word	Definition
Newtonian fluid	A simple fluid in which the state of stress at any point is proportional to the time rate of strain at that point; the proportionality factor is the viscosity coefficient.
Non-Newtonian fluid	Viscous fluid whose stress versus strain rate is non-linear. (ex. Polymer)
Polymer	(Poly-)=Many and (-mer) = unit. A long chain of covalently bonds atoms, primarily composed of carbon-carbon bonds in the backbone of the chain.
Polymer Chemistry	Organic Chemistry concepts that are used to construct polymers
Polymer Physics	Physics that govern the inter/intra-actions of polymer chains.
Viscosity	A measure of a materials resistance to flow. (Honey is more viscous than water)
Enthalpic Interactions	Attraction and repulsions due to molecular forces such as Van der Waals
Entropy	The amount of disorder in the system. Can be used to discuss how many configurations a polymer chain can take.
Shear Thinning	The decreasing of viscosity due to applied shear
Shear Thickening	The increasing of viscosity due to applied shear

Educational Standards

National and State

State of Texas TEKS

(6E) describe how the macroscopic properties of a thermodynamic system such as temperature, specific heat, and pressure are related to the molecular level of matter, including kinetic or potential energy of atoms

(6G) analyze and explain everyday examples that illustrate the laws of thermodynamics, including the law of conservation of energy and the law of entropy

Source:

Chapter 112. Texas Essential Knowledge and Skills for Science
Subchapter C. High School

Statutory Authority: The provisions of this Subchapter C issued under the Texas Education Code, §§7.102(c)(4), 28.002, and 28.025, unless otherwise noted.

---

§112.31. Implementation of Texas Essential Knowledge and Skills for Science, High School, Beginning with School Year 2010-2011.

The provisions of §§112.32-112.39 of this subchapter shall be implemented by school districts beginning with the 2010-2011 school year.

Source: The provisions of this §112.31 adopted to be effective August 4, 2009, 34 TexReg 5063; amended to be effective August 24, 2010, 35 TexReg 7230.

***Texas TEACH** Engineering*

(6E) describe how the macroscopic properties of a thermodynamic system such as temperature, specific heat, and pressure are related to the molecular level of matter, including kinetic or potential energy of atoms;

(6G) analyze and explain everyday examples that illustrate the laws of thermodynamics, including the law of conservation of energy and the law of entropy

Source:

http://www.teachengineering.org/browse_standards.php Year 2009

ITEEA Educational Standard(s)

***STL* Standards and Benchmarks**

Standard 4. Students will develop an understanding of the cultural, social, economic, and political effects of technology.

9-12
H. Changes caused by the use of technology can range from gradual to rapid and from subtle to obvious.
I. Making decisions about the use of technology involves weighing the trade-offs between the positive and negative effects.
J. Ethical considerations are important in the development, selection, and use of technologies.
K. The transfer of a technology from one society to another can cause cultural, social, economic, and political changes affecting both societies to varying degrees.

Standard 5. Students will develop an understanding of the effects of technology on the environment.

9-12
G. Humans can devise technologies to conserve water, soil, and energy through such techniques as reusing, reducing, and recycling.
H. When new technologies are developed to reduce the use of resources, considerations of trade-offs are important.
I. With the aid of technology, various aspects of the environment can be monitored to provide information for decision-making.
J. The alignment of technological processes with natural processes maximizes performance and reduces negative impacts on the environment.
K. Humans devise technologies to reduce the negative consequences of other technologies.
L. Decisions regarding the implementation of technologies involve the weighing of trade-offs between predicted positive and negative effects on the environment.

Standard 6. Students will develop an understanding of the role of society in the development and use of technology.

9-12
H. Different cultures develop their own technologies to satisfy their individual and shared needs, wants, and values.
I. The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures.
J. A number of different factors, such as advertising, the strength of the economy, the goals of a company, and the latest fads contribute to shaping the design of and demand for various technologies.

