Q&A with a SCIENTIST studying SELF-ASSEMBLY

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# NANOOZE

THE SELF-ASSEMBLY ISSUE

WHAT IS SELF-ASSEMBLY?

THE TINY SCIENCE OF SOAP BUBBLES

ALL ABOUT S-LAYERS

SCIENTISTS AND SIMULATIONS

BUILDING BETTER INSULATORS

ALL ABOUT THE THINGS TOO SMALL TO SEE

## Welcome to Nanooze!

*What is a Nanooze? (Sounds like nah-news.) Nanooze is not a thing, Nanooze is a place to hear about the latest exciting stuff in science and technology. What kind of stuff? Mostly discoveries about the part of our world that is too small to see and making tiny things using nanotechnology. Things like computer chips, the latest trends in fashion, and even important stuff like bicycles and tennis rackets. Nanooze was created for kids, so inside you'll find interesting articles about what nanotechnology is and what it might mean to your future. Nanooze is on the Web at **www.nanooze.org**, or just Google "Nanooze"—you'll find interviews with real scientists, the latest in science news, games and more!*

### HOW CAN I GET NANOOZE IN MY CLASSROOM?

*Copies of Nanooze are free for classroom teachers. Please visit **www.nanooze.org** for more information or email a request for copies to **info@nanooze.org**.*


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# THE SELF-ASSEMBLY ISSUE

## What is self-assembly?

Few things in life are free. It usually takes parts and tools and some energy to build stuff. But can you imagine a bunch of parts assembling into something all by themselves?

Some molecules can actually self-assemble to make interesting structures. To do that they need to have some parts that attract to each other and some parts that like to stick to something else. At the nanometer scale, these attractive forces are pretty powerful. So powerful that they can even overcome gravity.

## Self-assembly is all around us

Do you have to go into a high-tech laboratory to see things that self-assemble? Nah. It's all around you. Snowflakes are crystals of water that self-assemble in the sky. They start off with a piece of dust and crystals of ice form around it. They change in shape and size because of changes in temperature and the wind.

Soap bubbles also self-assemble—the soap molecules and the water molecules organize themselves to form one layer. And bucky balls, those curious things made up of only carbon, are self-assembled. They were discovered by a group of scientists who were looking for different forms of carbon found in far-off stars.

## In this issue...

We meet a scientist who is studying self-assembly, learn about how soap bubbles self-assemble, and look at how some of the newest products use parts that are made by self-assembly. We'll also explore how scientists can guess at how things too small to see might behave without even actually making them.

## NANO KNOW-HOW

*Learning about nano stuff is fun but it can be complex, so it helps to keep these four important facts in mind:*

### 1. All things are made of atoms.

It's true! Most stuff, like you, your dog, your toothbrush, your computer, is made entirely of atoms. Things like light, sound and electricity aren't made of atoms, but the sun, the earth and the moon are all made of atoms. That's a lot of atoms! And they're incredibly small. In fact, you could lay one million atoms across the head of a pin.

### 2. At the nanometer scale, atoms are in constant motion.

Even when water is frozen into ice, the water molecules are still moving. So how come we can't see them move? It's hard to imagine that each atom vibrates, but they are so tiny that it's impossible to see them move with our eyes.

### 3. Molecules have size and shape.

Atoms bond together to form molecules that have different sizes and shapes. For instance, water is a small molecule made up of two hydrogen atoms and one oxygen atom, so it is called $H_2O$. All water molecules have the same shape because the bonds between the hydrogen atoms and the oxygen atom are more or less the same angle.

Single molecules can be made up of thousands and thousands of atoms. Insulin is a molecule in our bodies that helps to control the amount of sugar in our blood. It is made up of more than one thousand atoms! Scientists can map out the shapes of different molecules and can even build most types of molecules in the lab.

