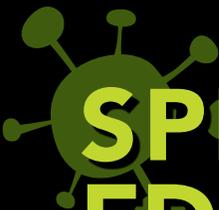
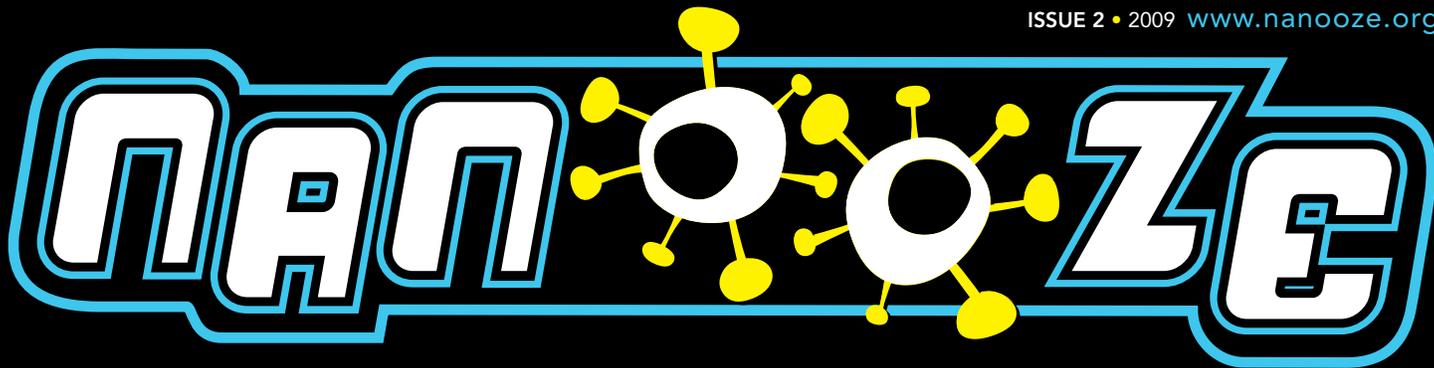


