MOLECULES: Lots of SHAPES and SIZES

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NANOOZE

Q&A WITH NANOSCIENTIST SETH DARLING

THE DISCOVERY OF DNA

NANO-TREES

nanooze.org

2011 C CHEMISTRY

International Year of CHEMISTRY 2011

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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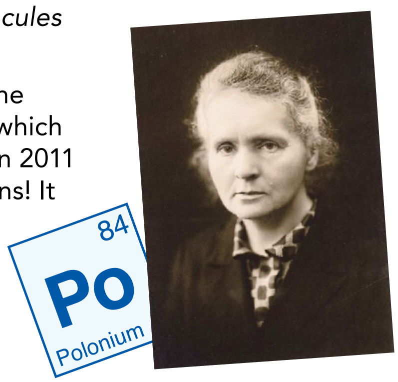
Molecules Have Size and Shape and the International Year of Chemistry

All things are made of atoms. Yup. Well, almost everything. The paper that Nanooze is printed on, the ink, the staples. You, your dog. Well, not sunlight, but the little pieces of dust in sunlight that you can see swirl around the air, those dust particles are less than 100,000 nanometers in size and made mostly of atoms. For the next few issues, we're covering the four important concepts that are described below. This issue focuses on: *Molecules have size and shape.*

These issues are also devoted to the **International Year of Chemistry**, which was celebrated around the world in 2011 by declaration of the United Nations! It was organized by IUPAC, the International Union of Pure and Applied Chemistry.



Marie Curie discovered the element polonium

One important event was the 100th anniversary of the Nobel Prize awarded to Madame Marie Curie, a very famous scientist, one of the few people to win that prestigious award twice and the only one to win it in two different fields of science: in 1903 for physics and 1911 for chemistry.

Madame Curie discovered the elements polonium and radium, and is credited with the phrase "radioactive." She used radioactive isotopes to treat neoplasms, which sometimes form cancerous tumors. A remarkable set of accomplishments!

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 Nanoscientist Seth Darling

Argonne National Laboratory

What was your childhood like? When you were a kid, what interested you about science? I wanted to be a scientist for about as far back as I can remember. Chemistry was my first area of curiosity. I think it was probably a fascination with the ability to turn things into other things, and maybe a bit of learning how people blow stuff up.

When you were looking at careers, what attracted you to join a national research laboratory? National laboratories like Argonne are amazing places because they sit at the boundary between university research labs, which are primarily focused on basic science, and industrial research labs, which are primarily focused on developing products. That allows us to span the entire range of research, including translating new ideas into innovative technologies.

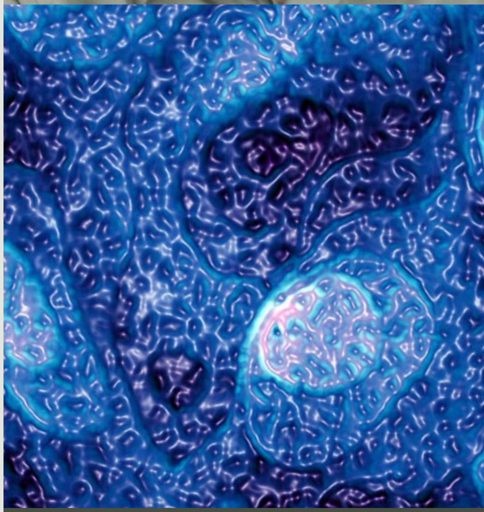
Working at a Department of Energy lab is perfect for me because my work is mostly on solar energy, and having an environment full of multidisciplinary experts all working on a big problem like the energy challenge is exciting.

What are your days like at work? What kind of science do you do? No two days are alike. I spend some time in the lab performing experiments. I also write and review papers, work on proposals for research funding, present my work to other scientists, do outreach with schools and museums, and my favorite part: planning, strategizing about, and discussing science.

