**Key:** Yellow highlight = required component

# Spinning Polymer Solutions for Life's Solutions

**Subject Area(s)** Chemistry

**Associated Unit** Solutions

**Lesson Title** Spinning Polymer Solutions for Life's Solutions

**Header**

**Figure 1**
**Image file:** ___?
**ADA Description:** A nonpolar solute is being dissolved in a nonpolar solvent.
**Source/Rights:** Erica Wilkes
**Caption:** The polymer polystyrene dissolving in d-Limonene

**Grade Level** 10 (10-11)

**Lesson #** __ of __

**Lesson Dependency**

**Time Required** 2-3 50 minute class periods, or a total of 150 minutes.

**Summary**
Students focus on the concept of polarity and how "like dissolves like" by experimenting with polystyrene and starch packing peanuts and trying to dissolve them in water and d-Limonene. Within the lesson, students learn about how polymer solutions are created in the process of electrospinning. This leads to the engineering design challenge where students design a water filtration system to remove copper out of water for the purpose of modeling real life application of nanofibers created from electrospinning.

**Engineering Connection**
Students apply their knowledge of polarity and how "like dissolves like" to relate to how an electrical engineer determines which solvent dissolves different polymers. Students are introduced to the concept of electrospinning and some practical applications of its resulting nanofibers. Lastly, student groups take on the role of an engineer as they design a water filtration system to purify copper out of water. Student groups test their design and share results. Student groups create adjustments to their designs, retest and share their new results.

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

and

Engineering design process

**Keywords**
Electrospinning, polymer, polarity, surface tension, polystyrene, starch, solute, solvent, solubility, solution, concentration, viscosity, d-Limonene, hydrophobic, hydrophilic

**Educational Standards (List 2-4)**
State STEM Standard

Florida: Science, Physical Science, Standard 8 Matter (Grades 9 -12) - Distinguish between bonding forces holding compounds together and other attractive forces, including hydrogen bonding and van der Waals forces.
*(Grades 9 - 12)*

and

Florida: Science, Physical Science, Standard 8 Matter (Grades 9 -12) - Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.
*(Grades 9 - 12)*

ITEEA Standard (required)

Technology: Design - Standard 10. Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving

NGSS Standard (strongly recommended)

Next generation science standards, Science, 9-12, Engineering Design-HS-ESS2-5 Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

and

Next generation science standards, Science, 9-12, Engineering Design-HS-LS1-6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

CCSS Standard (strongly recommended)

The main standard is:

SC.912.L.18.12 Discuss the special properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent.

However, all of the following also apply:

LAFS.910.WHST.3.9 Draw evidence from informational texts to support analysis, reflection, and research.

MAFS.912.N-Q.1.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

SC.912.L.17.15 Discuss the effects of technology on environmental quality.

SC.912.N.1.7 Recognize the role of creativity in constructing scientific questions, methods and explanations.

SC.912.N.3.5 Describe the function of models in science, and identify the wide range of models used in science.

SC.912.P.8.12 Describe the properties of the carbon atom that make the diversity of carbon compounds possible.

SC.912.P.8.13 Identify selected functional groups and relate how they contribute to properties of carbon compounds.

SC.912.P.8.5 Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.

SC.912.P.8.6 Distinguish between bonding forces holding compounds together and other attractive forces, including hydrogen bonding and van der Waals forces.

SC.912.P.8.7 Interpret formula representations of molecules and compounds in terms of composition and structure.

**Pre-Requisite Knowledge**
Students must have an understanding of the size of a nanometer, polymers, surface tension, polarity and solvents, and ability to record materials, procedures and data.

**Learning Objectives**
After this lesson, students should be able to:

- Identify factors that affect solubility, specifically temperature, pressure (for gases), and polarity of solute and solvent. "Like dissolves like."
- Explain how the structural formula of a molecule affects how it functions in regards to polarity and solubility.
- Explain how the size and surface area of a nanofiber can be useful in many applications.
- Design and build a water filtration system.

**Introduction / Motivation (5E – Engage)**
(Students are given an example of both a polystyrene and a starch packing peanut.) Make observations of both the polystyrene and starch packing peanuts. You plan on shipping a very fragile gift to a family member. The recipient of this gift will be at work during the day when the package is delivered. Therefore, the package will be left outside of the front door of the recipient's home and will be subject to the weather. A heavy rain storm is being predicted in this area by the weather channel. How can you determine which packing material would be best to use in this scenario? (Allow class discussion on possible properties that would be necessary for the packing peanut).

Since there is a threat of a heavy rain storm, it would be important that the packing peanut could withstand getting wet. Take your two packing peanuts and place them in the cup of water. Make observations. (Students should notice the starch packing peanut dissolving in the water, but not the polystyrene peanut).