NANOOZE



**SPECIAL
EDITION!**

NANOOZE: THE EXHIBIT

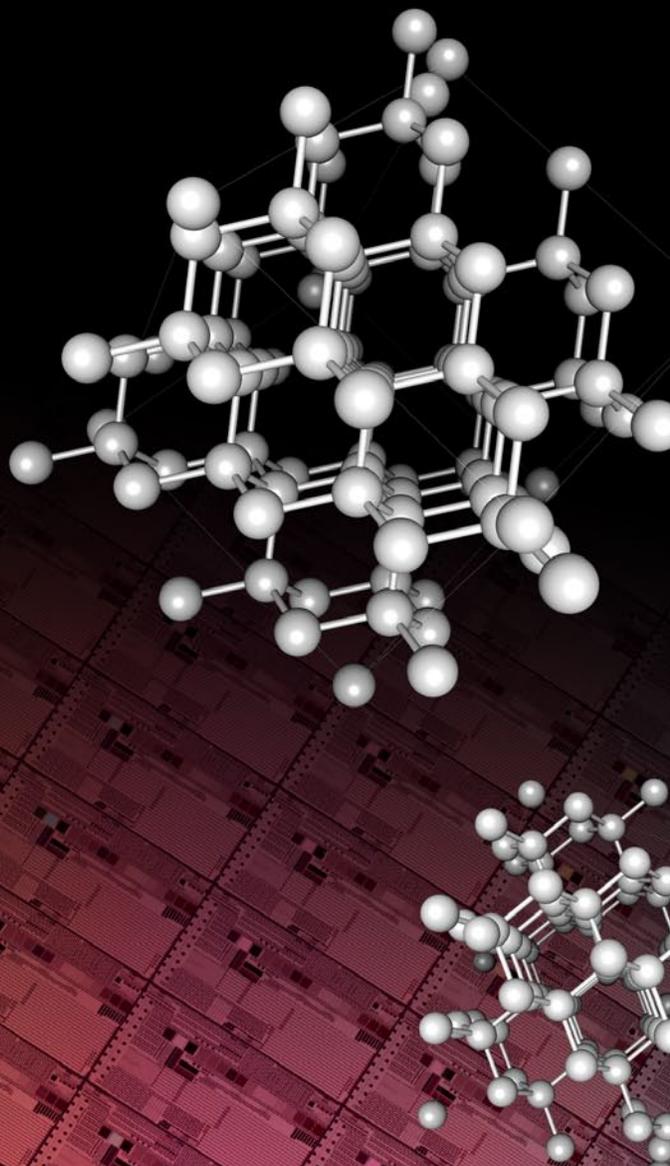
**AN INTERVIEW
WITH DON EIGLER**

**THE 4 IMPORTANT
THINGS TO KNOW ABOUT
NANOTECHNOLOGY**

**HOW LONG IS
A PIECE OF DNA?**

**CAN NANOTECHNOLOGY
HELP COMBAT CANCER?**

**THE FUTURE OF
CLEAN ENERGY**



NANOOZE

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.

© 2009 Cornell NanoScale Science and Technology Facility. Design by Emily Maletz Graphic Design. A project of the National Nanotechnology Infrastructure Network (NNIN) with support from the National Science Foundation.

NANOOZE

The Exhibit

Let's Get Nano!

What is it like to hang out with atoms and molecules? Well, you do it every day, because all things are made of atoms. But to really hang out with atoms and molecules, you need to go on a fantastic voyage and here is your chance. *Nanooze: The Exhibit* is an interactive exhibition currently touring the country. The exhibit was created by folks at Cornell University with support from the National Science Foundation who is making the tour possible.

To get ready for any kind of trip, you need to pack a few things, mainly ideas to keep in your head. For this trip remember that:

- All things are made of atoms
- At the nanometer scale, molecules are in constant motion
- Molecules have size and shape
- Molecules in their nanometer-scale environment have unexpected properties

The first thing that you need to do to begin this voyage to the world that is too small to see is get small, get nano. You start off at the macroscale, the place where we all live and hang out. But common objects like a butterfly wing, an oyster shell, a dragonfly wing, or a computer chip become exciting and complex when you zoom in 100—1,000,000—better yet—1,000,000,000 times. And when you get there, what you find out is that these molecules are moving around, making them hard to see and even harder to do something with. During your visit to the world that is too small to see you can even grab a molecule and stretch it out, then let go and see what happens.

It's one thing to see things that are too small to see, but it's more fun to make things that are too small to see. At *Nanooze: The Exhibit*, you can put together atoms and form different molecules, then take a look



Build a Carbon Nanotube (above), Dissolve a Crystal (left), and Build a Molecule (below), three of the exhibits you can experience at *Nanooze: The Exhibit*.



at the different shapes. Or you can take the atom transporter challenge where you match your skills at moving atoms just like nanoscientists do.

Remember, *Nanooze: The Exhibit* is traveling around the country. To see if it's going to be near you, check out www.nanooze.org.