My research no longer fits into one area like chemistry or physics, which is a common situation for nanoscientists. Now my group works in a mixture of those fields plus materials science, electrical engineering, and even a little bit of economics. Our focus is on solar energy, but we also study topics like self-assembly (materials that organize themselves, like in the Rough Waters image) and nanoscale patterning.

You won first place in the National Science Foundation Visualization Challenge with the picture titled Rough Waters. Did you set out to take a neat picture or did it just happen? We collected data that are the basis of this image as part of an experiment. We had no intention to capture something beautiful. The structure that the molecular layer exhibited was pretty cool-looking, so we did a bit of work to give the image a nice color and look, and this is the result.

You used a special instrument called an atomic force microscope. How does that work? An atomic force microscope (AFM) is basically a super fancy record player. Record players are those things DJs use to scratch. It works in a completely different way than optical microscopes, and it is usually used to “see” things that are too small to see with visible light. It works by moving a very sharp tip back and forth across a surface and feeling the structures on the surface. A laser bounced off the back of the tip is used to measure the tiny movements. AFMs can even see individual molecules if the tip is sharp enough and there aren’t too many vibrations.



Making Waves
Seth’s prize-winning nanoscale image, titled *Rough Waters,* was created in a lab with an atomic force microscope.

Rough Waters Credit: Seth B. Darling, Argonne National Laboratory, Steven J. Sibener, University of Chicago

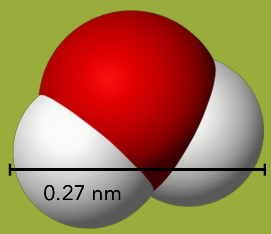
Where do all the shapes come from? In this image, there are two types of shapes. There are larger rounded shapes and smaller dimples within these. The larger shapes are actually different layers of atoms of the gold surface that sits below the layer of molecules. The little dimples are a result of the fact that there are two types of molecules on the surface, and they have different heights. This difference in height is very small, less than a billionth of a meter, but an AFM can measure it quite accurately.

Do you think that you might become an artist and give up the life of a scientist? Definitely no plans to stop being a scientist. I love my job. Also, I’d never cut it as an artist. Luckily, as a scientist you often get to use some artistic skills when preparing figures to communicate your results and ideas, so we can all dabble a bit.

How is a **record player** like an **atomic force microscope**?

Sizing Up a Molecule

Molecules are made up of atoms and all things are made of atoms. Not *quite* everything; light isn't, and sound isn't either. But the things that we see when light hits them are made of atoms, and we hear sounds because the molecules in the air transmit sound energy from one place to another.