### 4. Molecules in their nanometer-scale environment have unexpected properties.

The rules at the nanometer scale are different than what we usually encounter in our human-sized environment. For instance, gravity doesn't count because other forces are more powerful at the molecular level. Static and surface tension become really important. What is cool about nanotechnology is that we can make things that don't behave like we expect. **Things are really different down there!!**

# Q&A with Aaron Strickland

*Postdoctoral Research Associate and National Science Foundation Discovery Corps Fellow*

*Aaron adds calcium, a key ingredient for S-layer protein assembly, to a solution containing S-layer protein molecules.*

***Where did you grow up and what was your childhood like?*** I was born and raised in Wyoming. I'd say I was a pretty "normal" kid with interests that ranged from sports to hunting and fishing. My father was an ecologist for the Wyoming Game and Fish Department and my mother was an elementary school teacher. I have one older brother. I attended public school and devoted a lot of time to competitive sports and probably not enough time to my schoolwork. I did well in school but I would not say I *excelled* until I got into college.

***When you were a kid what interested you about science? What was the first experiment you did?*** I was probably most interested in the natural sciences as a kid, which is likely a result of growing up in Wyoming. Wyoming has a lot of amazing wildlife and geological formations, which inspired me to learn about these things that were literally at my doorstep.

The first "real" experiment I did as a kid was in my high school science class. I exposed growing plants to acidic water to simulate acid rain. At the time—and still today—I am interested in how people affect the natural world around them. It was very fulfilling for me to systematically design an experiment to study how plants respond to contaminants such as acid rain. I was actually awarded a scholarship to college for that work, and this competitive aspect of science was also appealing to me.

***Did you always think you were going to be in research?*** Definitely not. I had the usual dreams of becoming an astronaut or doctor as many other kids. I started my college life out wanting to pursue medical school, which quickly turned to engineering and then I settled on chemistry.

Near the end of my college career I was able to work on an independent research project and it was then that I knew I liked science research. With some direction by my professors I was given freedom to pursue a research idea that I came up with. Mistakes and hardships occurred along the way; however, the work involved creative thought, intense learning and problem solving, which were all very energizing for me.

***Where do you come up with your ideas?*** Though I don't think I have the type of experience and understanding to develop truly "groundbreaking" ideas, my interests are very broad and I have a decent ability to connect the dots between seemingly unrelated scientific concepts or problems.

For example, I read scientific literature and attend scientific discussions outside my immediate field of chemistry, and try to apply my skills as a chemist to solving problems using a different and hopefully better approach. I may read a scientific paper on how glucose sensors work for treatment of diabetes and draw from my scientific background to answer the question, "How would I build a glucose sensor?" Most of my ideas start with me brainstorming in a very general way, and then refining an idea by filling the gaps either through discussions with other scientists and/or learning about what is known.

***Do you see molecules?*** I'm a little embarrassed to say yes, I do "see" molecules. However, I see them as drawings on paper, which is how chemists—especially organic chemists like myself—visualize the makeup or interactions of the chemicals we use. In many ways, visualizing these molecules actually allows me to progress an idea I may have without actually doing any physical work. Tough job, I know.

***One area that you have worked in is self-assembly. What's that all about?*** Self-assembly is exactly what it sounds like: it makes stuff out of material without any help. Though most often things tend to get messy, under appropriate conditions, disordered objects like groups of molecules will come together (self-assemble) into organized structures or patterns. Like the process of forming ice from water.

*(Continued on page 6)*

# Soap Bubbles:
## The Beauty of Self-assembly

No assembly required. Just puff. That is about all you need to make a soap bubble. Well, of course you need soapy water and something to make a thin layer of soapy water. But add a slow and careful puff of air and you've got everything you need to make a beautiful bubble. You don't have to build the bubble bit by bit with your hands. When you blow a bubble, the soap and water molecules organize themselves automatically into thin layers through the process of self-assembly.

Soap bubbles are made of a layer of soap molecules, a layer of water molecules, and then another layer of soap molecules all kind of sandwiched together (think a piece of bread, a piece of cheese, and another piece of bread). Except that this sandwich is really thin, about 1/100$^{th}$ the width of a hair. The layers are so thin that you can't see them with your eyes.

