National Nanotechnology Infrastructure Network
Serving Nanoscale Science, Engineering & Technology

Student Worksheet

Using Modeling to Demonstrate Self-Assembly in Nanotechnology

Imagine building a device that is small enough to fit on a contact lens. It has an antennae and a translucent screen across the pupil of the eye that allows you to see arrows giving you directions as you drive to an unknown destination. Imagine designing tiny monitors that are put into your blood stream to constantly check the levels of cholesterol or sugar. The information is readily available without taking any blood and can be used for early detection of heart disease or diabetes. These science fiction-like devices could soon be reality with the work of many researchers in the area of nanotechnology.

Materials

- 1 pkg of modeling materials
- 1 piece of butcher paper
- 1 set of cards
- 1 set of markers

How do scientists build something so small?

Nanotechnology is an area of study that integrates many disciplines, math, biology, chemistry, physics, computer science and technology. Engineers using nanotechnology build devices that are very, very small. These devices are called Nanoelectromechancial Systems (NEMS). How small do you ask? Well, a nanometer is one billionth of a meter (10^{-9}m). To understand how small this is, look at your fingernails. You can't see them growing, but you know they are, because over time they get longer. The human fingernail grows approximately one nanometer (nm) per second! That's a very tiny amount! To build devices that are that small presents a great challenge.

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Consider the following:

1. What materials would you need to build a sand castle and what are some of the obstacles that would make it difficult for you to build it?

2. Now think about creating a castle that is only 10nm tall and 5nm wide, smaller than one grain of sand. What are some of the difficulties engineers must overcome in order to build these tiny devices?

So how do engineers do what seems to be magic? Well, instead of working with large amounts of materials, they must work with very small amounts…just a few molecules at a time. (You can see where the chemistry comes into play here.) But good knowledge of chemistry will only get you so far. Knowing molecules, their properties and behaviors, is only the beginning. There is no way that a person can physically build these devices by using their hands or a robot, so they must rely on "self-assembly".

3. What do you think "self-assembly" means?

You guessed it…the devices must build themselves. Of course, the devices will need some guidance from the engineer. So where do engineers get the tools to do this tiny work? They must look to the experts on self-assembly. What "experts" am I talking about?

4. What is something that does its own "self-assembly" and creates a perfectly working "device"? (Hint: It is happening all the time, all over the earth.)

*** Check Point: Raise your hand and have the teacher go over your progress so far.**

So biological molecules are studied by researchers in this field to see how they can be used to interact with inorganic molecules and serve as tiny parts of the NEMS.

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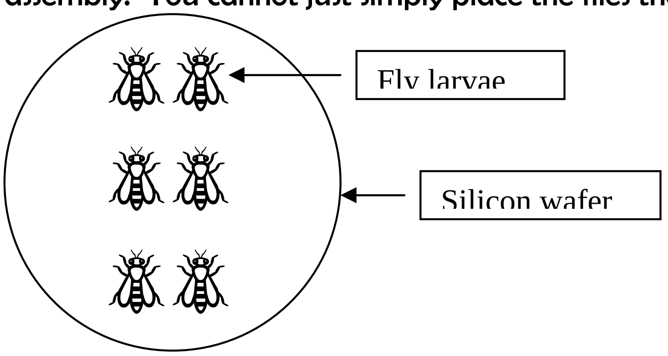
For example, DNA, a long string like molecule, is being investigated to be used as a possible wire when coated with gold. DNA is the organic biological molecule, and gold is the element that can actually carry the current of electricity. When you put the gold and DNA together, you get a wire that is "nano" size, in other words, very, very small.

YOUR TASK: Today your task will to make a model using self-assembly to create a fruit fly prison. You must arrange tiny fruit fly larvae (not quite developed fruit flies) in an orderly fashion stuck to a wafer. A wafer is similar to a microscope slide, but made of different materials and usually round in shape. It acts as a base for what you are working on. The ultimate goal of your research group is to be able to put a radio transmitter on the back of the fruit fly. In order to accomplish this, the fruit flies must be arranged on this tiny platform (the wafer) in a very exact spot. Your fruit flies must be arranged as shown in the picture below. The catch is that you must use self-assembly. You cannot just simply place the flies there.