Q&A

with Don Eigler

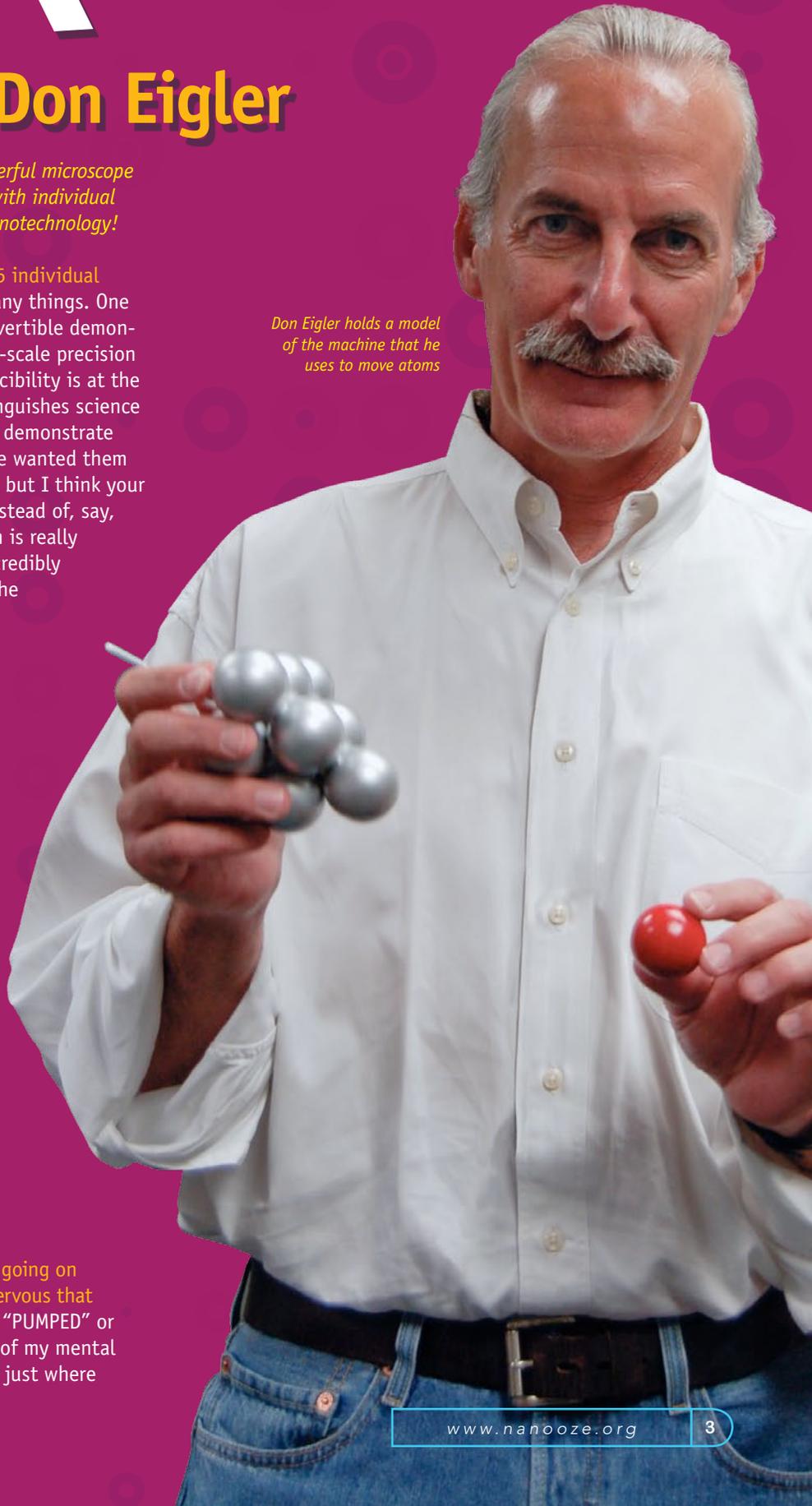
In 1989, Don Eigler and his team at IBM used a powerful microscope they built as a tool to spell out the letters "I-B-M" with individual atoms. It was one of the most important feats in nanotechnology!