Why do you think the starch peanut dissolved in the water? (Students are then given a short reading on the structure and properties polystyrene and starch. Students have already learned about the properties of water.) Read over the following information on polystyrene and starch to help you determine why the starch peanut dissolved in the water. Determine how the structures of these molecules affect their properties and the way they function. Write your findings in your notebook. (Students can perform a read-and-say something with their shoulder partners as described in Kagan strategies.)

(After the reading, students reevaluate their decision on which polymer would be better to use in shipping packages. Students should relate the fact that the starch peanut dissolves in water and may dissolve if it rains. Polystyrene is nonpolar and will not dissolve in water. Starch is polar and water is polar. Starch has hydroxyl (--OH) groups that hang off the main chain which react with water molecules to form hydrogen bonds.)

You have just learned the concept that "like dissolves like". Polar solvents will dissolve polar solutes and nonpolar solvents will dissolve nonpolar solutes. This concept is important in engineering as electrical, mechanical, chemical and biomedical engineers need to determine which solvents can be used to dissolve certain solutes. Both of the electrical and mechanical engineering departments at the University of South Florida (USF) are creating nanofibers through a process called electrospinning. In this process they must dissolve polymers in like solvents.

(Connect to the PowerPoint [see external link] that explains the process of electrospinning and possible applications. After explaining this process, allow students to dissolve polystyrene in d-Limonene to make fibers. Students must wear gloves). You will now have an opportunity to make some fibers. After putting on your gloves, place 1mL of d-Limonene into each beaker. Now try dissolving a polystyrene and a starch peanut in separate beakers of d-Limonene. Discuss your results with your shoulder partner and explain these results in your lab notebook. Assess students by discussing results and explanations with student groups. Polystyrene dissolves in d-Limonene because both are nonpolar. Starch does not dissolve in d-Limonene because it is polar.) Now that you have dissolved your polystyrene peanut in the d-Limonene, place some of the solution inside of your gloved hands. Gently clap your hands together and slowly pull them apart. You are now creating fibers. Do you think these fibers that you are seeing are nanofibers? (Make sure students understand nanofibers are too small to be seen individually without the aid of a microscope. Pass around a sample of a nanofiber mesh if possible.)

**Lesson Background & Concepts for Teachers (5E – Explain)**

Polarity is due to an unequal sharing of electrons within a molecule. For example, water is considered a polar molecule because the oxygen is more electronegative then the hydrogen atoms. Therefore, the oxygen atom has a greater electron affinity. The electrons will tend to stay around the oxygen atom, making it have a partial negative charge and the hydrogen atoms have a partial positive charge. Atoms that have a similar electronegativity, such as carbon and hydrogen, will share electrons evenly in nonpolar covalent bonds. A molecule made up of carbon and hydrogen atoms will be nonpolar.