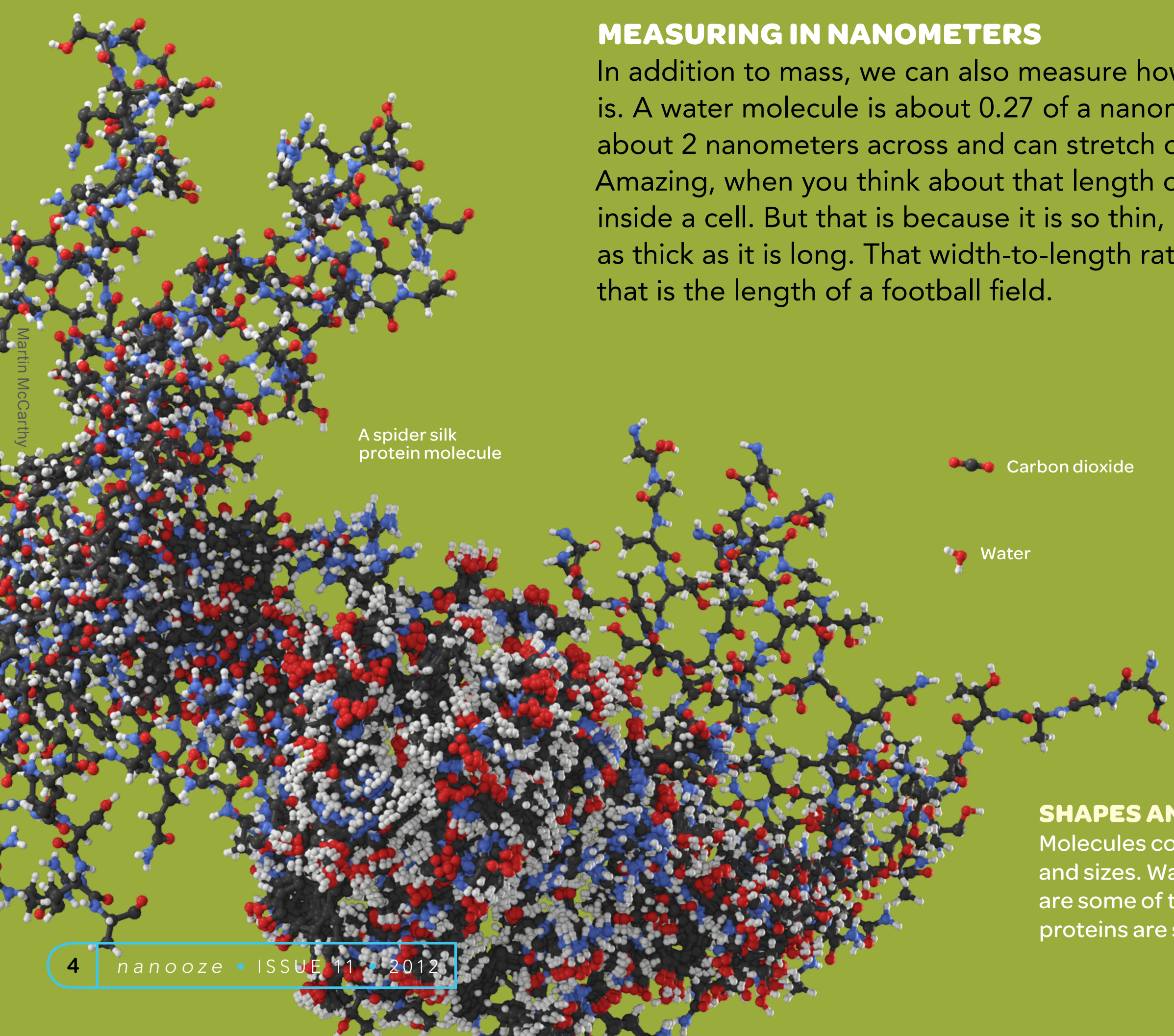
A WATER MOLECULE
A water molecule has a molecular weight of 18 and is about 0.27 of a nanometer across.

MOLECULAR WEIGHT

Molecules have size and different molecules are different sizes. When talking about the size of a molecule, most scientists will mention its molecular weight. That is the total weight of all of the atoms in the molecule. So water, which is made up of two hydrogen atoms (1 atomic mass unit each) and one oxygen atom (16 atomic mass units) has a molecular weight of 18 (well, 18.01528 to be exact). Glucose has a molecular weight of 180. DNA, which is very long, can have a molecular weight that is around 10^{10} (about the weight of one human chromosome).

MEASURING IN NANOMETERS

In addition to mass, we can also measure how big a molecule is. A water molecule is about 0.27 of a nanometer across. DNA is about 2 nanometers across and can stretch out to meters in length. Amazing, when you think about that length of DNA being stuffed inside a cell. But that is because it is so thin, about 1/1,000,000,000 as thick as it is long. That width-to-length ratio is like a human hair that is the length of a football field.