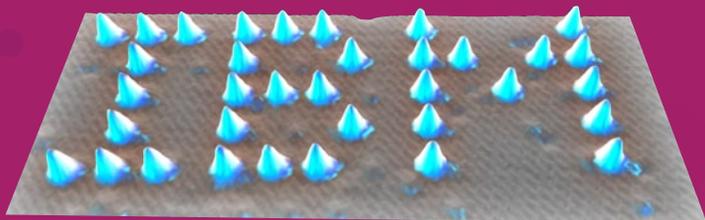
You and your colleagues spelled out I-B-M using 35 individual atoms. What were you thinking? I was thinking many things. One of the things I wanted to achieve was an incontrovertible demonstration that we could position atoms with atomic-scale precision over and over again. I have long held that reproducibility is at the very core of experimental science. It is what distinguishes science from pseudo-science. So I wanted a way to clearly demonstrate that we could reproducibly put the atoms where we wanted them to go. Writing out "I-B-M" accomplished this goal, but I think your question is more along the lines of why "I-B-M" instead of, say, "A-T-O-M" or "M-O-M." The answer to that question is really very simple: payback time. I was (and still am) incredibly beholden to the company, and the individuals in the company, that gave me a job when I needed one, and then provided me with every opportunity and resource I needed to achieve professional success. Writing out "I-B-M" with xenon atoms was a way of providing return on the investment. But even more, there was a sense of loyalty and pride that this was an IBM accomplishment.

Was it hard to do? Did you have to spend late nights in the lab? The actual writing of "I-B-M" took 22 hours with a few breaks. Sometimes I would get a letter finished and then mess it up and have to go back and position the atoms again. Nowadays it would take about fifteen minutes. Was it hard? The 22 hours were as delightful as I imagine the first flight of the Wright brothers at Kitty Hawk [North Carolina] must have been. The hard part was the five years of work (two after completing my Ph.D. and working in a university, three at IBM) pioneering low-temperature Scanning Tunneling Microscopy. As for late nights...I have spent countless late nights in the lab. Comes with the territory.

So you do this work but you really can't see what is going on until you look at it under a microscope. Were you nervous that it might not work? Not nervous at all. "STOKED" or "PUMPED" or "AMPED" would be a more appropriate description of my mental state. It is always exciting to see the atom appear just where you intended to place it.

Don Eigler holds a model of the machine that he uses to move atoms





The famous "IBM" that Don Eigler and his team spelled out with 35 xenon atoms.

Some of the things that you created are really cool to look at but can you tell us a bit about why this technology is important? You are mistaken if you think that what we have done in the lab is technology. What we have done is exploratory science that helps to broaden the foundations of knowledge upon which information technologies are built. Without extending those foundations, we can only go so far before progress grinds to a halt. Is keeping the IT [information technology] revolution going important? You betcha!

Did you want to be a scientist when you were a kid?

As a kid I was always designing and building gizmos and trying to make them work. Now that I'm an "adult," the only difference is that people pay me to do it! I'm a gizmologist with a love of nature and an unquenchable curiosity about how nature works. I guess that makes me a scientist.

Ten years from now, will nanotechnology change our lives?

It all depends upon what you call nanotechnology. Rather than get everyone confused about what is or is not nanotechnology, let's just think about the role that nanometer-scale structures play in our lives and are likely to play in the future. From the transistors in the computer on which I am composing this sentence, to the coatings on the window in front of me, to the drugs and chemicals that are already a part of everyday life, nanometer-scale structures are crucially important. As time goes on, our ability to engineer and fabricate new and useful nanometer-scale structures will only increase. Nanotechnology will have a profound impact on our lives.

Do you see atoms when you look at stuff?

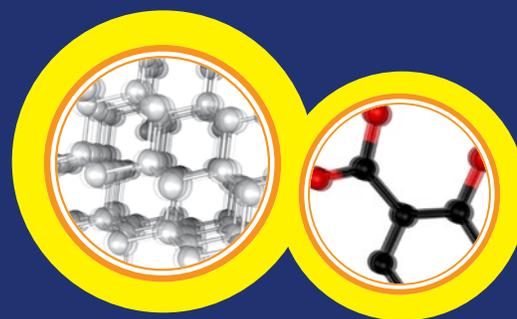
Yeah. I see atoms everywhere. Having the "hands on" experience of working with individual atoms has changed the way I see myself and the world around me. In the past, I used to see myself as a whole and separate entity from the rest of the universe. Now, when I look at the world around me I have a sense of affinity for everything. That rock you see there...yep...atoms! You see that star in the sky? Yep...atoms! And just look at yourself...atoms! When you see yourself this way, you cannot help but take on a different perspective. And, oh, yes...you are never alone.