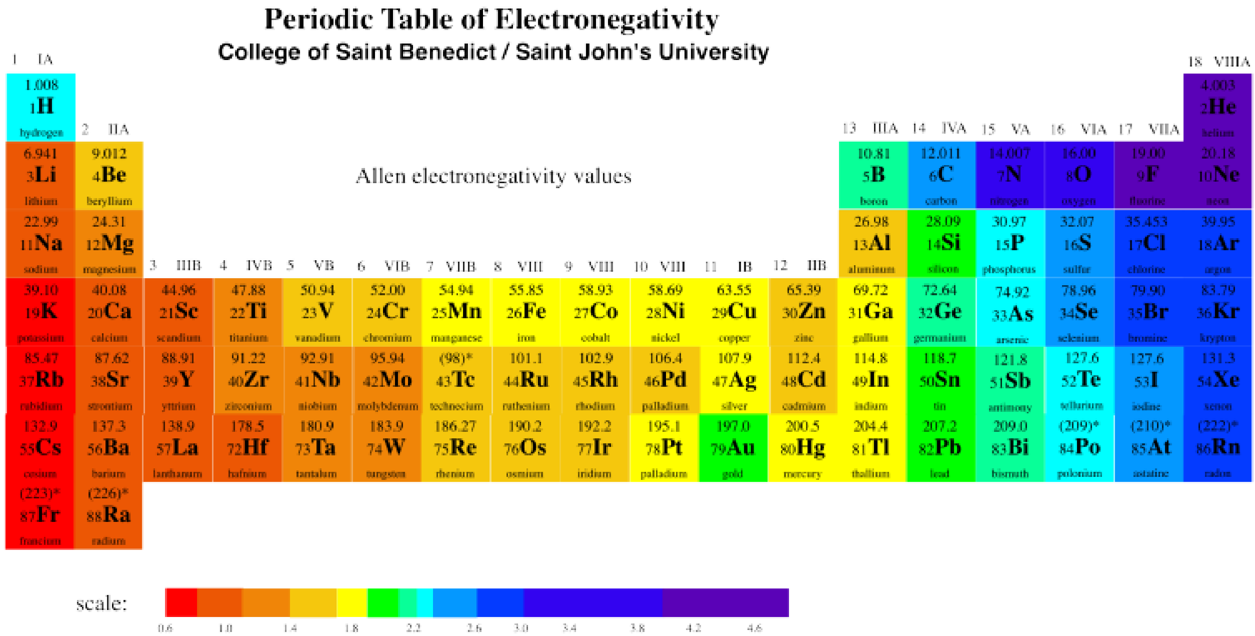



**Image 2**

**Image file:**

**ADA Description:** The periodic table is colored showing a trend that as you move from left to right, and bottom to top, electronegativity of atoms increases.

**Source/Rights:** http://employees.csbsju.edu/cschaller/Principles%20Chem/atoms/atomperiodic.htm

**Caption:** Electronegativity Trend in the Periodic Table

The trend in electronegativity on the periodic table shows the most electronegative atoms being in the top right as Nitrogen, Oxygen and Fluorine. Molecules with these atoms can perform hydrogen bonding and would most likely be polar. The hydrogen bond is not actually a "bond" but an attractive force due to dipole forces.

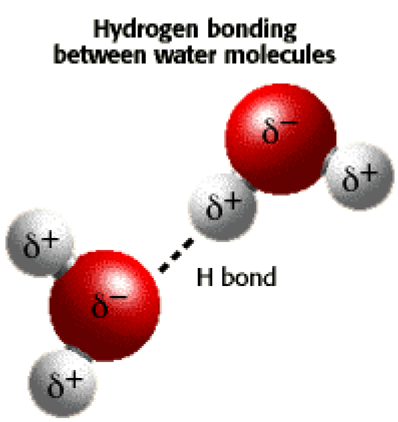



**Image 3**

**Image file:**

**ADA Description:** There is an electrostatic attraction between the partial negative charge on the oxygen atom of one water molecule and the partial positive charge on the hydrogen atoms of another water molecule.

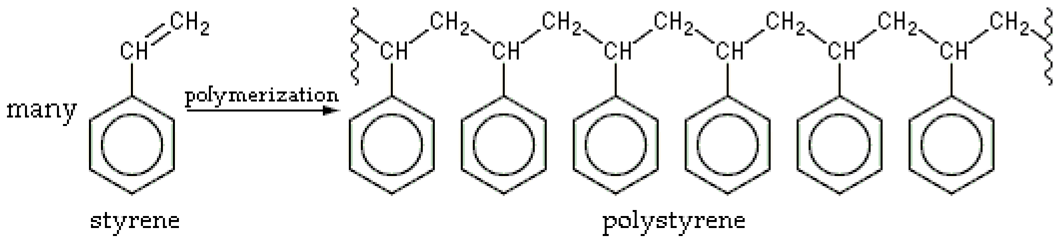
**Source/Rights:** http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html

**Caption:** Hydrogen bond between water molecules

A polar molecule can dissolve in water since the partial positive side of the polar molecule would be attracted to the partial negative oxygen atom of the water molecule. The partial negative side of the polar molecule would be attracted to the partial positive hydrogen atoms of the water molecule. Thus, like dissolves like. Polar solvents dissolve polar solutes and nonpolar solvents dissolve nonpolar solutes.

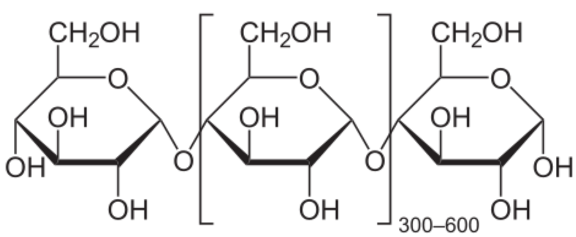
In this lesson, we are using two polymers; polystyrene, which is nonpolar, and starch, which is polar. Their polarity is due to their chemical structures that are shown below:

**Polystyrene:**




| **Image 4** |
|---|
| **Image file:** ___? |
| **ADA Description:** A styrene monomer is undergoing polymerization. As many styrene monomers join together, a polymer of polystyrene is formed. |
| **Source/Rights:** Copyright © [http://www.wikipedia.org/](http://www.wikipedia.org/) |
| **Caption:** Figure 2. Molecular structure of polystyrene. |

**Starch:**




| **Image 5** |
|---|
| **Image file:** ___? |
| **ADA Description:** Glucose monomers can be linked by glycosidic bonds to form a polymer of starch. |
| **Source/Rights:** Copyright © [http://www.wikipedia.org/](http://www.wikipedia.org/) |
| **Caption:** Figure 3. Molecular structure of starch. |

