The UNEXPECTED PROPERTIES Issue

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NANOOZE

WATER AT THE NANOSCALE

Q+A WITH A NANO FLOWER MAKER

LIGHT AND GRAPHENE

COMPUTER CHIPS: HOW SMALL CAN THEY GET?

An experiment to test the unexpected properties of water at the nanoscale

Emily Maletz / Nanooze

nanooze.org

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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On the Cover
Because of the way water molecules and the copper atoms in the penny interact with each other at the nanometer scale, it is possible to put many more drops of water on a penny than you might think!

Emily Maletz / Nanooze

Molecules in their nanometer-scale environment have unexpected properties!

Well, that is a lot to think about...since we can't really see atoms and molecules except with very powerful microscopes and also when they are cooled down to a temperature close to absolute zero. You have to use your imagination!

Molecules can behave in ways we don't expect. At the molecular level, gravity is almost not a factor, so molecules will stick to things. Water molecules move in straight lines like cars along a freeway. And light can be captured, released and divided into all of the colors that we can see (and a lot that we can't see). Being able to build materials on the nanometer scale and creating new devices with unexpected properties is what makes the field of nanotechnology exciting.

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 Nanoscale Flower Maker Wim Noorduin

Where did you grow up? I grew up in the Netherlands in a town close to the German border named Venlo. I spent most of my youth playing outside digging holes and making huts.

When did you first think that you might be interested in science? In high school, during chemistry experiments. I already liked making fires, fireworks and cooking, and in these experiments everything came together.

You are a postdoctoral fellow, meaning you have your PhD and are now doing some more training at Harvard. What do you want to do next? I want to set up my own research team to explore all the possibilities of these microflowers, ranging from the fundamental understanding up to the development of applications such as optical materials.

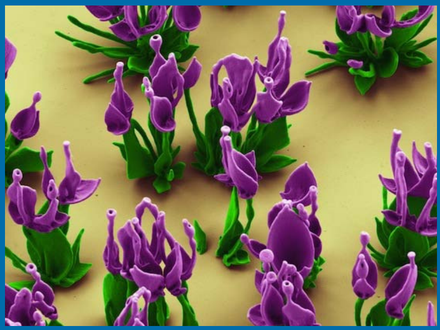
So you create these super cool nanometer-scale flowers. How did that idea pop into your head? At the start of my postdoc, I was reading a book named *Pattern Formation in Nature* by Philip Ball, in which he describes how different kinds of patterns can emerge. The pattern formation processes that could occur in liquids made me wonder if there were systems in which such a pattern could be frozen in the solid state, and if it would be possible to control their shape while they are growing.

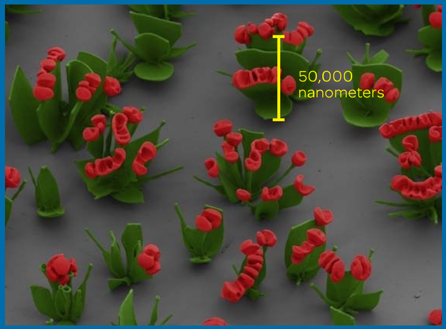
These images have colors but, hey, we know better, and things like this don't have colors at the nanometer scale. So how do you decide what kind of colors to create? The images are taken with an electron microscope, which indeed only produces black and white images. Many of the structures, however, can be colored because you can add different dyes to the solution in which the structures grow. With a confocal microscope you can then see the different dyes that are incorporated. Based on these different images, I decided how to color the data from the electron microscope.

Are these nanometer-scale flowers useful? At this moment we can only use the vases for small microbouquets. However, scientists are very interested in making structures with these dimensions to use as optical materials or catalysts, for instance. Currently we are developing better ways to control the precise shape and material composition of the structures, which will be necessary to make useful materials from these flowers.

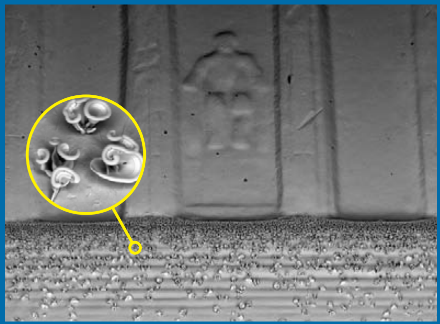
Did you know you were going to make these flowers or was this just something that happened? The more I played with the system the more shapes I was able to make, such as vases, coral and stem-like structures. The flowers represent a selection of the things that are possible. To demonstrate the control that can be achieved with this system I started to sculpt and assemble the different shapes together in flower-like compositions. For instance, we used the vase shapes as real vases by planting flowers inside them. With this level of control, the next step will now be to make useful shapes.

What do you do for fun? The growing of the microflowers is of course a lot of fun. However, I also like to do a lot of things outside of the lab. I really enjoy road biking, running, cooking and eating the results with friends.