Technological Literacy: Content for the Study of Technology, Executive Summary © ITEA, 2000 (PDF format, 10 pages, 219KB)

Learning Objectives

- State what is a polymer.
- List everyday items that are made of polymers.
- Briefly explain Newtonian (simple) and Non-Newtonian (complex). Students should be able to name one simple and one complex liquid. Discuss viscosity

- Explain shear thinning and shear thickening in short details. Focus on the overlying idea not on the details. Focus on shear thinning as it is relevant to polymers
- Explain Barus, Faye, and Weissenberg effect and why they are unique to polymers.

Introduction / Motivation

The goal of this lesson is to introduce polymer materials, to discuss how polymers behave different than "simpler" materials, and then to show some of the unique behavior polymers can possess. The concept that the participants need to be thinking about is—Why does a polymer behave differently than say water?

Teacher Notes

****Please review and read the student handout before attempting this lesson. It covers, in layman terms, the origin of the behavior and is an excellent reference for this subject matter. The handout is copied and pasted into the Lesson Background and Concepts for Teachers. Furthermore, all of the demos have been recorded and placed on Youtube. The links are provided in the Multimedia support section.

Preparing the Demos

Two sets of demos will be performed to show the Weissenberg, Barus, Kaye and defying gravity effect. One will use a polyvinyl alcohol (PVA)solution that is crosslinked with Barax and will require a power drill and a glass rod (this will be used to show the various effects). The other will require a bunch of rubber bands and a large wooden rod. These will be discussed in detail later on.

Making the PVA Solution:

1. Heat 100 ml of water to 80C and add in 4 grams of PVA
2. Stir the solution with heat until the PVA is dissolved
3. In another beaker add 20 mL of water and 1 gram of Barax
4. Mix the two solutions and allow time to crosslink
5. Add a color die if desired

Note: If you have difficulties making the solution, a more detailed method is described by NC State and can be found in the attachments.

Performing the demos and giving the Lesson

Before you start, discuss what a polymer is and why they are important. Examples are everywhere. The one I like to give is the fact that 2 in 1 shampoo/conditioner has block copolymers (BCPs) in it. BCPs are where two different types of polymers covalently bonded together. One likes the shampoo matrix and one does not, resulting in the formation of micelles (see *Lesson Background* for more information). In the core of the micelle you can store things such as conditioner. You don't want to shampoo and condition at the same time but instead shampoo and THEN condition. To do this, relies on the interesting behavior of polymers. When you are washing your hair the micelles remain closed because they are surrounded by the shampoo matrix. When you rinse your hair, the shampoo is diluted with water and the micelles open up, releasing the conditioner. While I like this example it may be a bit complex. Example such as chairs, car bumpers, and plastic bottles will serve the same purpose.

After the intro, gauge the classes' knowledge. Ask them about Newtonian and Non-newtonian fluids. Ask them if they have watched the corn starch/water videos and what type of fluid that is (Non-newtonian). Get a feel of the knowledge base and begin the demos. See *Assessment* for more ways to gauge the students' progress.

Weissenberg

Have a beaker of water, a beaker of PVA solution prepared earlier and a power drill with a glass rod as the bit in front of the class. Ask the class what they think will happen when you spin the drill in the water. (Will the water move toward or away from the rod?). After the students answer, perform the demo, showing them that water will move away from the rod. Then ask what will happen when you place the rod in the PVA solution. (Will the solution move toward or away from the rod?)

Perform the experiment, showing that the PVA solution will move up the rod.

Ask the students why this happens. After they guess perform the macroscope demo of salt, rubbers and the rod. Have a pile of salt and rotate the rod in the salt. The salt will move away from the rod. Have a pile of rubber bands and rotate the rod in them. The rubber bands will "grab" the rod and begin to move up.

Begin to explain that the interaction between the salt and the rod, and the rubber band and the rod. As the rod rotates, it is "throwing" the salt away from the rod, overcoming the interactions between the salt and the rod. With rubber bands, there is a large in attraction between the rubber band and the rod due to the wrapping of the rubber band around the rod. If the rubber band is long enough, the free ends grab other rubber bands in the bulk and drag them toward the rod. Due to decrease of entropy and enthalpic interactions in the system, the rubber bands have to move up the rod.

<u>Kaye Effect</u>

The following two effects (Kaye and Barus) are a bit subtle and can just be watched on youtube should the demo prove too difficult.