So why does a puff of air cause these thin layers to self-assemble? How do the molecules know which way to move? And why do they make a big bubble instead of just flying off into the air? Well, soap molecules have two different parts—one part likes water and the other part doesn't. The part that likes water is called hydrophilic, the part that doesn't is called hydrophobic (hydro=water, phobic=afraid of).

When there's a little water around, the soap molecules form a layer with the part that likes water on one side of the layer and the part that doesn't like water on the other side. Do that on both sides of a thin layer of water and, presto, you have a bubble.

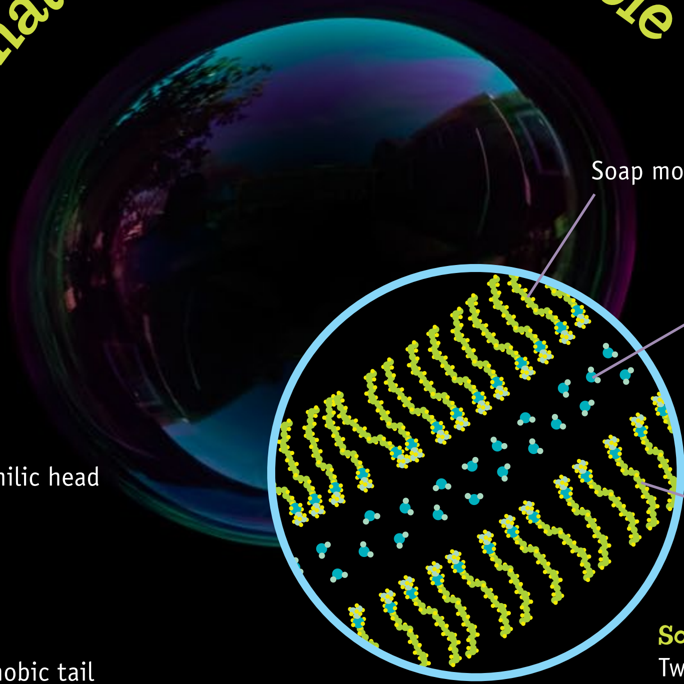
There is another nanoscale phenomenon that happens with soap bubbles. Look closely at the bubble and what do you see? Colors—all of the colors of the rainbow. And what's cool is that the colors change as the bubble is carried along by the breeze.

At the nanometer scale, unexpected things happen, including the bending of light. The thin layers in a soap bubble diffract light and, depending upon the thickness of the layer, different colors of light are diffracted.

So the surface of a soap bubble looks like lots of little swirling rainbows because the thickness of the layers is always changing. The layers don't change much, only a few hundred nanometers, or less than one-thousandth the width of a hair.

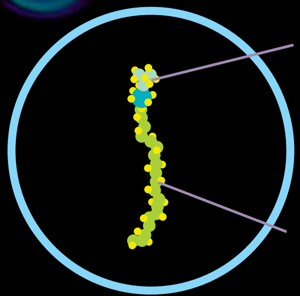
The rainbow colors on a bubble's surface are created by tiny differences in the thickness of the bubble's wall.