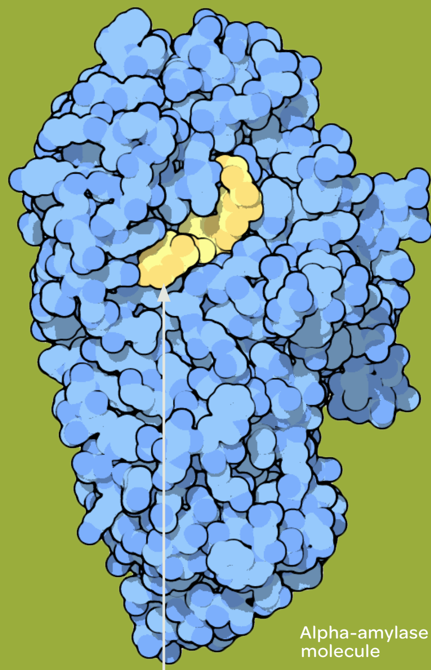


Martin McCarthy

SHAPES AND SIZES
Molecules come in many shapes and sizes. Water and carbon dioxide are some of the smallest molecules, proteins are some of the largest.

How Molecules Shape Up

Do molecules have a real shape or are they just some kind of random blob like a piece of jello? Well, molecules do have shape (even the molecules that make up jello have shape) and their shape is important. Some molecules, like enzymes (which are proteins), have shapes that help them do their job.



Alpha-amylase molecule

David S. Goodsell / RCSB PDB

AMINO ACIDS

Proteins are made up of long strings of amino acids. There are about 20 different amino acids that are commonly found in nature and, like DNA, the sequence of amino acids is important. These long strings of amino acids fold up because the amino acids form weak bonds with each other. Each amino acid interacts with a lot of other amino acids in the protein to give it a very specific shape.

ENZYMES AND STARCHES

Enzymes like the one that breaks down starch also have a very specific shape that helps them cut long molecules of starch into smaller ones. Starch is a long, skinny molecule made up of lots of molecules of glucose. Starch is about 1.4 nanometers across (a bit less than DNA) and can be more than 10,000 nanometers long!

NANO GROOVES

The enzyme that breaks down starch, alpha-amylase, has a deep groove and the starch molecule can fit into that groove. The groove is only 3 nanometers deep (that is 1/30,000 the width of a hair). Once the starch is inside this groove, a special set of amino acids get to work and break the bonds that hold the starch molecule together. It works because of the shape of the enzyme, the way it holds the starch, and those special amino acids being *just* close enough to do their job. Move those special amino acids away by just a few nanometers and they won't work anymore.

A MOLECULE'S ACTIVE SITE

The groove in the enzyme and the special amino acids work together to form what is called the "active site."

The active site of every enzyme is different, but each active site has a unique shape that makes it easy to hold whatever molecule is being worked on and a special set of amino acids to actually *do* the work.

CHANGING MOLECULE SHAPES

Take a protein—heat it up and sometimes it loses its shape and then really does form a blob. Just fry an egg and the proteins in the egg white go from being almost clear to white, the proteins forming blobs that no longer stay in solution. The same kind of thing happens when you make cheese: the milk proteins form blobs and you get a curd.

The Most Famous Molecular Shape

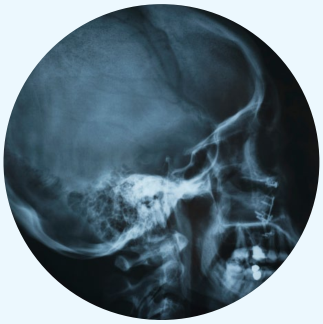
Think of the shape of a molecule. What image pops into your head? Probably the double-helix shape of DNA. It is so familiar that when you see a double helix, you immediately think of DNA.

The double-helix shape of DNA was discovered by Francis Crick and James Watson in 1953.