Hold a syringe of water over a beaker of water and ask the students what will happen when you shoot the water into the beaker. Do the same with PVA solution. The PVA Solution will skip off the surface. Explain that this is due to the shear thinning of the polymer acting as a lubricant resulting in the fluid "skipping" of the surface. Discuss the origins of shear thinning as described in the lesson background section. Explain that this is different than the shear thickening that you see in the corn starch videos. Instead of the fluid becoming solid like, the floor would begin to flow as you ran across it.

<u>Barus Effect</u>

Watch the video of the three effects to readdress the first two phenomenon. After the barus effect comes up, ask them why they think that happens. Explain that energy is put in to compressing the polymer chains, decreasing the entropy. When the polymer exit the die, it can expand and increase entropy again. Again this is discuss in detail in the lesson background section.

<u>Defying Gravity</u>

This is some of the unique behavior of polymers. What if I could defy gravity? Have a syringe, a beaker of water, and a beaker of PVA Solution. Place the syringe in the water and begin to slowly draw some out. As you slowly draw, ask if they think you could continue to pull the water from the beaker while removing the syringe from the beaker. Of course you can't. Perform the same experiment with the PVA. You should be able to pull the PVA solution out while removing the syringe out of the beaker. This is due to chain entanglements. Use the rubber bands to show that as you pull on one, the others are dragged with it.

Polymer Lab

The lab is meant to help reinforce the large molecule nature of polymers. By creating a Silicon ball, students will observe a phase change as the polymer precipitates out of solution as it crosslinks. The lab is taken from Flinn and list in the associated activities. A short explanation over why the ball bounces is included in the *Associated Activity* and *Additional Multimedia Support* section. This activity has its own assessment.

Lesson Background & Concepts for Teachers

If you want to use micelles as an example more information can be found here (http://en.wikipedia.org/wiki/Micelle)

The following was meant to serve as a handout to students but serves as an excellent reference for the teach as well.

Weissenberg

The Weissenberg effect is the instance where the polymer travels up the rod, in contrast to say water that moves away from the rod as it spins. By considering the differences between long chain polymers and water, let us see if we can figure out why this is the case.

As you already know polymers are long chains atoms, most typically with carbon-carbon backbone. These chains interact and entangle, similar to a pile of string. For the case of water, the water has a certain affinity to the rod. As the rod spins, the centrifugal effect throws the water molecule away from the rod. For polymers however, there are many more interactions with the rod per molecule and so much more for is required to remove the polymer from the rod. The chains are also entangled, so as the rod tries to throw the chain of the rod it has nowhere to go and begins to wrap around the rod. As the chain wraps around the rod, it drags more chains closer to the rod due to entanglements. So this explains why polymer come close to the rod but why do they travel UP the rod?

Entropy and Enthalpy

Entropy

Say the classroom was a fraction of the size and you guys were force to be extremely close to one another. What would you want to do? Move in closer or move away from each other? Obviously, you would want your own space and move away from each other. Plenty of room to stretch your arms and legs. Polymers (anything for that matter) are the same. They want to increase **ENTROPY** or disorder of the system.

Enthlapic Interactions

At the same time, say that you are standing next to your friend. While you would like to be able to stretch your legs, since you are next to your friend it is not so bad that you are unable to do so. There is an attraction between both of you. However, if you are next to you nemesis, you would be even more inclined to move. There is repulsion between both of you. This is analogous to **ENTHALPIC INTERACTIONS**. Polymer chains also experience attraction and repulsion due to Van der Waals forces. Given that all the chains are very similar, the chains like each other.

The desire for you to move is balanced between the desire to increase entropy and the enthalpic interactions with your friends. In the case of the polymer chain, their desire to increase their ability to stretch about is greater than their attractions and some net movement has to take place. Since they can't move down the rod without running into other polymer chains, the only option is to move up.

Assessment:

1. What did you observe in the Weissenberg Demo?
2. Name a consumer product that you think would exhibit the Weissenberg Effect.
3. Do you want to maximize or minimize entropy?

Barus (Die Swell)

The Barus effect is similar to the Weissenberg effect in that it is again it can be explained by the balances of the entropic and ethlapic contributions. Think back to the video of the three effects. What happened in for the Barus effect? As the polymer exited the die, it expanded and swelled. Figure 1 (below) shows a general scheme of this effect. Let us see if we can work out why.