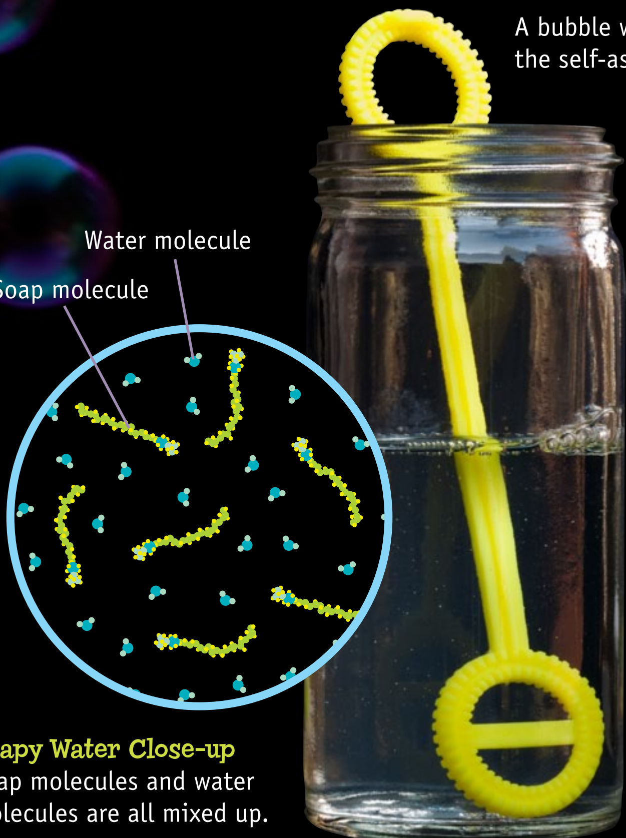
# The Anatomy of a Soap Bubble




**Soap Bubble Close-up**
Two layers of soap molecules sandwich a thin layer of water molecules.

**Soap Molecule**




A bubble wand helps start the self-assembly process.

**Soapy Water Close-up**
Soap molecules and water molecules are all mixed up.

## Try It Out!

### Big Homemade Bubbles

1 cup ultra dish soap (Joy or Dawn brand)
12 cups pure water (distilled works best)
1/4 cup glycerin or light corn syrup (Karo brand)

Combine ingredients and stir gently. Letting the mixture rest overnight helps make bigger bubbles that last longer. Keeping your bubble containers dirt and dust free helps too. Use a coat hanger or wire to make your own bubble wands of all sizes!

*If you have regular dish soap instead of concentrated, use 1 1/2 cups. Distilled water is best, but tap water works too. You can find glycerin at the drug store.*

(Continued from page 3)

Currently, I am studying a self-assembly process that exists in nature on the surface of many bacteria. If one looks at these surfaces with a really powerful microscope there is very amazing structure and order to the surface, which is made of protein we call S-layer protein. S-layers contain patterns of peaks and valleys and pores that are arranged in perfect patterns, such as tiny hexagons, that repeat over the entire surface of the bacteria. These hexagons are spaced at only 20 nanometers apart and form a very stable layer that helps protect the bacteria.

We would like to repeat this S-layer assembly in the laboratory to study this natural process, and to make use of this precise arrangement of matter over relatively large areas. In the future, this process could be used to build unique catalysts, optical devices, sensors, and other things that cannot be achieved using current technologies. For example, if we can build self-assembled structures with conductive nanoparticles, we could jump-start advances in longer-lasting batteries or build smaller computing chips.

***Does everyone who finds out you are from Wyoming think you are a cowboy?***
Mostly, and I have to explain to them that despite having horses, I in fact drove a car or rode a bus to school and NOT a horse or a horse-drawn wagon.

Listen to Aaron's story in *Chronicles of a Science Experiment*, produced by *EarthSky* at www.earthsky.org.

## *What's an S-layer?*

*The term S-layer is short for surface layer. S-layers are the outermost layers on bacteria and are composed of identical proteins that form a repeating self-assembled structure. The thickness of an S-layer is between 5 and 25 nanometers.*



# *Staying in shape with S-layers*

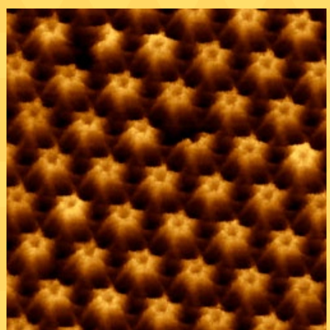
### Not everything that is made on the nanometer scale is made in a laboratory.

Nature is full of nanometer-sized stuff, some of which happens by self-assembly. DNA and proteins are made using enzymes, little tools that take the parts and put them together, so these are not self-assembled. Then what is?

### Well, on the outside of some bacteria is a material called an S-layer.

S-layer stands for "surface layer," which proves that scientists are not always clever in figuring out names for things. An S-layer is made up of just one protein that has the special ability to form large crystals (sort of like salt). The crystals are two-dimensional, flat, and made up of only a single layer of protein.