Tiny nanometer-scale flowers
The tiny flowers that Noorduin builds are about 50 micrometers (50,000 nanometers) tall, that's about half the width of a human hair.



A field of tiny flower structures on a penny.

Images Courtesy of Wim Noorduin

At the nanoscale water is interesting stuff—it bends and it doesn't mix.

Water, Water Everywhere

...nor any drop to drink

An average drop of water *is about* **50,000 nanoliters**

That saying is from an old book called *The Rime of the Ancient Mariner*, a story about some old sailor who just came back from a long voyage at sea. What does that have to do with nanotechnology? Well, not much other than a drop is a lot when you think about it on the nanoscale. Your average drop is about 50,000 nanoliters.

SURFACE TENSION AND LAMINAR FLOW

A drop forms because of surface tension—the molecules in water are attracted to each other and to the thing from which they are dropping. Turn on a faucet just enough to get it to drip and watch it. When the size of the drop becomes too much for the surface tension, plop, we get a drop.

At the nanoscale, water is interesting stuff. It bends and it doesn't mix. Don't just take our word for it, ask Leonardo da Vinci. Back in 1513, da Vinci sat down and drew pictures of the way water moves around things like rocks and sticks. What he saw (and so can you) is that water close to an object like a rock or a stick seems to bend around it. This is an example of laminar flow, which means the water is being affected by the object and causing a drag.

Imagine at the nanometer scale that the molecules of water are interacting with the molecules on the surface of the stick. They would come in close contact with the stick and, sort of like friction, the water molecules would slow down because of these powerful forces.

THE REYNOLDS NUMBER

These forces are described by what is called the Reynolds number, named after its discoverer, Osborne Reynolds. Back in 1875 he demonstrated laminar flow using a series of tubes and dyes. He showed that laminar flow was dependent on a number of factors: the speed of the fluids, their thickness, and their temperature. At the nanometer scale, liquids behave differently than at the macro scale and you get laminar flow.

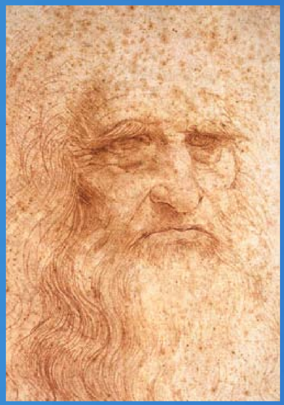
FOCUSING A FLUID

Laminar flow only happens at the nanometer scale. Most of the time water flow is turbulent and things mix in with the water. Sometimes turbulent flow is good—when we are washing clothes or enjoying a beautiful waterfall. The properties of laminar flow are very useful

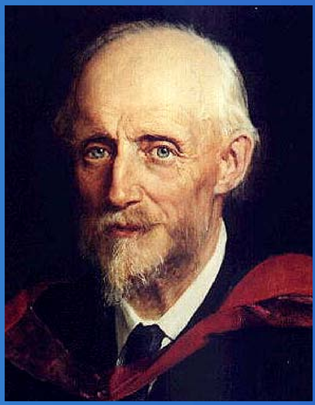
A penny can hold **36** drops of water

Water Mavens

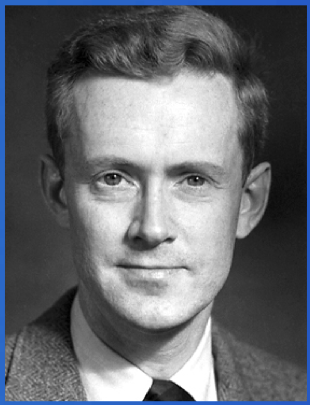
The work of these three scientists has contributed greatly to our understanding of water and its properties. Today's nanoscientists build upon work that they developed to work with the unique characteristics of fluid movement.



Leonardo da Vinci
Artist, scientist, inventor and early documenter of *laminar flow.*
1452–1519



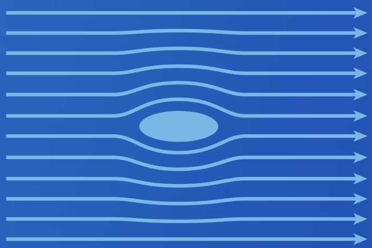
Osborne Reynolds
Innovator in the field of fluid dynamics. The *Reynolds number* was named after him.
1842–1912



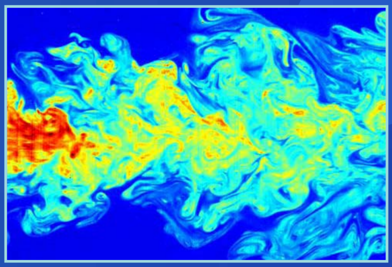
Edward Mills Purcell
Nobel Prize-winning physicist and science advisor to presidents Dwight D. Eisenhower, John F. Kennedy, and Lyndon B. Johnson.
1912–1997

Wikipedia

A STICK IN A STREAM
You can observe laminar flow by watching how water interacts with sticks and rocks in a stream.