Nanotechnology is new and cool and there are zillions of things to read about it. But what's really important to know before trying to figure out what all this nanotechnology stuff is about? Here are four things to keep in mind.



1. All things are made of atoms.

Really? Everything? Most stuff, like you, your dog, your toothbrush, even your computer, is made entirely of atoms. Things like light, sound and electricity aren't made of atoms, but the sun and the moon are all made of atoms. That's a lot of atoms. Even when there seems to be nothing, there are lots of atoms. One cubic centimeter of air (that is the size of a sugar cube) has around 10^{19} atoms. If there are that many atoms in some thin air, well, there must be atoms everywhere.



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

So how come we just don't shake apart? Because the motion is *atomic motion* and when you have a lot of atoms the motion of any individual atom is hard to see. So to see them, scientists do a couple of things. First, they put a giant vacuum on whatever they want to look at just to get rid of all of the other atoms that might crud up the atoms they're interested in. Remember that there are around 10^{19} atoms (that's 10,000,000,000,000,000,000 atoms!) in one cubic centimeter of air. And scientists can't really tell one atom from another when they're in motion. So next, they need to cool things off to slow the atoms down as much as possible. Cold, almost absolute zero, which is about -460°F . You can't get to absolute zero, but you can get close.

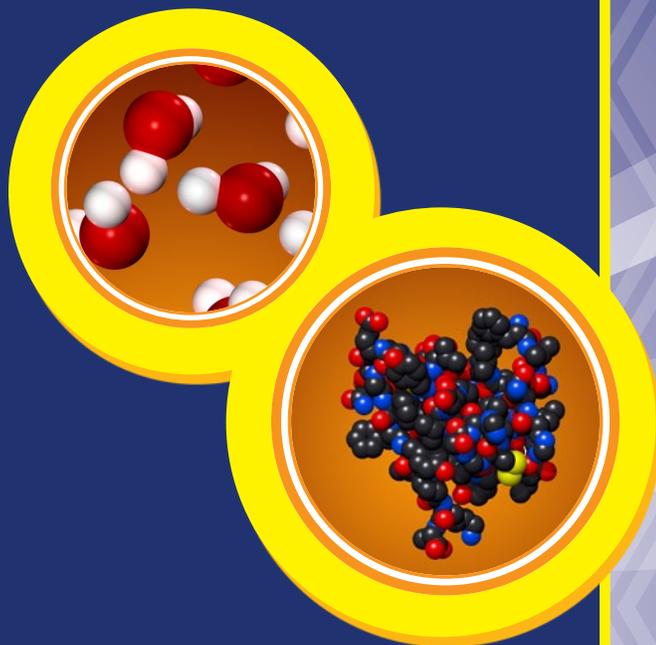
THE FOUR IMPORTANT THINGS TO KNOW about

NANOTECHNOLOGY

3. Molecules have size and shape

Atoms bond together to form molecules. Water is a molecule made up of one oxygen atom and two hydrogen atoms, so it is called H_2O . It has a particular shape because of the angle of the bonds that hold the two hydrogen atoms to the oxygen atom. That gives it a 3D shape.

Bigger molecules have more complicated shapes. Like the protein on the right, insulin, which helps us store and use energy from food. Its very shape helps insulin to function, because its shape is a result of its individual atoms, and all of the bonds and interactions that happen between those atoms. So the shape of molecules is pretty complicated.