Polystyrene is a common polymer used in the process of electrospinning. It is dissolved in a nonpolar solvent to create a polymer solution that is placed inside of a syringe. An electric field is then applied as the positive terminal is connected to the tip of the syringe needle and the negative terminal is connected to a collector plate. The applied electric potential overcomes the surface tension of the polymer solution. A polymer jet is then ejected from the syringe needle tip and is deposited onto the collector as a non-woven web. The repulsive electrostatic forces create bending instabilities that cause the jet to spiral as its traveling to the collector. To minimize the instability, the jet undergoes plastic stretching, which reduces its diameter, thus forming extremely thin fibers. If one uses a low polymer concentration, or low molecular weight polymer, fibers may not form due to the lack of polymer chain entanglements and the jet breaking down into droplets as an electrospray instead.

The nanofibers that are created from electrospinning have many possible applications such as scaffolds for tissue engineering, water filtration, protective military clothing, drug delivery, would healing, lightweight heat managing materials in aircraft and spacecraft, electromagnetic shielding, and various other electrical and optical applications.

D-Limonene is a nontoxic , organic solvent that comes from orange extract. The food grade oil comes out of the rind and is distilled from the orange juice when the oranges are pressed for juice. The technical grade oil is collected as a layer on top of water after the pressed peels go through steam extraction and condensation.

**Vocabulary / Definitions**

All definitions come from http://www.merriam-webster.com/

| Word | Definition |
|---|---|
| polymer | A chemical compound that is made of small molecules that are arranged in a simple repeating structure to form a larger molecule. |
| polarity | The condition of having positive and negative charges and especially magnetic or electrical poles. |
| surface tension | The attractive force exerted upon the surface molecules of a liquid by the molecules beneath that tends to draw the surface molecules into the bulk of the liquid and makes the liquid assume the shape having the least surface area. |
| solute | A dissolved substance; *especially* **:** a component of a solution present in smaller amount than the solvent. |
| solvent | A liquid substance that is used to dissolve another substance. |
| solution | An act or the process by which a solid, liquid, or gaseous substance is homogeneously mixed with a liquid or sometimes a gas or solid. |
| solubility | Degree to which a substance dissolves in a solvent to make a solution. |
| concentration | The relative content of a component (as dissolved or dispersed material) of a solution, mixture, or dispersion that may be expressed in percentage by weight or by volume, in parts per million, or in grams per liter. |
| viscosity | The property of resistance to flow in a fluid or semifluid.<br>The ratio of the tangential frictional force per unit area to the velocity gradient perpendicular to the direction of flow of a liquid —called also *coefficient of viscosity*. |
| hydrophobic | Lacking affinity for water. |
| hydrophilic | Of, relating to, or having a strong affinity for water. |

## Associated Activities (5E – Explore)

Engineering Design Challenge:

Give Students the engineering design challenge to purify copper out of water. Student groups create a design for water filtration given certain materials (Sand, gravel, cotton, filter paper, charcoal, popsicle sticks, cups, packing peanuts, anything else from home, Styrofoam cup, beaker, ring stand, string, paperclips)

Next day - Students finalize plans if necessary and build water filtration system to test it. Students test water using a water testing kit to see if copper remains. Students share results and make adjustments to their plans to achieve a better result. Students filter a second sample of water and test to see if their adjusted design was able to remove more copper than their original design.

### Lesson Closure

In summary, you have learned about factors that affect solubility, specifically temperature, pressure (for gases), and polarity of solute and solvent. In learning the concept that "like dissolves like", you investigated how polar solvents will dissolve polar solutes and nonpolar solvents will dissolve nonpolar solutes. You are able to explain how the structural formula of a molecule affects how it functions in regards to polarity and solubility. This concept is important in engineering as electrical engineers need to determine which solvents can be used to dissolve certain solutes in creating solutions for electrospinning. The resulting nanofibers can have many applications in real life, such as water filtration, biomedical devices, thermoreflective military applications, energy generation and wound healing. Even though cotton fibers are not nanofibers, you should have an understanding of the function of nanofibers in filtering. This functionality is due to their extremely small size and large surface area. Therefore, nanofibers can be classified as functional materials. They can perform different functions based on what compounds or materials you use to create the polymer solutions. For example, if we incorporate cactus mucilage into the polymer solution before we electrospin it, the polymers that are created will have the cactus mucilage within them to adsorb arsenic out of water. You modeled the filtration process performed by nanofibers by creating your own water filtration design.

## Assessment (5E – Evaluate)

**Pre-Lesson Assessment**
*Descriptive Title:* Bellwork Questions

**Post-Introduction Assessment**
*Descriptive Title:* Teacher discussion with students

**Lesson Summary Assessment**
*Descriptive Title:* Exit Slip

**Homework**
*Descriptive Title:* Students write a paragraph explaining how temperature and pressure (for gases) affect solubility after reading their text or performing research on the internet. Students must cite the website they used.

