Teacher's Guide

Make a Microfluidic Device to Investigate Properties of Solutions

Grade Level: High school

Subject area(s): Chemistry

Time required: (6) 55 minute periods + out of class time

Learning Objectives: 1. Understand & apply properties of solutions; 2. Understand vocabulary of solutions & nanotechnology in microfluidics; 3. Design & build a solutions-manipulating device.

Summary: Solutions exist everywhere. Helping students to understand basic concepts of solutions such as concentration, molarity, molality, conductive and colligative properties, mixing, and laminar flow is often arduous and time consuming unless you have them develop the concepts on their own. A major aspect of project-based learning (PBL) is having students build and/or use devices in experiments to understand the concepts of chemistry, in this case solutions. This lesson focuses on having students design and test a microfluidic device to investigate the properties of solutions. The lesson activities combine concepts learned in the previous semester (energy, frequency, wavelength, and bonding) together with the aforementioned concepts of solutions to provide students with an engaging project that will help them understand how all of these are interrelated.

Purpose: Students will construct a microfluidic device that is capable of either mixing or separating mixtures.

Lesson Background Information: The structure of matter is due to the arrangement of atoms, molecules, or ions. Atoms are less than 1 nm in diameter, typically 0.1 to 0.5 nm. Every type of atom has a unique electron shell configuration, energy signature, and ability to bond with other atoms. Because of these unique properties, molecules are produced with their own distinct molecular alignments or shapes, polarities, and charges. In fact, when we start looking at properties of individual molecules or smaller groups of molecules (at the nanoscale), we find that many of the properties we have come to expect and rely on in the macroscopic world (our "normal" world) don't hold true.

For example, from quantum mechanics, we understand that every orbital that an electron can occupy in an atom has its own discrete energy signature at the atomic or molecular (nano) level, but when we observe the macroscopic characteristics of something, we can often only give it properties such as color, texture, malleability, etc. We already have some idea that the color we see is an average of the wavelengths of photons released by several different electrons returning to ground state. Texture of a substance will change based on the magnification level we are viewing matter at and malleability of a metal can subjectively change with its thickness.

But why do these properties of matter seem to change? Well, first off, at the nanoscale of molecules, the force of gravity doesn't really matter compared to the electromagnetic force of electrons. Think about it; gravity will pull you in until you are stopped by the electromagnetic repulsion of a solid -- you fall until you hit the ground. Secondly, quantum mechanics defines the energy and movement of these nanoparticles rather than classical mechanics. Furthermore, in very small particles you have a greater surface to volume ratio than in large particles. For instance, the surface to volume ratio of the earth is roughly 4.7×10^{-13} whereas the surface to volume ratio of a molecule of methane is roughly 2×10^{-11}, almost 43 times greater. This means that the surface reactions of the particle with the environment become much more important than either its volume or diameter. Finally, because surface area is so much relatively greater on these small particles, their motion and collision with other particles becomes highly important.

What we haven't really dealt with until now is how nanoscale differences in matter end up being useful to us. For example, copper atoms move as small clusters of about 50 nm in their form and this lets copper metal appear malleable or bendable. Something similar happens with electrons (metallic sea of electrons) when sets of electrons in clumps of pure metal can move a certain amount, thus letting electricity flow and promoting magnetism. In fact, aluminum, a metal not known for being magnetic, can become magnetic when the diameter of the particle is less than 0.8 nm. Zinc oxide, a common component of sunscreen, is suspended in its solvent at a particle size of around 20 nm. This size allows the molecule to keep many of the same properties of the "bulk" material except now the particles are transparent to most visible light but are large enough to scatter harmful UV rays. This is why nano-zinc sunscreen is translucent but non nano-zinc appears white and opaque.

This lesson focuses on microfluidics devices that are useful in working with liquids, solutions or suspensions on a scale between 1000 to 100,000 nm, the scale of a red blood cell in blood or other fluid up to the size of small parasites. Often these devices are called "lab-on-a-chip". In fact, the trend these days towards smaller, faster, and cheaper laboratory diagnostics for humans is being driven by nanotechnology advancements in both electronics and microfluidics. For an overview of all microfluidic applications see the Wikipedia listing in resources.

Microfluidics is a technique for manipulating liquid samples and a lab-on-a-chip device is very small device that automatically controls the flow of a liquid sample to react with one or more chemicals or sensors. The chips typically have sets of channels, sensors, mixing chambers, and/or valves to control sample movement. These micro/nano-sized devices can run several biochemical tests at one time from extremely small samples such as a drop of blood or urine. The most common examples are home pregnancy tests, drug tests, yeast infection tests, glucose monitoring, and strept tests. So why is nanotechnology important to this? It has the ability to make small devices, microfluidic channels in the micro and nanoscale dimensions, on chips capable of analyzing very small quantities of analyte.