If we consider the classroom analogy again, we can get a pretty good idea of what is happens. You are in a classroom but one of the walls can move in and out. The wall slowly moves toward you. Eventually you have to move closer and closer together until you get close enough that through either (or both) entropic or enthalpic contributions you want more space and you begin to push back on the wall. Now imagine the door suddenly opens and you are allowed to leave. You are naturally going to pour on into the hallways and spread out. This is essentially what happens with the Barus effect.

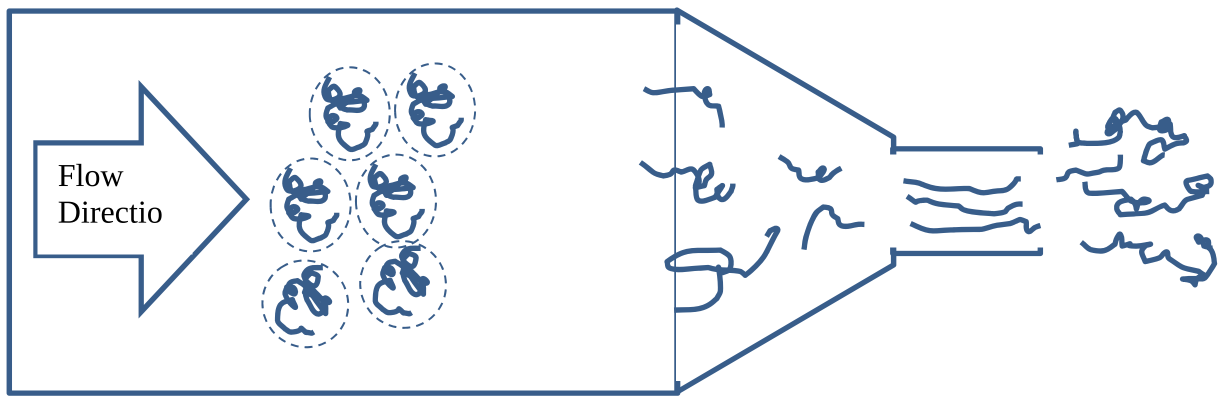

Figure 1 In the large diameter section the polymer chains are relaxed and take up a more natural configuration. As the diameter restricts, the polymer chains get closer together and deviate from that equilibrium configuration. Once the polymers exit the die, it can return to a more favor shape by expanding.

You have a bunch of polymer chains in a confined space and the plunge slowly puts energy into the system forcing the polymer through the die. As it does this the chains have to move in closer together (**decreasing entropy**) and the chain align. The chains move through the die, while pushing on the walls. Once the chains exit the die, they are free to relax and stretch out again by swelling (**increasing entropy**).

Assessment:

1. Which has more entropy available to them… a chain that is forced to be straight or a chain that can free move?
2. Explain why water does not swell after exiting the die. Compare the state of entropy in the die and the one after the die. Is it different or the roughly same?

Kaye

The Kaye effect is a little different. There are a few different theories as to why this takes place so what we explore here may be only part of the reason (or possibly not the reason). **Start by writing down you observations of the Kaye effect that you saw in the video.** The polymer appears to "skip" off the surface. This possibly due to what is known as **SHEAR THINNING**. The polymer outside of the polymer stream shear thins and acts a lubricant allowing the stream to slide or skip of the surface. So let us look at what shear thinning is.

Shearing Thinning

You may have seen those popular Youtube videos showing people running across the pool full of corn starch? Well this is due to **SHEAR THICKENING,** the exact opposite of shear thinning (I will briefly explain shear thickening in class). What you should imagine is a solid floor that as you run across it the ability for the material to flow increases (decrease in viscosity which the fluid's resistance to flow) and you fall through instead of running across. Let us try to explain this on a molecular level. Use Figure 3 as a reference.