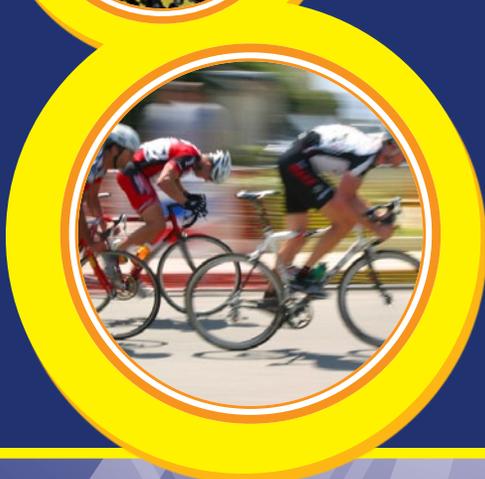


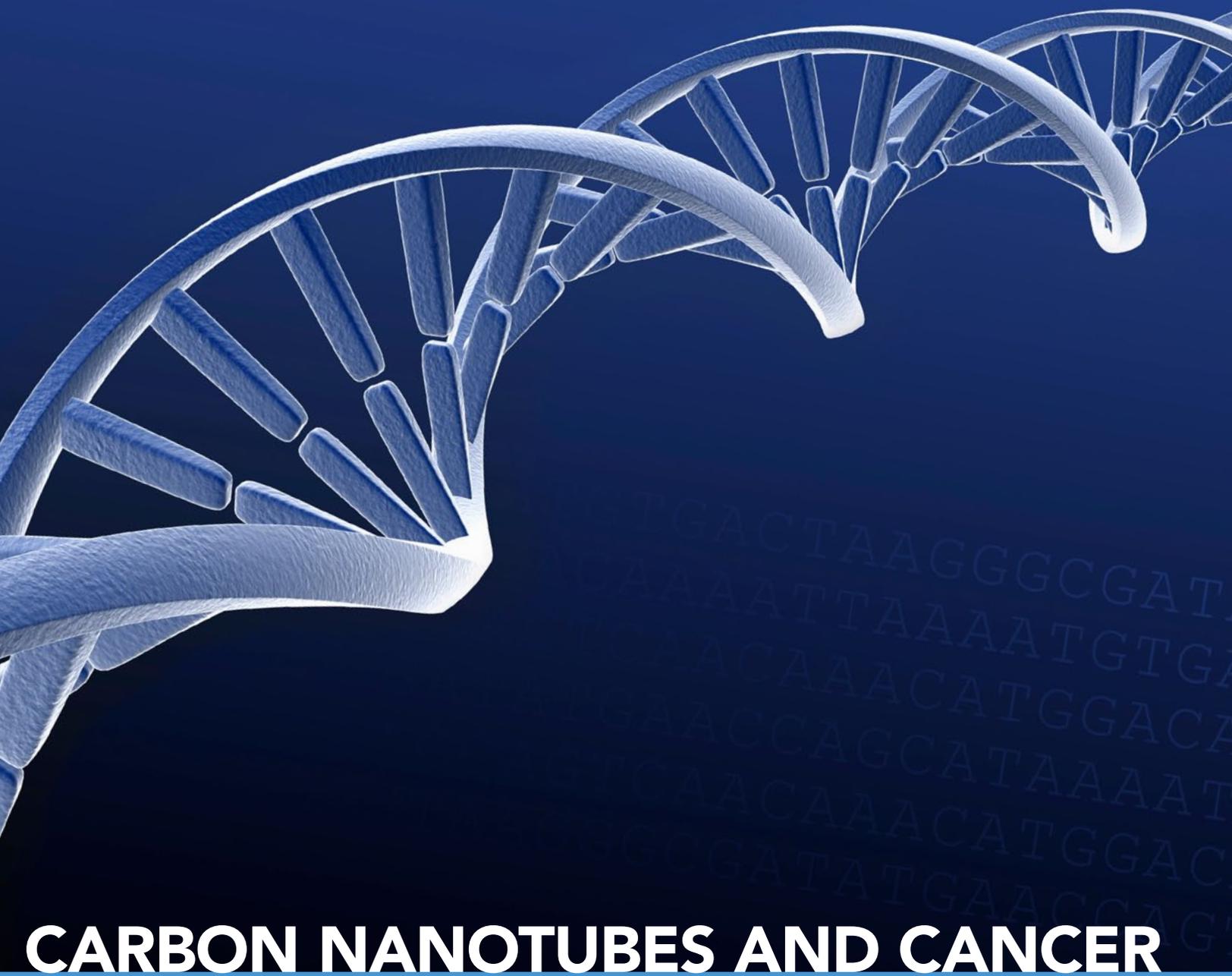
4. Molecules in their nanometer-scale environment have unexpected properties.