As noted above, microfluidic devices are currently being developed and utilized for a host of biological and chemical applications, specifically applications in which solvents/solutions can play a key role in the isolation, separation, reaction and processing of substances either suspended or dissolved in various solvents. In this lesson, students will use the crosslinking or polymer hybridizing properties of a sheet of polystyrene plastic film, "*Ezee-Shrinks*" or "*Shrinky-Dinks*", along with a negative etching process (printer ink) for constructing an investigative tool to examine properties of solutions. This lesson has been designed based on published articles [Refs 1-5] that use polystyrene plastic to create the device rather than the cleanroom based method that uses photolithography. The "device" is designed and then printed to a translucent sheet of Ezee Shrinks. The printed sheets are then heated in an oil bath with sufficient energy to significantly crosslink the polymers in the sheet that are not protected by the ink. Note that most of the literature uses toaster or conventional ovens but these do not have an even heat distribution for effectively shrinking the devices. The consequence of sheet shrinkage, except under the printer ink, is a "raising" of the unpolymerized polymer into a three-dimensional shape. This will effectively allow students to manufacture a "master mold" of a device that can be copied several times.

The copies of the master mold are made using polydimethylsiloxane (PDMS) an elastomeric polymer that is inert, nontoxic, and transparent. Furthermore, it is relatively inexpensive and easy for students to handle. Students simply need to mix appropriate volumes of the two starting solutions together, pour this mixture onto the master mold (in a petri dish), degas under vacuum, bake and remove the molded device, punch holes for the fluid input/outputs and affix the manufactured device to a glass plate.

Investigation of solution properties begins upon completion of the device. Students will be provided by the instructor a choice of several possible investigations into properties of fluids or solutions: a) mixing of two or more dyes (diffusion or mixing; b) titration of acids and bases using indicator; c) separation of sediments; d) hydrophobicity; or e) laminar vs. plug flow.

References:

1. Chen, C-S, D.N. Breslauer, J.I. Luna, A. Grimes, W-C. Chin, L.P. Lee and M. Khine (2008) Shrinky-Dink microfluidics: 3D polystyrene chips. Lab on a Chip 8:622-624.
2. Grimes, A. D.N. Breslauer, M. Long, J. Pegan, L.P. Lee and M. Khine (2008) Shrinky-Dink microfluidics: rapid generation of deep and rounded patterns. Lab on a Chip, 8: 170-172.
3. Hemling, M. J. A. Crooks, P.M. Oliver, K. Benner, J. Gilberston, G.C. Lisensky, and D.B. Weibel (2013) Microfluidics for High School Chemistry Students. J. of Chemical Ed. 91:112-118.
4. Microfluidic Devices. Accessed at: https://chem.beloit.edu/edetc/nanolab/shrink/index.html
5. Ngyuen, D., J. McLane, V. Lew, J. Pegan and M. Khine (2011) Shrink-film microfluidic education modules: Complete devices within minutes. Biomicrofluidics 5: 022209.

Development and distribution funded by the **National Science Foundation**

Pre-requisite Knowledge: understanding of: solutions and mixtures, molecular bonding, laminar flow, safe lab procedures

Materials for constructing devices: (class of ~20)

Nitrile gloves	12 glass plates (4x4 works well)
6 plastic mixing cups	6 rolls scotch tape
Vacuum pump & large desiccator	6 petri dishes (150mm diameter)
PDMS	6 disposable scalpels/safety razor blades
6 sheets Ezee-shrinks/shrink dinks	6 biopsy punch (2mm diameter)
6 hot plates	2" wide of double-sided tape
6 timers	Baking oven (capable of 60oC
1 laser printer	sharpie
6 wooden stirring sticks/plastic spatulas	Glass slides (25x75mm)
6 thermometers	Vegetable oil (400 mL/group)
6 scissors	6 Forceps or tongs
6 600 mL beaker	Rulers (with metric and imperial)
Metal tubing (to fit I/O holes)	Clear rubber tubing (to fit I/O holes)
Dispensing pipets	Small syringes for dispensing solutions

Chemicals for the 5 design challenges such as acids, bases, etc.

Safety Information: The PDMS is essentially non-toxic and safe to work with. So are the Ezee Shrinks. Caution students when working with the hot plates, oven, and oil since these items will be hot. Care must also be taken when working with the scalpels, razor blades and dispensing needles with students spending a few minutes reviewing "sharp"s etiquette and procedures. Glass plates and slides also deserve a few minutes of safety review.

Advance Preparation:

- Assemble all materials for easy student access
- Printout Appendix A and Appendix B
- Double check that hot plates, oven, and desiccator are in working order.

Suggested Teaching Strategies or Troubleshooting Tips:

- Student designs should not be larger than 10 x 10 cm. They should print at least 4 of their designs on the polystyrene sheet.
- An **optional** first step of degassing the PDMS is to have students place the mixing cup into the desiccator for 10-15 minutes before pouring into the petri dish. Then they perform a second degassing with the petri dish as in instructions.
- Sheets should be clear and capable of laser printing. Ink jet printers do not work with this activity.
- Glass plates need to be larger than the "shrunken" device so 4"x4" is recommended.
- Hemling et al (2014) recommended Grafix, KSF50-C shrink sheets from Amazon.
- Optional PDMS flaming – see YouTube resource below.