So how do engineers manipulate molecules to self-assemble into the devices they want to create? Scientist must rely on how molecules naturally attract to one another by their physical properties and use this attraction to their advantage to step by step manipulate the molecules' behavior.
Consider the following:

5. Why do you go to the fair or an amusement park?

Just like you are enticed by the delicious food and fun rides, molecules have preferences and we must entice them. Here are some rules to remember about molecules:

1. **Polar molecules with like charges (++ or --) will repel (move away) from one another.** For example, if there are two negatively charged molecules, they will move away from one another. If there are two positively charged molecules, they will also move away from each other.

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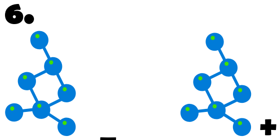
2. Polar molecules with unlike charges (+-) will attract (move towards) to one another. For example, if there is one positively charged molecule and one negatively charged molecule, they will move towards one another.
3. Non-polar molecules (uncharged or neutral) will congregate with one another in a water environment because they are hydrophobic (water fearing). Non-polar molecules repel polar molecules. For example, oil consists of non-polar molecules and will not dissolve in water, but form droplets or clusters of oil molecules. These non-polar molecules are clustering together and staying away from the polar water molecules that have both a slightly negative and positive end.

Look at the following examples below. On your paper, decide whether the two molecules will attract or repel.

6.



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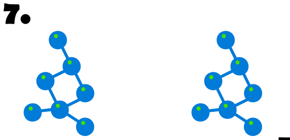
7.



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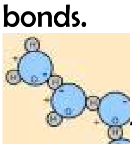
Tiny forces resulting from these attractions, such as capillary action and surface tension, are also important to engineers because these forces are needed for a device to self-assemble. For example, water is a molecule that has a slightly negative end (the oxygen end) and a slightly positive end (the hydrogen end), which allows these molecules to want to stick to one another. These attractions are called hydrogen bonds.



This attraction causes a tiny force, called surface tension. This force can be very powerful. Some insects use this to their advantage, such as a water glider that slides across the surface of the water. Engineers use this force to their advantage. Water molecules are able to push non-polar molecules into groups. You will find surface tension useful in building your fly prison.

8. What molecule would push a polar (charged) molecule away?

*** Check Point: Raise your hand and have the teacher go over your progress so far.**

Let's look at the materials at your desk! Go through the following items below and read aloud about each item to the group. (There is a card for each one.) As one person reads, have another person write about it on the butcher paper. <u>Write what the item is and what can be attracted to it or what its function is. Look for connections!! See below for an example.</u>

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Butcher Paper

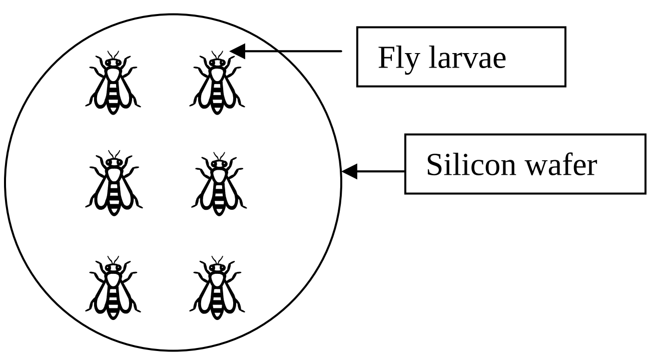
Wafer
-made of silicon

Gold – yellow highlighter
-sticks to silicon
-can covalently bond to SH groups

*** Check Point: Raise your hand and have the teacher go over your progress so far.**

Now that you have discussed the connections between the modeling tools, decide how to build your fly prison, step by step.

REMEMBER: Your goal is to put the fly larvae on the wafer as shown in the picture below by self-assembly.



9. Write down step by step your plan of attack and write why you are taking each step, by filling in the provided chart.

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Procedural Step of Assembly:	Why you are taking this step?
1.	
2.	
3.	
4.	
5.	
6.	

When you have agreed on your steps, go ahead and build your prison with the items given.

10. Draw a diagram of the final result with each item labeled.

11. Now show your model to the teacher. *Congratulations on making your fruit fly prison!*

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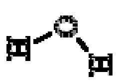
Take the Water Maze Challenge!