What is cool about nanotechnology is that we can make things that don't behave like we expect. So we can make these tiny little particles called quantum dots that are made of just a few hundred atoms. They fluoresce, which means that if you shine a light of a certain color on them, they give off light at a different color (wavelength). Their properties depend on their size, which is only a few nanometers, and the atoms that they are made up of. Quantum dots have applications in things like solar cells and in detecting diseases.

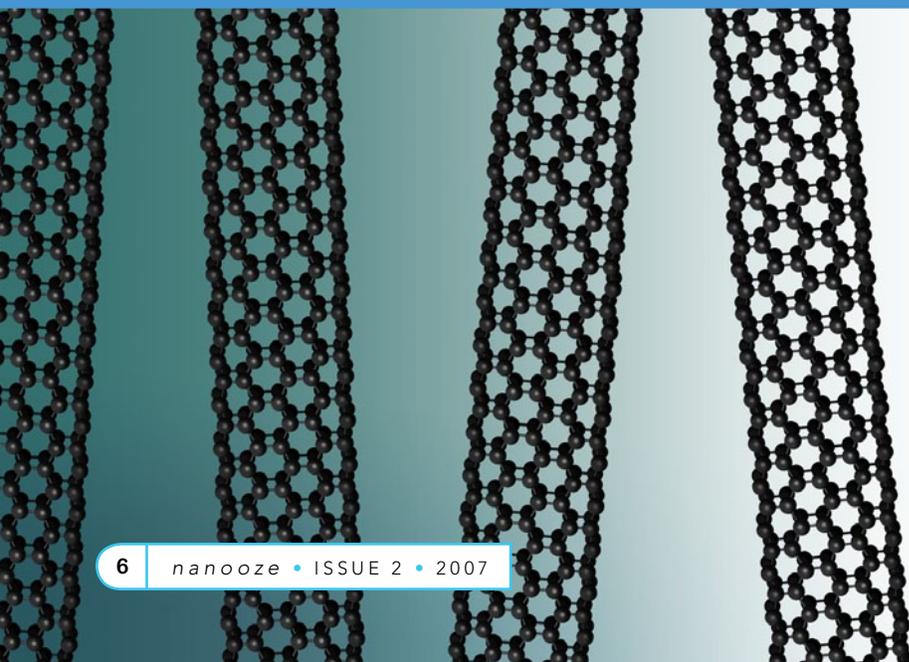
Another example is carbon nanotubes, which are long tubes of just carbon (shown on the left). But because of the way carbon atoms are bonded together in carbon nanotubes they have unique properties. One is that they can act as semiconductors, meaning that sometimes they allow electrons to pass through and other times they don't. Semiconductors are really important for making computer chips since they can be made to act like little switches turning on and off depending upon if they are allowing electrons to move through or not.

Carbon nanotubes are also really strong. Stronger than steel. So one application is to create a space elevator where you could get on and get pulled into space. For now, of course, that's way in the future, but carbon nanotubes are being used in tennis rackets and bicycles right now to make them strong but very lightweight.





CARBON NANOTUBES AND CANCER



Can nanotechnology be used to help combat cancer?

Cancer is a very complicated disease. It's not just one thing, so it's hard to figure out and then treat. Cancer is a disease where your own cells go haywire, they grow and don't stop. So they're still the same as normal cells in a lot of ways but they *behave* differently. Treating cancer is a problem, because if you use things that are really toxic, it will kill the normal cells, too.