- It is recommended that the students create at least 4 devices so that they can choose the best one for their solution challenge. In addition, you may want to have the students design a control device and this will allow the testing of a control.

Suggested Instructional Procedure:

Time	Activity	Goal
Day 1	a) Intro to solutions b) Guided dialog on vocabulary	a) Students will learn some of the basics of solution chemistry and watch a video on solutions. (https://www.youtube.com/watch?v=9h2f1Bjr0p4; https://www.youtube.com/watch?v=MDHlaTHbEgM b) Students will learn vocabulary of solutions, nanotechnology, microfluidics
Day 2	a) Intro to Polymers. Examples in everyday life. b) Intro to microfluidics c) What is nanotechnology?	a) Students will learn the basics of monomers and relate the assembly of monomers to polymers. Students will compete to name the most numbers of polymeric substances they can. (https://www.youtube.com/watch?v=rHxxLYzJ8Sw https://www.youtube.com/watch?v=UwRVj9rz2QQ) b) Students will learn what a microfluidic device is and how they operate. (check out Lutetium Projects Microfluidics #1, 2 & 3 on YouTube; see resources section for link) c) Students will have a brief intro to nanotechnology.
Day 3	a) Intro to "Ezee-Shrinks". First day of designing a device. b) Comparison and Contrast of Various Designs	a) Students will relate the simple sheet of polysterene plastic they will be working with to the polymers they previously studied. Groups of students will design one of five different devices in a project-based environment to complete a *Specific Goal*. b) Students will enhance their understanding of a microfluidics device in the context of solutions and polymer chemistry by critiquing each other's designs.
Day 4	a) Fabrication of Master Molds b) Write-Up of Fabrication I.	a) Students will collaborate to manufacture the Master Mold of their microfluidics device design from the previous school day, taking care to observe all reactions/problems along the way. b) Students will begin their formal write-up of the fabrication process of the "Master Mold", which will later be combined with their experimental results.
Day 5	a) Fabrication of Microfluidics Devices. b) Write-Up of Fabrication II.	a) Students will collaborate to manufacture their actual microfluidics devices, enhancing their knowledge of stoichiometry, polymer hybridization, and activation energy in the process. b) Students will begin their formal write-up of the fabrication process of the "Device", which will later be combined with their experimental results.
Day 6	a) Testing of Microfluidics Devices. b) Drawing of Conclusions. c) Finalization of lab write-up.	a) Students will design and conduct open-ended experimental designs and testing of their microfluidics devices. b) Students will draw highly critical conclusions of their design in the context of solutions, design parameters and *Specific Goal* completion. c) Students will receive the weekend to finalize their lab write-ups at home and will turn in a group lab write-up.

Learning Objectives:

1. Understand and apply properties of solutions and nanotechnology (polymer chemistry) to improving “quality of life”.
2. Understand the vocabulary of both solutions and nanotechnology in the context of microfluidic devices.
3. Design and build a functional solutions-manipulating device at a “nano-scale”

Expected Outcomes:

1. Students will better understand and apply the information gleaned from media presentations on solutions, polymer science and nanotechnology (news, articles and trade journals) and apply said information to their daily lives.
2. Students will be conversant with the languages of solutions, polymer science, and nanotechnology.
3. Students will gain a better understanding of the applications of all three disciplines in society.

Guided Dialog:

Dialog reflects the thought processes of the participants and argument-based dialogue often helps to enhance participants understanding of scientific processes. To this end, vocabulary will be explicitly introduced on the first day of this project-based lesson and will be enhanced through routine implicit contextual use on a daily basis throughout the lesson.

Vocabulary Terms:

Solvation	Molarity	Mixing
Solubility	Mass/mass	PDMS
Solution	Monomer	Nanotechnology
Soluble	Polymer	Microfluidics
Insoluble	Hybridization	Diffusion
Miscible	Activation energy	Flow/laminar flow
Immiscible	Master mold	Nanoscale
Concentration	Device fabrication	Nanometer

Additional Online Resources:

- Overview: What is microfluidics? https://ufluidix.com/resources/definitions/
- Wikipedia: Lab on a chip. https://en.wikipedia.org/wiki/Lab-on-a-chip
- Wikipedia: Microfluidics. https://en.wikipedia.org/wiki/Microfluidics
- What is Microfluidics? https://www.news-medical.net/life-sciences/What-is-Microfluidics.aspx
- Microfluidics Adventures #1 – 3 from The Lutetium Project on YouTube. https://www.youtube.com/watch?v=b8zE2i755-k; https://www.youtube.com/watch?v=68p3qAm4i7U; https://www.youtube.com/watch?v=EYuyRUjnTgc
- Microfluidics: A general overview of microfluidics. https://www.elveflow.com/microfluidic-reviews/general-microfluidics/a-general-overview-of-microfluidics/
- Nanotechnology 101 from the National Nanotechnology Initiative https://www.nano.gov/nanotech-101
- Introduction to Nanotechnology https://www.understandingnano.com/introduction.html
- How to flame PDMS with butane flame: https://www.youtube.com/watch?v=nrXNYpFANog.