**Lesson Extension Activities (5E – Extension)**

1. Students can research a polymer solution used in electrospinning for a particular application.
2. Students can continue to compare polarity through the use of an oil clean up activity.

The suggested time is 2 hours to complete this activity comparing 3M Oil Sorbent with Cotton Balls: (Cellulose Polymer is a straight chain polymer that is hydrophilic and insoluble in water because of β(1→4)-glycosidic bonds between D-glucose monomers, but is polar because it has OH groups that can hydrogen bond to polar molecules like water): http://www.terrificscience.org/lessonpdfs/PolymerLab16.pdf

**Additional Multimedia Support**

PowerPoint

Youtube links in PowerPoint

**References**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Uyar Tamer and Besenbacher Flemming "Electrospinning of uniform polystyrene fibers: The effect of solvent conductivity" *Polymer* (2008) Vol. 49, No. 24, pp. 5336-5343.

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**Attachments**

Bellwork

Exit Slip

Reading on Polystyrene

Reading on Starch

PowerPoint on electrospinning with video links (Please see external link)

**Other**

**Redirect URL**

**Contributors**

Erica Wilkes – teacher at King High School, Rasudha Muppaneni-graduate student at USF, Manopriya Subramanyam-graduate student at USF, Hruday Katakam-graduate student at USF, Brian Bell-graduate student at USF, Samuel Perez-graduate student at USF, Sylvia W. Thomas, Ph.D.-electrical engineering professor at USF

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Department of Mechanical Engineering, University of South Florida

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**Classroom Testing Information**

**Pre-Lesson Assessment**

Bellwork Questions

1. What property of water causes it to have surface tension?
2. What causes a molecule to be polar?
3. Explain what happens when you pour oil into water.

**Lesson Summary Assessment**

Exit Slip Questions

1. What property will determine if a solute will dissolve in a solvent?
2. What is a general rule for making solutions?
3. What type of materials can be dissolved in water?
4. Will a molecule made up of carbon and hydrogen atoms dissolve in water?

Functional Materials Report – Polystyrene
Erica Wilkes
July 2014

Polystyrene is a polymer made from the synthetic aromatic monomer styrene. Styrene in turn comes from the catalytic dehydrogenation of ethylbenzene. Although ethylbenzene is found naturally in petroleum, the majority of it is produced by combining benzene, a component of crude oil, and ethylene, a natural plant hormone that is also produced by steam cracking gaseous or light liquid hydrocarbons by the petrochemical industry, in a chemical reaction that is acid catalyzed (Wikipedia, 2014).

Polystyrene has the chemical formula $(C_8H_8)_n$. Its structure consists of a long chain hydrocarbon where the center carbons are bonded to benzene rings, or phenyl groups. Free radicals are used to initiate the polymerization of the styrene monomers by breaking the vinyl group's carbon-carbon pi (double) bond and creating a carbon-carbon sigma (single) bond, thus extending the chain with another styrene monomer. This method creates atactic polystyrene where phenyl groups are randomly placed on either side of the polymer, preventing crystallinity. It is the atactic polystyrene that is commercially produced. Syndiotactic polysterene can be produced with the phenyl groups on alternating sides of the molecule through the Ziegler-Natta polymerization method. However, because polymerization is slow using this method, it is not used commercially. There is also an isotactic polystyrene, where all of the phenol groups are on the same side. This is also not produced commercially (Wikipedia, 2014).

The structural formula of polystyrene and its polymerization are shown below.

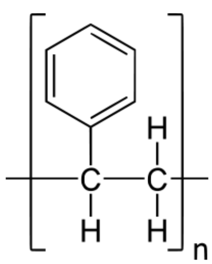

Fig.1 Structural formula of polystyrene (Wikipedia, 2014).

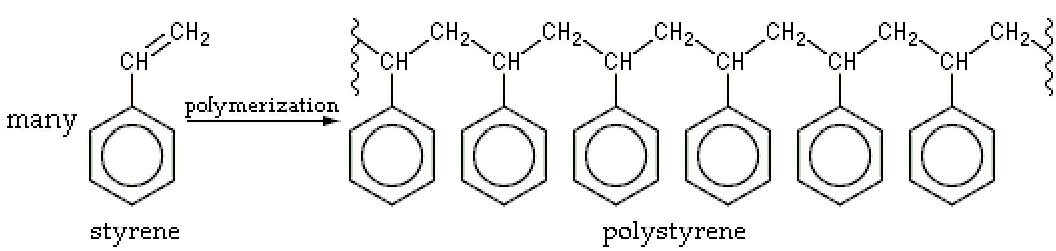


Fig.2 Polymerization of polystyrene (Wikipedia, 2014).