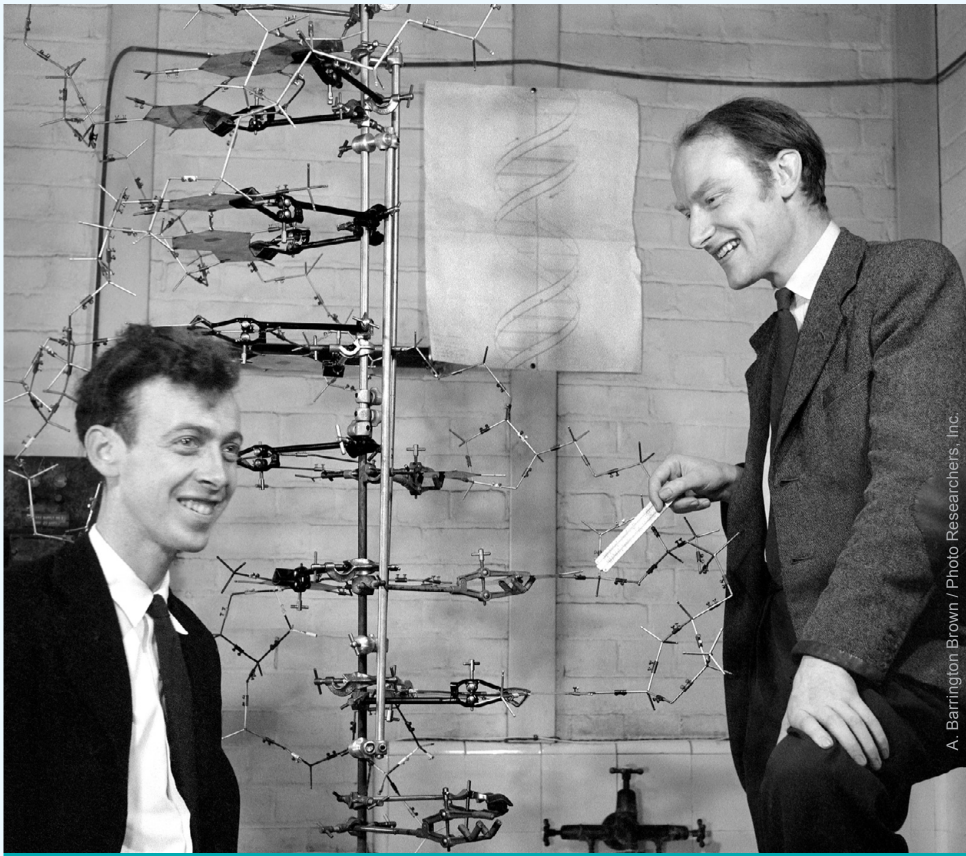
They won the Nobel Prize for their efforts, work that was helped out by a few other people, including Rosalind Franklin, who used x-rays to help figure out the structure of DNA. X-rays are very powerful and they are used to look at your teeth or maybe a broken bone becuase x-rays can penetrate skin.

If molecules are crystallized, then their shape can be figured out using x-rays. Think about a pool table and hitting one ball into another. The ball that you hit might go in one direction and if you are a really good pool player you can guess where the ball might go. Figuring out the shape of a molecule using x-rays is kind of like that because the way that the x-rays bounce off a molecule can be predicted. It is called x-ray diffraction. Watson and Crick used an x-ray that Rosalind Franklin took to help uncover the structure of DNA.

The shape of DNA, like every other molecule, is determined by the atoms and the bonds between the atoms.



What do the game of pool and x-rays have to do with molecular shapes?



A. Barrington Brown / Photo Researchers, Inc.

James Watson (left) and Francis Crick with their model of DNA. They published their findings on the structure of DNA in 1953 and were awarded the Nobel Prize in 1962.