PDMS can be purchased online at various suppliers with some listed here:

- DigiKey electronics: https://www.digikey.com/en/resources/about-digikey
- Slygard 184 Elastomer Kit at Dow https://www.dow.com/en-us/pdp.sylgard-184-silicone-elastomer-kit.01064291z.html
- Amazon: https://www.amazon.com/Electron-Microscopy-Sciences-Sylgard-184/dp/B00K335I0G

Next Generation Science Standards

- PS1.A Structure and properties of matter
- PS1.B Chemical reactions
- PS2.B Types of interactions
- HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials
- ETS1.A Defining and delimiting engineering problems
- ETS1.C Optimizing the design solution

Contributor – Greg Hair, PhD., Meadowbrook High School, Gwinnett County Schools, Georgia

Supporting Programs – NNIN RET Program at Georgia Institute of Technology NSF - EEC 1200925; National Nanotechnology Coordinated Infrastructure NSF – ECCS 1626153; Southeastern Nanotechnology Infrastructure Corridor NSF - ECCS 1542174

Student Guide
(answers in red)

Make a Microfluidic Device to Investigate Properties of Solutions

Safety
Gloves and goggles should be worn when working with chemicals

DAY 1: Solutions and Guided Dialog/Vocabulary

Solutions: As a class you will review your knowledge on solutions and watch a video to help you recall your knowledge.

You make a solution when you brew coffee, make Kool-Aide, go to the bathroom, or almost anything else that has to do with life. To successfully complete this lesson on microfluidics you will need to know the following terms:

Solvation	Molarity	Mixing
Solubility	Mass/mass	PDMS
Solution	Monomer	Nanotechnology
Soluble	Polymer	Microfluidics
Insoluble	Hybridization	Diffusion
Miscible	Activation energy	Flow/laminar flow
Immiscible	Master mold	Nanoscale
Concentration	Device fabrication	Nanometer

Use your computers as a group to look up the definitions for each term. Write a one-sentence definition and draw a picture-example of what each term represents. Create a table in your lab notebooks as shown below. **If you don't finish in class, it's homework.**

Term	Definition	Picture

If time permits, have a class discussion on some of the terms you found difficult.

DAY 2: Polymers, Microfluidics and Nanotechnology

Nanoscale devices are used in many scientific disciplines and can routinely be found in many clinical, industrial, commercial, and consumer applications. You might want to check out the list of consumer products on the Project on Emerging Nanotechnologies inventory at: (https://www.nanotechproject.org/cpi/). Microfluidics, a type of nanoscale product, are devices developed to more efficiently perform what many humans and large machines have been used to accomplish in the past.

Microfluidics is the science of manipulating and controlling fluids, at nanoliter volumes in networks of micro-channels with dimensions from tens to hundreds of micrometers. This discipline takes its origins in the early 1990's and has grown exponentially. It is viewed as an essential tool for life science research or in a larger way in biotechnologies. Microfluidics emerged in the beginning of the 1980s and is used in the development of inkjet printheads, DNA chips, lab-on-a-chip technology, micro-propulsion, and micro-thermal technologies[1]

1. Wikipedia Microfluidics https://en.wikipedia.org/wiki/Microfluidics

Have you ever wondered where some of those incredible machines on CSI-type shows come from and how they work? Ever wondered how your automatic dryer knows when your clothes are dry enough? Ever wondered how a lab can run over 300 different tests on your blood for under $250? All of these are accomplished by what is now routine: microchips, the same electronic assemblies that are in your computers, your smart phones, your gaming systems, etc.

BUT, we're only getting started!!! Remember what the prefix micro means! It means 1 X 10^{-6} of whatever your measuring, in our case meters. Look at your rulers on your desk and see what the distance of a millimeter is. Now imagine that you have an object in which most of the sizes are a thousand times SMALLER than that millimeter. That's the microscale routinely in use in all microchips today.

Many of the most advanced electronics are starting to use nanoscale (1 x 10^{-9} meters) chips, chips in which the sizes are a thousand times SMALLER than your microchips. In other words, nanoscale chips are now working on the size of larger molecules and small atomic polymers. That's small!!!!

The structure of matter is due to the arrangement of atoms, molecules or ions. Atoms are less than 1 nm in diameter, typically 0.1 – 0.5 nm. Every type of atom (just over 100) has a unique electron shell configuration, energy signature and ability to bond with other atoms. Because of these unique properties, molecules are produced which have their own distinct molecular alignments or shapes, polarities, and charges. In fact, when we start looking at properties of individual molecules or smaller groups of molecules (at the nanoscale), we find that many of the properties we expect and rely on in the macroscopic world (our "normal" world) don't hold true.