Polystyrene is used as a polymer in the process of electrospinning to create fibers that range in diameter from nanometers to a few microns. This is a simple, repeatable process that involves placing a polymer solution, or melt, into a syringe or cap to which an electric field is then applied. The applied electric potential overcomes the surface tension of the polymer solution. A polymer jet is then ejected from the syringe needle tip and is deposited onto the collector as a non-woven web. The repulsive electrostatic forces create bending instabilities that cause the jet to spiral as its traveling to the collector. To minimize the instability, the jet undergoes plastic stretching, which reduces its diameter, thus forming extremely thin fibers. If one uses a low polymer concentration, fibers may not form due to the jet breaking down into droplets as an electrospray instead. Changing the polymer concentration, and thus the viscosity, changes the diameter of the fiber and the number of beads that form on the fiber. An increase in viscosity has been shown to increase the fiber diameter. Viscosity is determined by both the concentration and molecular weight of the polymer (among other factors) (Shenoy *et al* 2005). The fact that polystyrene has a high molecular weight is important due to the fact that both concentration and molecular weight affect the number of polymer chain entanglements, which plays a huge role in fiber formation. The higher the molecular weight, the more chain entanglements. This affects the viscoelastic behavior of the polymer solution during electrospinning since the chain entanglements act similar to chemical cross links but allow the chains to slide past each other. Thus, there are sufficient forces to overcome capillary instability and hold the jet together, yet enough low enough strain rates to allow viscoelastic behavior and avoid fracture causing fiber breakage (Shenoy *et al* 2005). There are many other parameters that affect electrospinning and fiber formation, such as the properties of the polymer solution including solution conductivity, solution surface tension and solvent volatility (Shenoy *et al* 2005), as well as infusion rate, applied voltage, distance to the collector, motion of the collector, humidity and temperature (Kumbar *et al* 2008).