“Seeing” Shapes of Molecules

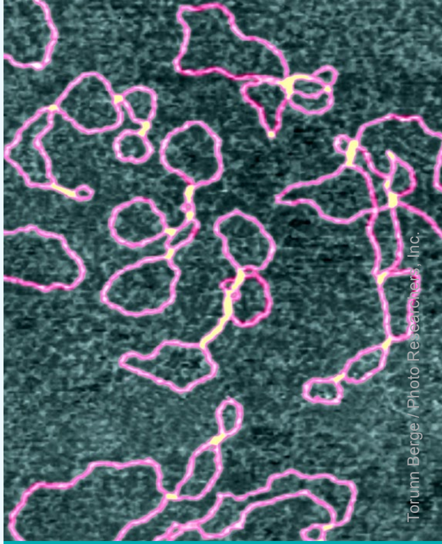
How do we know if a molecule has a shape? Well, there are various ways, but the most direct is to use a very powerful microscope like the atomic force microscope. That is what Seth Darling used to “see” his surfaces and all those shapes that make it look like waves on the ocean.

The world’s most powerful micro-scopes don’t see things with light.

They see things by feeling with a very sharp tip on the end of something that looks like a needle. The tip is so sharp that it’s only a few atoms wide, so as it is moved across something tiny, like a single molecule, it can feel the shape.

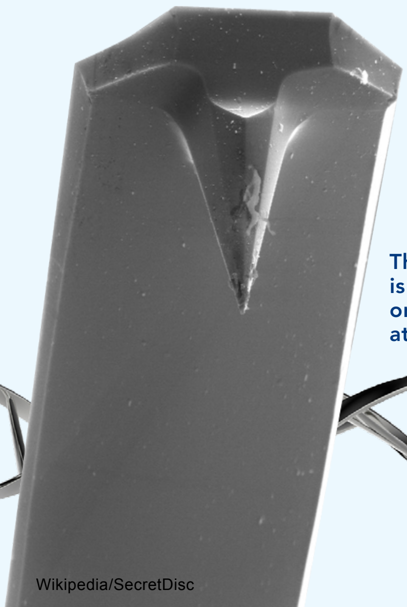
These very powerful microscopes are called atomic force microscopes, because they can see things by feeling the forces between atoms. So with an atomic force microscope you can see things as small as a strand of DNA or even individual atoms.

These microscopes use computers to help convert the information from tapping on a surface to generate a three-dimensional view of an object. So with the world’s most powerful microscope, scientists have been able to ”see” DNA and report that it is a double helix just like Watson and Crick showed over 50 years ago! Or, more recently, Seth Darling was able to see his material.



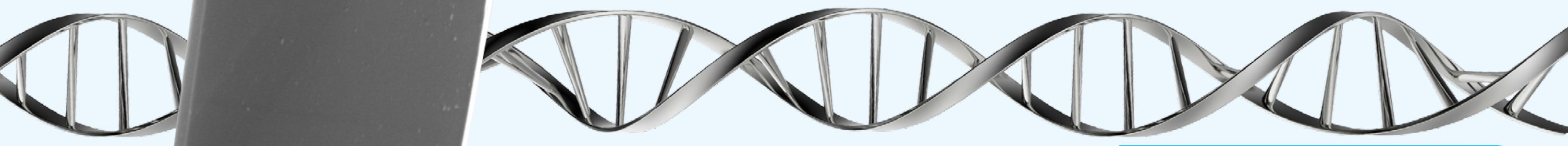
Torunn Berge / Photo Researchers, Inc.

DNA plasmids imaged with an atomic force microscope at a magnification of 75,000X. Plasmids are circular DNA molecules that are found in some bacteria and yeast cells. These plasmids code for different things including resistance to antibiotics and, in some cases, toxins that can make you sick.