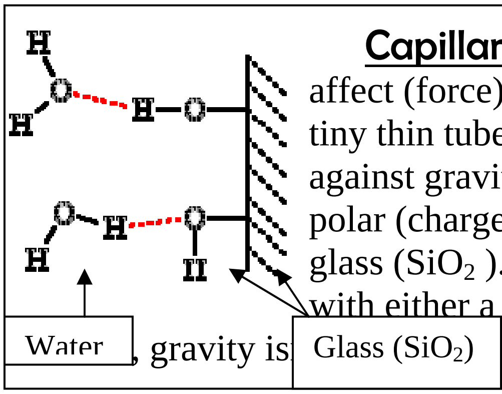
Your challenge now is to design a maze that water molecules are able to move from one end, down a desired path, to the other end of the maze. You can use the tools/molecules from the last activity as well as some additional ones listed below. Use only the tools you feel necessary to use to achieve your goal. You will make a colored diagram of your final plan on a piece of butcher paper large enough for your presentation. Be prepared to explain how each of the components are self-assembled and how the system will work to accomplish this goal.

NOTE: At this level of "smallness", gravity is not a factor to consider. For example, if you drop an ant from the Empire State building, the ant lives…for small things gravity is not a force that has significant effects.

Additional Tools/Molecules:



__Water__ Water (H_2O) is a polar molecule that has a negatively charged end and a positively charged end.



__Capillary Action__ Capillary action is the physical affect (force) that occurs with water on the walls of a tiny thin tube. Water climbs up the walls of the tube, against gravity, because of the strong attraction of the polar (charged) water molecule and the polar surface of glass (SiO_2). Water can use this force with molecules with either a positive or negative charge. At very small , gravity is rce.

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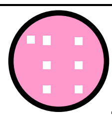
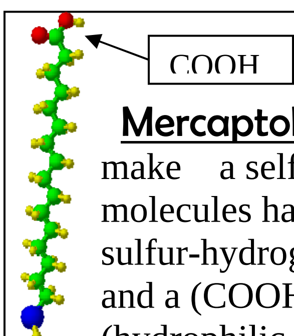
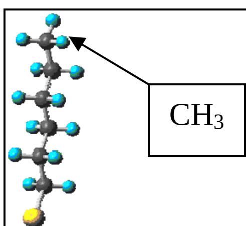


Masks A mask is designed to block out UV light. In this activity, you can design your own pattern of your mask and make as many masks as you would like.



Mercaptohexadecaonic Acid (MA) MA molecules are used to make a self-assembled monolayer (SAM) on a wafer. These molecules have a sulfur-hydrogen (SH) on one end that can covalently bond to gold, and a (COOH) group on the top that is negatively charged (hydrophilic- water loving). UV light at 254nm can break the covalent bond between the sulfur and the gold.



Hexadecane Thiol (HT) HT molecules also can be used to make a self-assembled monolayer (SAM) on a wafer. These molecules have a sulfur-hydrogen (SH) on one end that can covalently bond to gold, and a (CH_3) on the other end that is non-polar (hydrophobic). UV light at 254nm can break the covalent bond between the sulfur and the gold.

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Now its time to brainstorm! You need to answer the following questions in order to accomplish your goal. You don't need to write the answers to these, but use these as a guide to get started.

1. Review how what molecules and tools you have to work with.
2. What is the polarity of water? What does it attract to?
3. How will you move the water molecules?
4. How will you keep the water molecules going down one path?
5. How are you going to manipulate the self assembly of this design that will put all the molecules in the places that you want them?
6. What mask(s) will you use?
7. What order will you apply the molecules to the wafer?

Below is an area to write the steps you decided on and why:

Procedural Step of Assembly:	Why you are taking this step?
1.	
2.	
3.	
4.	
5.	

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If you have more steps, write them on the back of the paper.

****Now be sure to draw your design on the butcher paper with the parts labeled.**

Below is a space to write down why/how you predict the water molecules will follow the chosen path:

What are some specific parts of your plan that you are unsure of as to whether or not it will work?

Presentation Preparation:

1. Everyone must have a speaking part.
2. In your presentation, discuss the following:
   - The steps of assembly
   - The reasons for the steps
   - The final maze design
   - How the maze moves the water molecules
   - Some concerns as to how well this will work
3. Have the butcher paper with the design clearly drawn and labeled. Make your words and drawings big, colorful, and easy to read from the back of the room.