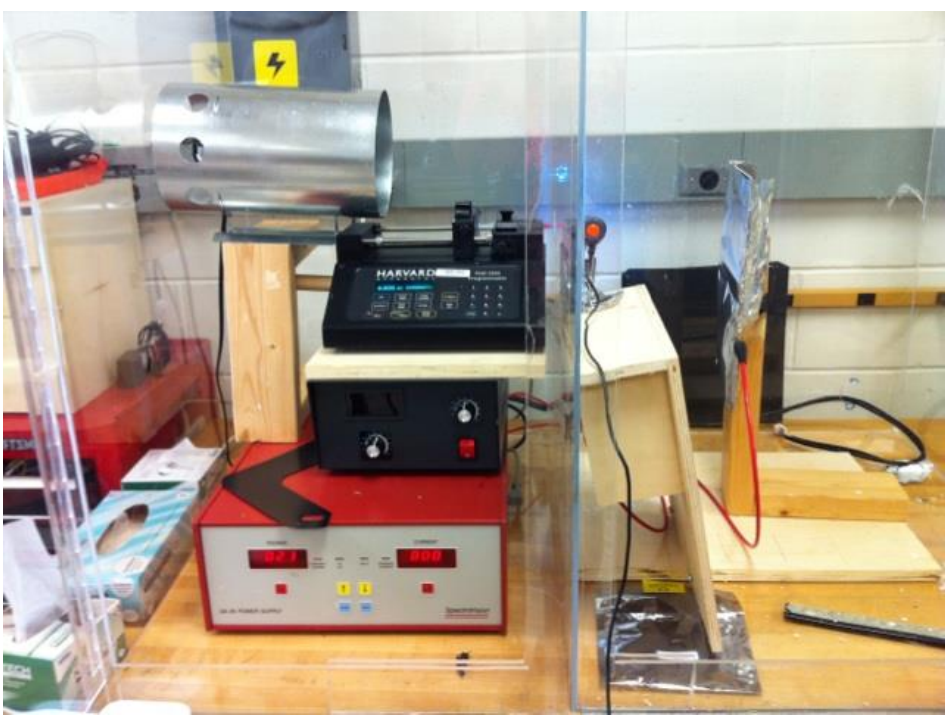


Fig.3 Electrospinning equipment

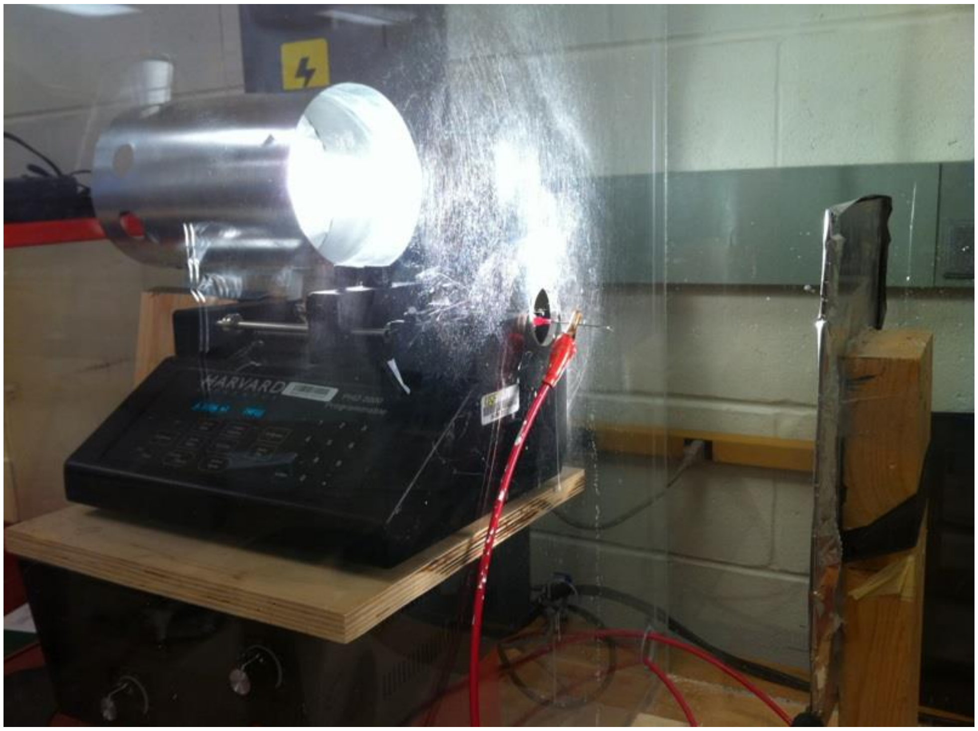


Fig. 4 Electrospinning equipment with fibers evident at the syringe tip.

Since polystyrene is not conductive, it must be dissolved in a conductive solvent, such as dimethylformamide (DMF), d-Limonene or Toluene, for electrospinning to take place. It will then be part of a polymer solution that would react to the electric field that is created. Solutions with low conductivity will create fibers that have many beads (Kumbar *et al* 2008). However, if one attempted to electrospin only the conductive solvent without the polystyrene, fibers would not be formed and the result would consist of electrospray instead.

Fig. 5 Polystyrene dissolving in d-Limonene

Nanofibers have a diameter of less than 1 µm and therefore have an extremely high surface area to mass ratio. Due to this property, and a variety of pore size, they have unique mechanical properties for chemical or physical surface functionalization. Other materials can be added to the original polymer solution to give the nanofibers particular properties for various applications such as tissue engineering, enzyme immobilization, ion exchanger and sensors (Uyar and Besenbacher 2008). In the Advanced Materials Bio and Integration Research (AMBIR) Laboratory at The University of South Florida, cactus mucilage is being added to the polystyrene solution to create nanofibers that can help filter heavy metals, such as arsenic, out of water. Since polystyrene is immiscible in water, it will not dissolve as it is filtering water. Cobalt doped antimony tin oxide (ATO) is being added to the polystyrene solution to create nanofibers targeted for thermal reflective military applications. These lightweight fibers can coat military devices and resist laser induced damage (Richard 2013).

The AMBIR lab is also striving to find nontoxic, environmentally friendly solvents to use for electrospinning and to include in their life-cycle assessments using the computer software SimaPro. In an effort to avoid using HAP (hazardous air pollutant) solvents, the AMBIR lab is using Formula 66 to replace toluene. Polystyrene did not originally dissolve in Formula 66 at room temperature. Since polystyrene is a thermoplastic polymer with a low melting point of about 240°C and a glass transition temperature of 100°C, we are able to dissolve it in formula 66 using heat. Polystyrene has a very high molecular weight with its polymer chains interacting through weak, intermolecular forces, or Van Der Waals forces, even though each hydrocarbon chain has high intramolecular strength. When heated, the chains are able to slide past each other, making the material flexible and elastic. Because of its thermoplasticity, polystyrene can also be extruded to create everyday items such as plastic utensils and DVD cases. Expanded polystyrene foam is used to make packing peanuts and extruded polystyrene foam is used to make Styrofoam (Wikipedia, 2014).