What's cool about the S-layer is that it has tiny holes only a few nanometers wide, spaced out a few nanometers apart. Think about a window screen, the kind that you use to keep out bugs when the window is open. But the holes on an S-layer screen are about a million times smaller. That is so small that even most molecules can't fit through.



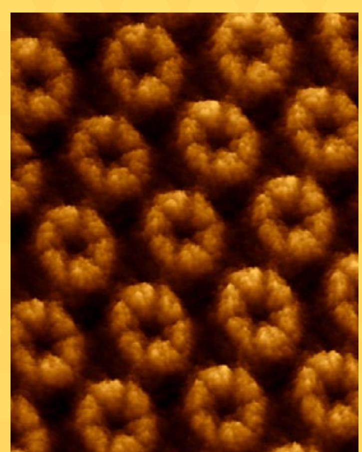
*Atomic force microscope image of the inner surface of a protein S-layer*

### Why do bacteria need S-layers?

S-layers help give bacteria shape. Without them many bacteria would just be a big blob and shape is sometimes important. S-layers also might protect the bacteria from other things, like other bacteria. But S-layers probably also help keep most molecules inside the cell and other molecules outside of the cell. Kind of like a barrier that separates the inside of the cell from the outside.

### Are S-layers useful to us?

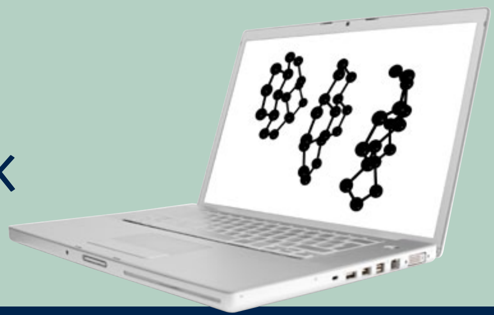
Scientists are very interested in making nanometer-scale structures. They are using S-layers to make nanowires, really thin wires that are a lot taller than they are thick. How thick? A few nanometers, and thousands of these will fit across the width of a hair.
One thing that nanowires can be used for is making rechargeable batteries. Scientists think that nanowires would make really good parts for batteries—batteries that last longer and hold more of a charge. All this from a little bacteria, all this stuff that is made by self-assembly.



*Atomic force microscope image of the outer surface of a protein S-layer*

*S-layer images courtesy of Simon Scheuring*

# **Simulations:** How Scientists Work With What They Can't Even See



**All things are made of atoms—the air we breathe, the rain that falls from the sky, the computers we use every day—even our own bodies are made of atoms and molecules. But even though they are all around us, we can't see a single atom or molecule with our eyes.**

Nanoscientists use powerful microscopes called **scanning probe microscopes** to "see" atoms and molecules. In school or maybe at home you probably used an **optical microscope**. With those microscopes you can see cells. Scanning probe microscopes are a lot different than optical microscopes. Instead of using lenses and light to magnify a specimen, scanning probe microscopes "see" by using a really tiny needle as a probe. This special needle is used to "feel" the surface of a specimen and it sends back information that makes a kind of picture. So under the right conditions, you *can* see atoms and molecules.

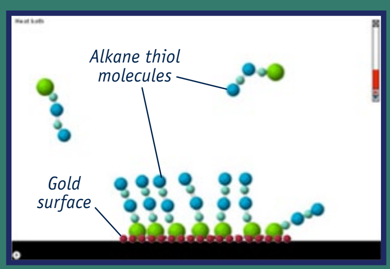
Scanning probe microscopes are pretty big and are tricky to work. The really tough part is getting the atoms and molecules to stay still. Since atoms and molecules are in constant motion, the only way to do this is to keep them really cold, because the colder they are the slower they move. How cold? Almost absolute zero, five degrees Kelvin—that's minus 450 degrees Fahrenheit. Brrr!!! The other problem is that you have to get rid of most of the atoms, which means working in a vacuum because even air has a lot of atoms.