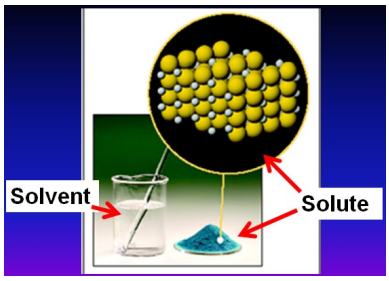
For example, in quantum mechanics we know that every orbital an electron can occupy in an atom has its own discrete energy signature at the atomic or molecular (nano) level. But, when we observe the macroscopic properties of something, we often only give it properties such as color, texture, malleability, etc. We already have some idea that the color we see is an average of the wavelengths of photons released by several different electrons returning to ground state.

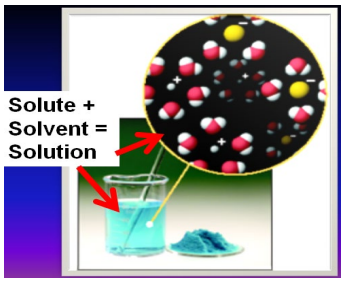
We also know that the texture of a substance will change based on the magnification level we are viewing it at and malleability of a metal can subjectively change with its thickness.

But why do these properties of matter seem to change? Well, first off, at the nanoscale of molecules, the force of gravity doesn't really matter compared to the electromagnetic force of electrons. Think about it; gravity will pull you in until you are stopped by the electromagnetic repulsion of a solid (you fall until you hit the ground). Secondly, quantum mechanics defines the energy and movement of these nanoparticles rather than classical mechanics (high school physics). Furthermore, in very small particles you have a greater surface to volume ratio than in large particles. For instance, the surface to volume ratio of the earth is roughly 4.7×10^{-13} whereas the surface to volume ratio of a molecule of methane is roughly 2×10^{-11}, almost 43 times greater. This means that the surface reactions of the particle with the environment become much more important than either its volume or diameter. Finally, because surface area is so much relatively greater on these small particles, their motion and collision with other particles becomes highly important.

Just how do nanoscale differences in matter end up being useful to us? For example, copper atoms move as small clusters of about 50 nm and this allows copper metal to appear malleable (bendable). Something similar happens with electrons (metallic sea of electrons) when groups of electrons of pure metal can move a certain amount, thus letting electricity flow AND promoting magnetism. In fact, aluminum, a metal not known for being magnetic, CAN become magnetic when the diameter of the particle is less than 0.8 nm. Zinc oxide, a common component of sun screen, is suspended in its solvent at a particle size of around 20 nm. This size allows the molecule to keep many of the same properties of the "bulk" material EXCEPT now the particles are transparent to most visible light but are large enough to scatter harmful UV rays. That is why nano zinc oxide sunscreen in translucent but non-nano zinc oxide is white.

Enter Microfluidics. Remember we said that microfluidics represented a type of nanoscale device that can more efficiently accomplish what larger machines perform for today. Just as the name implies, we will be working with liquids at a very small scale, in our case solutions. Remember, solutions are a homogenous mixture of a solvent (usually water or some organic liquid) and a solute (the material dissolved into the solvent).





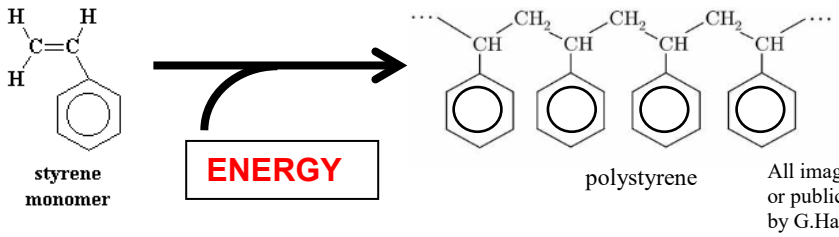
[All images are public domain or public domain modified by G.Hair; studfile.net/preview/61778743]

You will be designing, building, and testing a device that can accomplish a certain task working with different solutions. Finally, since we can't really make chips that are on the nanoscale in our high school chemistry labs, you will be designing chips at the millimeter scale and shrinking

them to the micrometer scale using polymer chemistry and heat energy, two more concepts to wrap our heads around!

Polymer Chemistry:

Polymer chemistry deals with the structure and properties of macromolecules, really large molecules like DNA and RNA and polymers which are long chains of repeating molecules called monomers. Polymer chemistry finds new ways to synthesize or use these molecules. You will be using sheets of a polymer called polystyrene to make your microfluidic devices. You most likely know this material as Ezee-Shrinks or Shrinky Dinks.



All images are public domain or public domain modified by G.Hair

Even more cool is that you can *manipulate* your sheets of polystyrene into making your microfluidics devices. A common manipulation is to cross-link or hybridize the chains of polystyrene. This will "shrink" the distances between those large aromatic rings between polystyrene chains. ***How do you think you might cross-link the polystyrene chains?*** (Hint: What happens to a cheap plastic toy that sits out in the sun too long?)