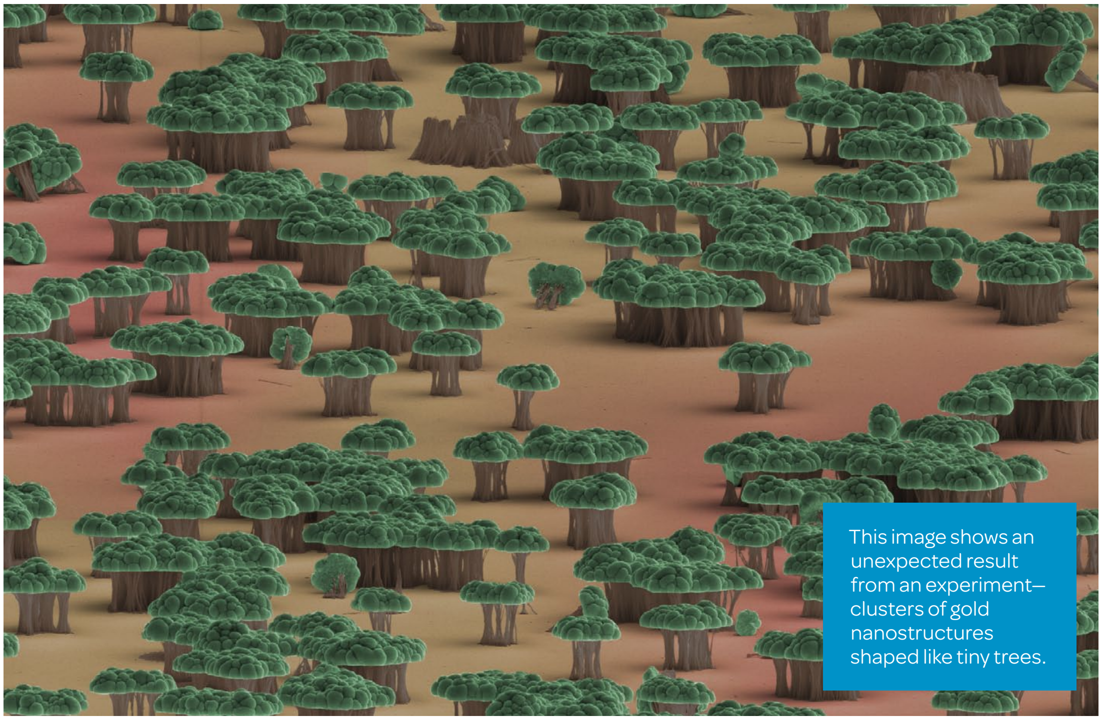
Wikipedia/SecretDisc

The tip of an AFM micoscope is made of silicon and is only a few nanometers wide at the sharpest point.



A Tiny Forest?

Sometimes science is very cool!



This image shows an unexpected result from an experiment—clusters of gold nanostructures shaped like tiny trees.

Jeong-Hyun Cho

Everything we do in science is always predictable, right? It always comes out the way we plan it. Put it on a piece of paper and it happens? WRONG! Most of the time science is just that: science, research, you set things up and you hope for things to work.

Sometimes things work in unexpected ways. Take this picture for example. Looks like a bunch of trees, maybe tiny trees, maybe a tiny forest, maybe with tiny bears. WRONG! Those little trees are gold nanowires capped with blobs of gold on top. The trunks are only about 1.5 nanometers in size.

Gold is used as a catalyst to "grow" different kinds of nanowires. The gold takes atoms of silicon out of a gas and starts to build wires made of silicon. The process is called "chemical vapor deposition." As the wire gets longer, the gold, which started off on the surface, gets pushed up. Kind of like a tree growing, except the tree grows from the gold "seed."

Green trees with brown trunks? Not exactly. At the nanometer scale there is no color since these objects are smaller than the wavelength of visible light. The picture, taken with a very powerful electron microscope, was colorized by a very creative scientist hoping that you might imagine they were nanometer-sized trees.

"Synthesizing new nanomaterials is like cooking, only you have to use completely new ingredients and tools. You never quite know what's going to come out the first time—but with practice we manage some pretty gourmet dishes." - Tom Picraux

The scientists behind the nano-trees

Tom Picraux (on right) and Jeong-Hyun Cho at the Center for Integrated Nanotechnologies (CINT) remove a sample from the scanning electron microscope where the unexpected image of "nano-trees" was taken.