Fig. 6 Nanofiber mat

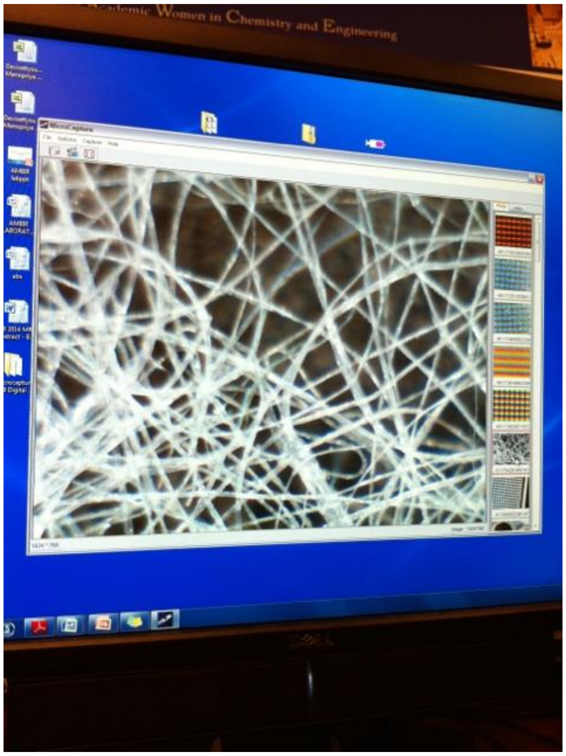


Fig.7 Nanofibers magnified 150x

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Functional Materials Report – Starch
Erica Wilkes
July 2014

Starch is a polymer made from the monomer, or monosaccharide, glucose. The glucose units join by glycosidic bonds to create a polysaccharide. This carbohydrate is created by plants from the water and carbon dioxide plants use during photosynthesis. Plants make starch for energy storage. It has two main forms; a linear or helical form called amylose or a branched form called amylopectin (Wikipedia, 2014).

Starch has the chemical formula $(C_{12}H_{22}O_{11})_n$ (Wikipedia, 2014). Each repeating glucose unit in starch has a hydroxyl group on the C-2 and C-3 atom. The third hydroxyl group that was on the C-6 of the glucose monomer is no longer there due to the glycosidic bond that forms during polymerization. Starch granules are attracted to each other via hydrogen bonding due to the hydroxyl groups. These hydroxyl groups also cause starch molecules to be hydrophilic and therefore soluble in water. One nice feature about the starch polymer, is that it is completely biodegradable. This property, along with its hydrophilicity, lends to the fact that starch has poor mechanical properties (Lu *et al* 2009).

The structural formula of starch below:

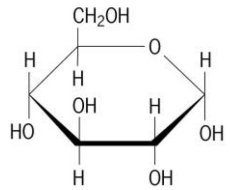

Fig. 1. Structural formula of glucose (Thefreedictionary, 2014).

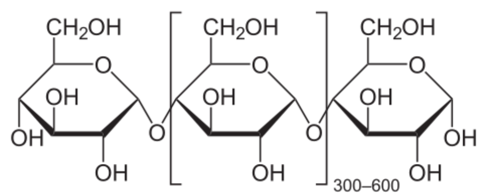

Fig. 2. The Polymerization of glucose into starch (Wikipedia, 2014).

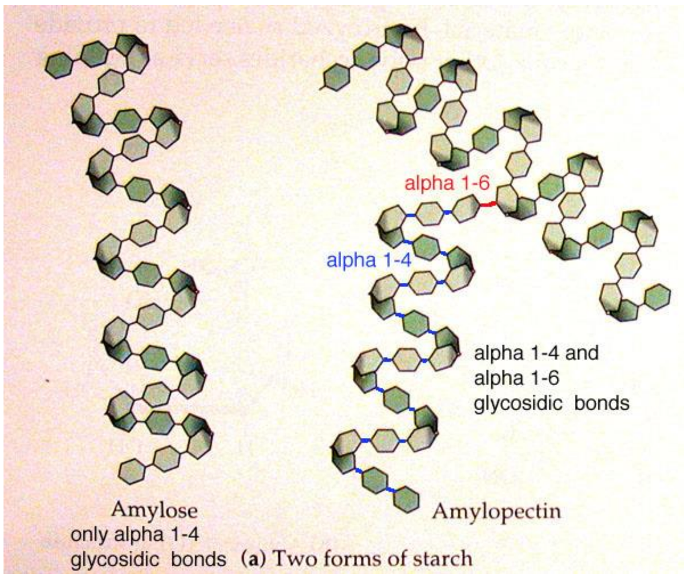


Fig. 3. The two forms of starch (Wikipedia, 2014).

## References

The Free Dictionary. 2014 Farlex, Inc. Accessed 29 July 2014. (2 forms of starch) http://encyclopedia2.thefreedictionary.com/

Lu D. R., Xiao C. M. and Xu S. J. "Starch- based completely biodegradable polymer materials" *eXPRESS Polymer Letters* (2009) Vol.3, No.6, pp. 366–375

Wikipedia.com. The Wikimedia Foundation, Inc. Accessed 29 July 2014. (glucose, starch) http://www.wikipedia.org/