When you shrink the distances between bonds, you bend the polystyrene sheets. You now have a rounded area on your polystyrene sheet. How do you think you could add more heat to one part of your polystyrene sheet than another? (Hint: Which color of the EM spectrum essentially absorbs the energy of all of the colors?)

Each group should create a list of polymeric substances. These will be shared with the entire class. Which groups can name the most?

DAY 3: Designing your Devices

What can we do with our devices? You will be designing your device to do **ONE** of the following:

1. Automatically mix two or more dyes (diffusion).
2. Automatically neutralize an acid and a base and let you know it (diffusion & titration).
3. Separate a suspension from a liquid (sedimentation).
4. Separate non-miscible liquids from each other.
5. Keep two solutions separated while flowing *TOGETHER*(This is hard but can be done by YOU)!

Please have one member of your group come to the front and pull an assignment card from the deck.

Discuss your assignment with your group. What exactly does your device have to accomplish? Look at the notes on your Appendix A. In your lab notebook list at least three ideas you will need to answer or develop to solve your assignment. Use your computer to find ideas that might answer your questions or develop your design ideas. **Sketch** your designs in you lab notebook. **Outline** in your notebook an experiment to test your prediction. **Show** your design

and outline to the teacher who will approve it before your create it on the computer using PowerPoint. Save your computer designs as they will be used tomorrow for printing. Your teacher may share possible designs with you.

DAY 4: Making the Master Mold:

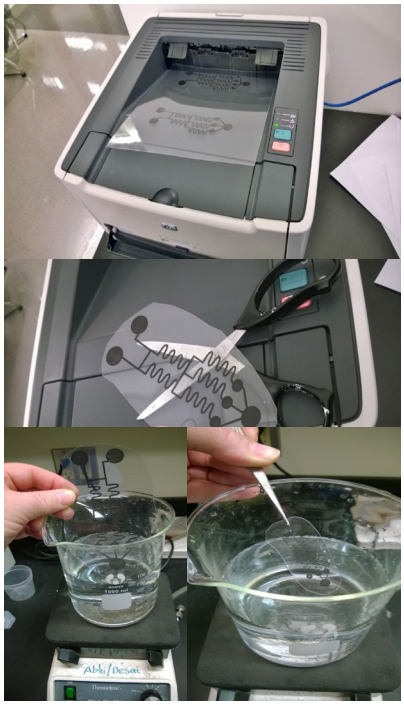
You will print your computer-designed device using a laser printer onto a sheet of polystyrene. Print at least four of the designs on the sheet. Next, your polystyrene sheet will shrink by 60% and at the same time become design three-dimensional!

Collect your Materials:

- 1 sheet of polystyrene (8"x 10")
- 1 pair scissors/group
- 1 600 mL beaker
- 1 hot plate
- 400 mL vegetable oil
- 1 thermometer
- 2 clean glass plates
- 1 petri dish
- 1 roll scotch tape
- 1 pair tongs or tweezers
- 1 sharpie
- 1 timer

This is to make one master mold. Your teacher may ask you to make 3 or 4 so that you can choose the best one for your device testing. Adjust your procedures accordingly.

Procedure:



1. Printing your design.
   a. One member of the group will pour 400 mL of vegetable oil into the beaker, place the beaker on the hot plate and begin heating the oil to 150°C. Use the thermometer to measure the temperature. (**Careful** this is really hot & can burn your skin).
   b. While the oil is warming, on your computer bring up PowerPoint and print out your design from yesterday onto the polystyrene sheet. Your design should be not be larger than 10 x 10 cm. Check with your teacher on size limit. Test it on a regular sheet of paper first!
2. Preparing your design
   a. Cut out your design. Try to leave about 1 cm (~1/2 inch) of space between your design and the edge of your cut.
   b. Continue heating and checking the oil until it reaches 150°C.

3. Shrinking your design
    a. Using the tong or tweezers, place your cut design into the hot oil.
    b. **IMMEDIATELY** start your timer set at 60 secs. When it buzzes, carefully remove your design from the oil. What has happened to your sheet & design?_*The sheet shrank and the design seemed to "raise up"*

4. Finalizing your master mold
    a. Lay your sheet onto one of the glass plates and **carefully** lay the second glass plate over it. Keep your polystyrene sheet flattened like this until it cools (3 – 5 minutes).
    b. Lift off the top glass plate and, using your tweezers or tongs, grab the polystyrene sheet and place it into a petri dish. **Very gently** blot your sheet dry with paper towels. Carefully tape the edge of your polystyrene sheet to the bottom of your dish with 3 small pieces of tape.

5. Using one of your phones, take a picture of your "device master mold" on the petri dish.

6. Record all observations in your lab notebook. Print and place a picture of your device master mold in the notebook.

Clean up:

- Pour the used oil into the waste oil container.
- Wash your beaker and glass plates in soapy water. Place them on paper towels to dry.
- Wash all tweezers and thermometers in soapy water and rinse.
- Dry everything.
- Make sure your hot plates are turned off.
- Make sure your tools & equipment are returned to the proper lab space.
- Log off/shut down your computers.