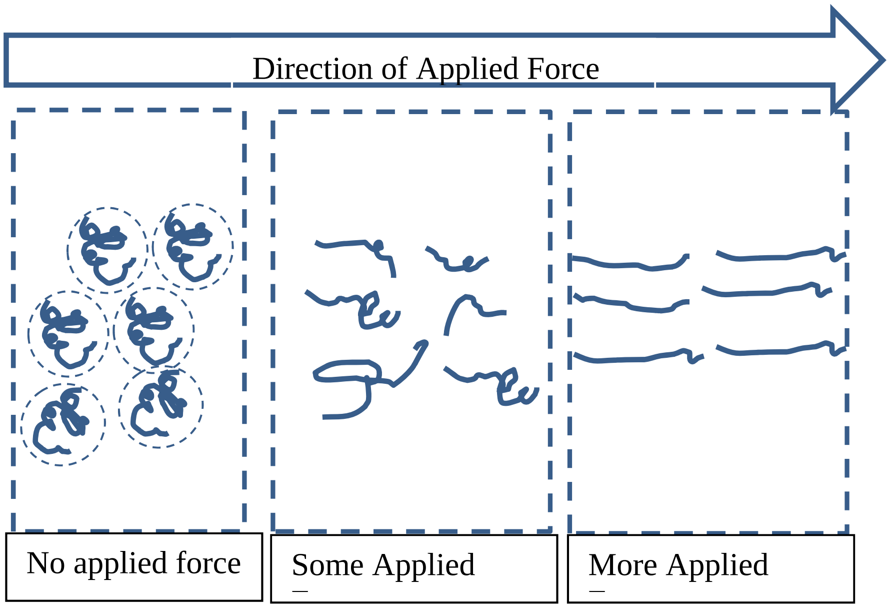

Figure 2 When no force is applied, the polymer are in a relaxed state. As more and more force is applied (it is also depends on how quickly it is applied but we will save that for another day) the polymers stretch out and can slid past one another.

Imagine that you are a long polymer chain. You have had sufficient time to relax and reach a state that minimizes your free energy (**maximized entropy**). This shape you would be in would roughly resemble a sphere (think about why water droplets form). As you move about, you collide with other sphere roughly the same size as you, and it take considerable time for you to go around each other. This is the starting point for this thought experiment. As stress (energy) is applied to the system you are disturbed from your little sphere and are forced to stretch out as you collided with each other. You are not allowed time to relax back to the original state (time constraints) and you remain in this stretched state. You and your neighbors become aligned. You are no longer colliding with large spheres. Instead you are just sliding past each other. Your resistance to flow or viscosity is greatly decreased and you can appear to skip off the surface.

Assessment:

1. What is shear thinning?
2. What is shear thickening?
3. Do lubricants generally possess high or low viscosity?

Associated Activities

Super Ball Lab- Student mix Sodium Silicate and Ethyl Alcohol to create their own super ball

Lesson Closure

Assessment

Pre-Lesson:

As mentioned in the *Introduction* section, when first discussing polymers see if the students can list consumer products that use polymers, and gauge their level of vocabulary dealing with polymer science.

When preforming the demos, ask the students which solution is more viscous (the water or the PVA solution).

Before performing any demo, always ask what they think will happen.

After playing the corn starch/water video ask them if that was shear thickening or shear thinning.

When discussing shear thinning, compare the relaxed state to the shear thinned state. Ask the student which as more entropy

There is also a post assessment handout attached in the *Attachments* section

Lesson Extension Activities

Additional Multimedia Support

Video of the three effects: http://www.youtube.com/watch?v=nX6GxoiCneY

Video of corn starch and water: http://www.youtube.com/watch?v=XjE24MAnDdY

Video of the Polymer Defying Gravity https://www.youtube.com/watch?v=w0Ib25BPR2I

References

Colby, R.H., Boris, D.C., Krause, W.E., Dou, S., 2007. Shear thinning of unentangled flexible polymer liquids. Rheol Acta 46, 569–575.

Hiemenz, Paul and Lodge, Timothy. *Polymer Chemistry*. Boca Raton, FL: CRC Press, 2007

Attachments

Lesson Handout
Lesson Assessment
Flinn Super Ball Activity
Super Ball Assessment
PVA solution write-up

Other

Redirect URL

Contributors

Brian Rohde and Don McGowan

Supporting Program

NSF GK12, College of Engineering, University of Houston