STRETCHING DNA

So I take a cell out of you and crack it open and pluck out your DNA. (Don't worry, you have many billions left and you shed like millions of cells a day from your skin.) Somehow I stretch it out like you might pull on two ends of a piece of spaghetti. How long is that piece of DNA? A nanometer? A centimeter? How about a meter. Really? Yep. DNA is really thin, about two nanometers across, and can fold and pack into a cell that is about ten micrometers across. DNA actually doesn't like to be stretched out and would rather fold up. We know something about the nature of DNA folding up—the double helix is formed because of the angle of the bonds that hold DNA together.

Nanotechnology is all about using tools to manipulate things at the nanometer scale. Imagine you are a scientist and you want to study a piece of DNA. But how do you take that piece of DNA and stretch it out like a piece of spaghetti? You could use an

optical trap, a powerful, focused beam of light that can catch a bead and hold it in place. Scientists can actually stretch out DNA by attaching small beads to the end of the strand and then tugging on the beads using an optical trap. You can even measure the force that it takes to stretch a piece of DNA: shut off the optical trap and the DNA folds up again, proving that it takes energy to stretch out a piece of DNA.

IT TAKES ENERGY TO STRETCH OUT A PIECE OF DNA

Scientists have even used DNA to build things, even things that move. To make DNA that can move from one place to another you need to design the DNA sequence so that it grabs on to one strand of DNA and then another. DNA is made up of four different bases: A, T, G and C. These bases bind to each other, A binds to T and G binds to C. So if you design your DNA it will be kind of like climbing hand over hand on a set of monkey bars, except these walkers are only a few nanometers in size.

So a better way to treat cancer is to use things that can be targeted. Smart things, things like carbon nanotubes.

Carbon nanotubes are made entirely of carbon, they are really thin, only a few nanometers across, and thousands could fit into a cell. But how to "target" carbon nanotubes to cancer cells? Professor Hongjie Dai at Stanford University came up with a pretty clever idea. He coats the carbon nanotubes with folic acid, which is vitamin B. It turns out that cancer cells

have a lot of folic acid receptors, proteins on the outside of a cell that bind folic acid. So the cancer cells bind with folic acid-coated carbon nanotubes and then the carbon nanotubes are absorbed inside the cancer cell.

One property of carbon nanotubes is that they absorb infrared light and heat up. So once the carbon nanotubes are inside the cell, Dai uses an infrared laser to heat up the carbon nanotubes. By directing the laser, the cancer cells with the carbon

nanotubes can be selectively heated up, while the normal cells don't heat up at all. It doesn't take much heat to kill a cell, only a few degrees and the cell begins to die.

Right now this is still just an experiment that Dai and his colleagues are doing in the lab and it will be a few years until they can test this in patients, but there is reason to be hopeful that nanotechnology will help cure cancer.

Solar Cells &

Quantum Dots

The Future of Clean Energy

Solar power is a great way to make electricity. It's clean and doesn't consume any non-renewable resources, like oil and coal. It takes energy from sunlight and converts it to electricity.

The challenge is that solar power could be more efficient. Only a few of the photons (those little packets of light) that strike a solar panel are eventually converted into electrical current. If more could be captured and converted, then smaller solar panels could be used to generate electricity instead of the large ones that are used today.

The types of solar cells currently used produce only one exciton for each photon that strikes it. What's an exciton? It is a negatively charged electron and a positively charged hole that are bound to each other.

Scientists at the National Renewable Energy Lab in Golden, Colorado, and others have shown

that quantum dots, tiny nanoparticles, can be more efficient for solar energy conversion.

Quantum dots are sometimes called artificial atoms. Made of chemicals like cadmium and selenium, these tiny particles are only a few nanometers in size. They are so small that they contain only a thousand or so atoms. Together they form a semiconductor, the same stuff used to make computer chips. But they're so small that they don't have any space to store energy.

Quantum dots can produce three excitons for every photon, meaning that they should produce three times as much electricity as the materials currently used for solar cells. That would help a lot in making new sources of safe energy.