Homework:

1. Why did your polystyrene shrink?
2. Why did your designs raise up to form a third dimension?
3. What do you think the logical next step will be with your master mold tomorrow?
4. When you perform your experiment later this week with your samples what do you think your results will be?

Answer questions in your lab notebook or separate paper for handing in to teacher.

Possible answers:

The polysterene shrank due to rearrangement of the bonds in the material during heating. Manufactured polystyrene is initially heated, stretched and then flash-cooled into an elongated shape. When polystyrene is reheated, the bonds return to their normal configuration and the sheet shrinks in size.

The design with the ink "bent" the polystyrene by temporarily protecting it from the heat of the oil. The shrinking polystyrene "bent" around the protected polystyrene. Everywhere you had ink, the polystyrene shrank a little less, thus giving it a "raised" surface.

The raised lines will turn into depressed channels/tubes in the mold impression tomorrow.

We will make a device full of channels that can separate of mix fluides

DAY 5: Making the Actual Device

You will use polymer chemistry to make the actual device from the molds you prepared yesterday. The polymer you will use is poly-dimethyl-siloxane (PDMS) and it will make the actual device from your polystyrene mold. PDMS is softer than polystyrene and is relatively safe for using around biological or water-based samples.

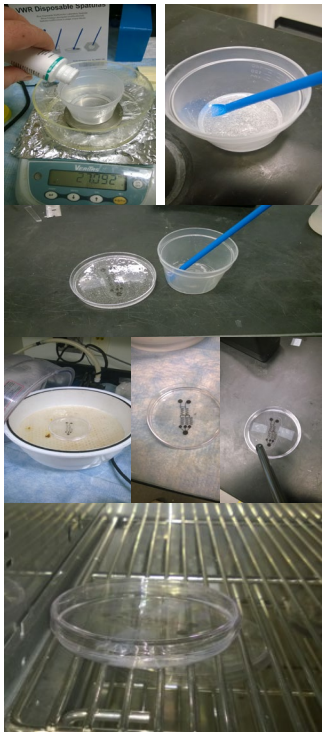
Collect your Materials:

- 1 mixing cup
- 1 electronic balance/group
- 1 plastic spatula/ wooden stirring stick
- Your petri plate w/taped master or masters
- Access to vacuum pump
- Access to desiccator jar
- 1 butane lighter or sharp probe/stick
- 1 electronic balance
- 1 baking oven set at 60°C
- PDMS monomer
- PDMS curing agent

Procedure:

1. Make the PDMS
   a. One member of the group measures out 30 g of PDMS monomer and 3g of curing agent into the mixing cup.
   b. Use the plastic spatula to mix the two liquids completely. Will turn milky because it's full of air bubbles.

2. Label your petri dish with a sharpie and pour in the PDMS mixture over your device(s).
   a. Place your petri dish into the desiccator.
   b. Turn on the desiccator pump and leave it on for 20 minutes.
   c. Turn off the desiccator pump and gently let the air back in.
   d. Remove any remaining bubbles by either poking bubbles with a sharp probe/pointed stick or flaming with butane lighter (instructor will demonstrate).
3. Place your poured plates into the baking oven at 60°C overnight.



Record your Observations and Formative Conclusions: data collection,

observation and extrapolation, and analysis of interim results

1. Why did gas bubbles form when you mixed your monomer and curing agent? If no gas bubbles formed, why not?
Gas bubbles formed because gas was caught by the spatula and dragged into the very viscous polymer. Once there, it was difficult for the gas to escape. If no bubbles formed, then we weren't mixing vigorously enough.

2. Why did most of the gas bubbles disappear in the desiccator jar? If you still had many gas bubbles, why?
As vacuum formed outside the liquid, the bubbles expanded enough to breach the surface of the liquid and escape. If there were a lot of bubbles left, then the vacuum was probably insufficient or applied for too short a time.

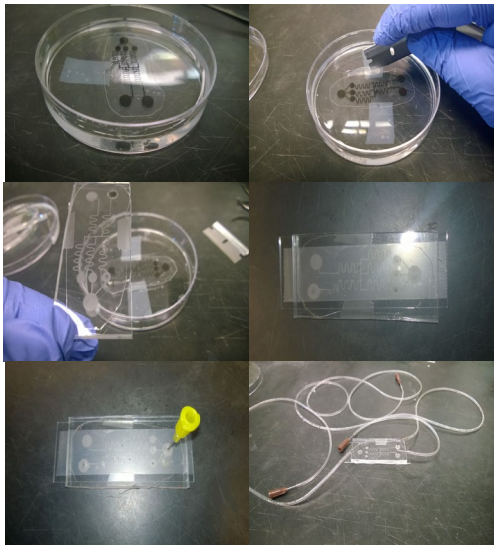
3. Why do you think you are heating your poured petri plates at a high temperature?
The elastomer (polymer strands that aren't cross-linked) are cross linked by the catalytic curing agent. The process is very slow unless heated. So, high temperature cures the fluid into a fairly solid gel.