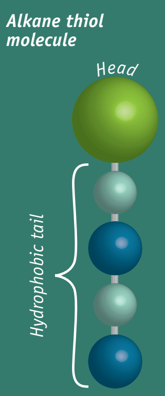
Scientists have one way to see how molecules behave without even making them or testing them for real. They can see how molecules *might* self-assemble using **simulations**. Simulations are done on computers that can figure out all of the forces that make molecules self-assemble. Sort of like a video game where you crash the car into the wall and it bounces off, simulating what might happen for real. It looks real because the computer figures out what it should look like and simulates the movements of the crash.

Scientists use simulations to figure out how to make better molecules, including ones that self-assemble better. Simulations help scientists make predictions without going into the laboratory or using a scanning probe microscope.

## A Self-assembled Monolayer Simulation

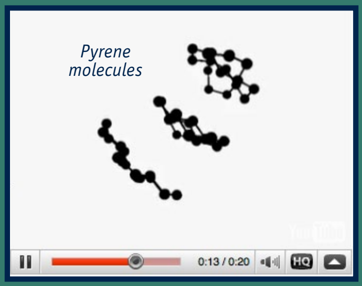
This simulation shows alkane thiol molecules self-assembling on a gold surface. The molecules move around and after a bit of time the heads of the molecules are attracted to the gold. As they begin to attract to the surface, they pack together because of the interactions between the long hydrophobic tails. When they finish self-assembling they form a layer that is only one molecule deep. It is called a self-assembled monolayer.




## A Weak Interactions Self-assembly Simulation

In this simulation, three pyrene molecules come together and stack one on top of the other. The world is a sticky place at the nanoscale. When molecules come close to one another they stick together through an action known as "weak interactions," another way that molecules can self-assemble.




### Check it out!!

To see animated versions of these simulations and others visit www.nanooze.org/selfassembly

# Using Self-assembly to Build Better Insulators

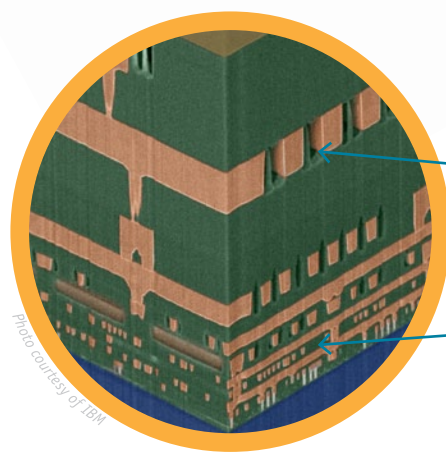
Many products we use, such as computers, cell phones and medical devices, contain nanometer-sized parts. A lot of these parts are integrated circuits, which have thin layers of metals separated by thin layers of insulators. The thinner the layers, the smaller the parts can be made—and smaller, thinner circuits can operate faster.

Insulators are things that don't conduct electricity—like the plastic covering of an electric cord. In computer chips, insulators are important because they keep electrons from hopping between circuits. But the smaller you make a computer chip the harder it is to make insulators.

Scientists at IBM discovered a nifty idea for using self-assembly to make smaller, more efficient insulators for computer chips. They figured out how to form self-assembled patterns of trillions of nano-holes in a special polymer. The polymer was then used as a template to etch patterns of tiny air holes into an insulating material. Air is a pretty good insulator. If you wear a big puffy down coat, the coat is warm because of the air that is trapped in the feathers. These little "airgap" insulators make the computer chips run 15% more efficiently. That might not sound like much, but it allows the chips to run cooler and faster. All because of self-assembly!

## What's an Insulator?

*An insulator is a substance or device that does not readily allow the passage of heat or electricity. The plastic coating on electrical wire is an insulator, keeping the electricity inside the wire.*




## IBM's Airgap Insulator

*This microprocessor cross section shows progressively smaller insulator layers. IBM scientists used self-assembly techniques to create the tiny airgap insulators on the bottom layers. This breakthrough reduces electrical interference, raises processor performance, and lowers energy consumption.*


## The Scientist Behind the Nanotechnology

*IBM scientist Dan Edelstein with an experimental version of the airgap microprocessor. The self-assembly technique used to create this chip draws on nature's ability to form intricate patterns, such as those found with snowflakes and sea shells.*