DAY 6: Cutting Out, Mounting and Using the Device

You will cut out your device, mount it, and then conduct your experiment with it.

Collect your Materials:

- 1 Scalpel
- 1 glass microscope slide
- 1 pair scissors
- Biopsy punch
- 1" cut double-sided sticky tape
- 2 or more x 1" sections metal tubing
- 2 or more x 6" rubber tubing
- Your experimental materials (vary according to your experiment)
- 1 Timer
- Pipets and syringes



Procedure: Use gloves when handling the device.

1. One member of the group obtains the petri plate from the oven and cuts the device(s) out from the mold. Using tweezers, carefully remove the PDMS mold from the polystyrene. Choose the best mold to use in the next steps. Or your teacher may ask you to use additional devices to have controls.
    a. Use the biopsy punch to create your inlets and outlets per your design. Use caution when handling the biopsy punch.

b. Lay a microscope slide flat on your lab bench.
c. Carefully mount a piece of double-sided sticky tape to the slide large enough to secure the device.
d. Mount your device to the sticky tape so that the hollow tubes face the glass slide (imprint side down). Press **gently** to make sure there are no bubbles between the tape and the device(s).

2. Attach the rubber tubing to the metal tubing sections. Attach the metal tubing sections to your device at the inlet(s).
3. Set up and prepare the chemicals for your experiment.
4. Using a syringe, place the chemicals into your device to run your experiment. This is an experiment you designed so fill in your protocol in your lab notebook.

Possible answers:

1. *We had a total of 4 devices mounted on slides. Our negative control device (no common mixing areas), positive control device (fluids mixed prior to being added), test device number 1 (see sketch on a previous page and test device number 2 (see sketch on a previous page.*

2. *Metal tube was inserted into each outlet channel and the tube and device primed with water. Fluid was added at the inlet using a pipetted tip for each reservoir and 100 mL of dye. Tubing from the outlet was lowered and gravity flow took over.*

3. *Fluid was allowed to flow through the device until both reservoirs were empty. Observations of the outlet were maintained on a constant basis*

4. *Degree of mixing was scored semi-quantitatively by comparing the degree of either green or brown color generation to a completely mixed vial of the two initial dyes.*

5. *The entire experiment was repeated three times to determine consistency of results.*

6. *Data is recorded below:*

Questions & Conclusions:

1. Did you observe what you predicted? If not, how did your observation differ from your prediction?
Answers will vary but could include: Yes, the negative control did not mix, the positive control did mix. Device #2 with the longer channel mixed better than device 1.
If not answer: *No real discrepancies.*

2. Did you have a control group? Why was it important to have a control group?
A control group should be able to give you a baseline indication of how your experiment will perform if it either has no ultimate effect (negative control) or a profound effect (positive control). Controls are also included as indicators of what parts of the experiment are still too

variable to rely on for quantitative data or to confirm the validity of assumptions leading up to the experimental group.

3. Do your observations leave you with any more questions? Do they enable you to make more predictions? If so, what are they?
Our data showed significant mixing but it still wasn't complete. It is obvious from our data, that the serpentine channels allowed for greater mixing but we may not have had enough to them. Is it possible to achieve better mixing by increasing the number of curves in the channels? We believe that to be the case and, based on our experimental data will increase the number of "switchbacks from 5 to 8 to help increase mixing.

4. What other issues or concerns were raised during your experiment and what might you do to address them?
Our dye mixing seemed to be hard to read at times. A lower molecular weight dye might diffuse faster and mix better (another set of hypotheses!). Also, the color of the dye could be darker or the background altered to make the dye more visible.

5. How did the fluid move through your device (mix, separate, laminar flow, turbulent, etc.)? If you were to scale up this device so that you were in the meter rather than the nanometer/micrometer scale, what would happen to your separation or mixing that you observed? Why?

The fluid mixed fairly well in our device, but, as we stated in answer 4, it could have mixed better. We had minimal laminar flow and the fluid was relatively turbulent. Scaling the device up would introduce much greater turbulence and gas inclusion causing mixing to occur much more rapidly and less smoothly. The extra turbulence would be two forces now having a greater effect; gravity would constantly be overriding mild laminar flow conditions, forcing a faster flow with greater turbulence or encouraging mixing in more directions and gas pressure would now have an effect on the ability of the two liquids to mix.

Draw Conclusions
Example: Based on your results, do you feel that _____? Explain your answer.

Our data suggest that fluids of similar viscosities can be mixed using simple serpentine channels to promote non-laminar flow and greater mixing of the two dyes. Fluids of highly different viscosities will have a much more difficult time mixing through simple non-laminar flow. The serpentine channels increase the turbulence through the corners by altering the flow rates of the two fluids, thus increasing the degree of mixing. Longer serpentine channels should enhance mixing.