LAMINAR FLOW
Fluid flows in parallel layers that do not mix.



TURBULENT FLOW
Fluid flows turbulently in eddies, and layers mix together.

in nanotechnology and we can use it to our advantage. We can focus solutions kind of like the same way we focus light, except instead of lenses we are using different streams of liquids. For example, focusing a fluid can be useful to make a test more sensitive, which means instead of needing a larger sample, we can concentrate a smaller one.

SWIMMING THROUGH MOLASSES

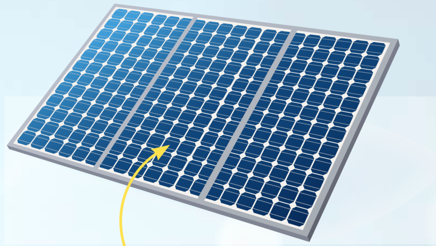
Why should we care? Well, aside from the technology, one of the interesting challenges is figuring out how nanometer-sized things could move through a liquid. One famous professor at Princeton (E. M. Purcell) declared that bacteria moving through water was like a person swimming through a pool of molasses. That's a pretty tough job because the viscosity of water at the nanometer scale makes it very difficult for a tiny thing to move through.

Now, if we think about building a tiny submarine to swim through our blood, we have the same problem. It would take a huge amount of energy to power that movement, which would require a huge battery. So it's a big challenge not just to make a tiny submarine, but also to have a powerful enough battery to make it run.

REYNOLDS NUMBERS IN REAL LIFE

There are examples of the Reynolds number around us in everyday objects. If you drink cappuccino (or even just hang out at those fancy coffee places), see if they make patterns with the steamed milk. Good baristas will make all sorts of pictures, usually things like leaves or curlicues. How does that shape stay in place? It all has to do with the Reynolds number and the surface tension of the coffee.

Water drop and coffee: iStockphoto, Penny and stream: Emily Maletz / Nanooze, Turbulence: Wikipedia



iStockphoto

We might be able to make solar cells much more efficient using quantum dot technology.

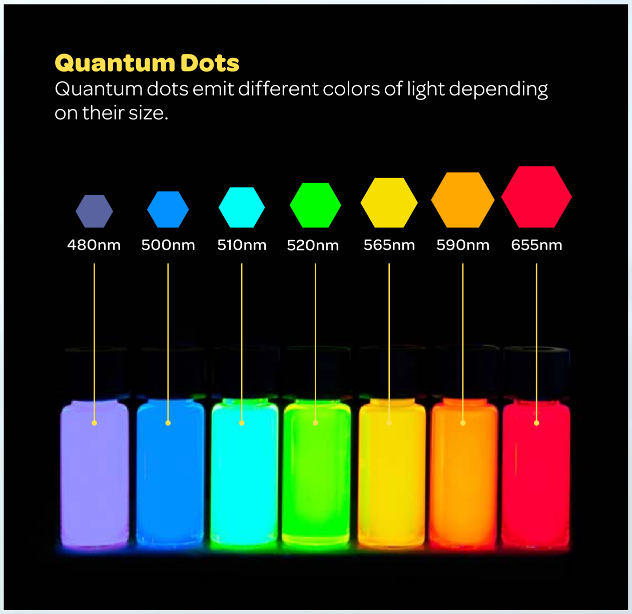
LIGHT
and Quantum Dots

All things are made up of atoms, except, well, stuff like light. We don't think about light being a physical thing because it's not made up of atoms, but light at the nanometer scale can do some odd things.

One of the things nanotechnology can do is to give us new materials—like quantum dots. Quantum dots are sometimes called artificial atoms and are 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. Quantum dots are fluorophores, which means that they can absorb light at one wavelength and emit light at another wavelength.

At the nanometer scale these quantum dots can catch a photon of light and then release it. What is cool is that the wavelength of light they emit depends upon the size of the quantum dot. Make a dot bigger and the wavelength of the light they emit gets longer. You can control its fluorescence by controlling its size.

Quantum dots are neat because they have a lot of applications. Today they are used in research to tag molecules and follow them around. But they also have applications in solar cells and cancer therapy. In solar cells, the ability to tailor their absorption and emission of light is important to help make solar cells more efficient. Finding cancers might someday be easier using quantum dots. These tiny little beacons might help find cancers deep inside the body and much earlier than current methods.



Wikipedia and Emily Maletz / Nanooze

At the nanometer scale, things like quantum dots have unexpected properties and can help us do some exciting things.

CARBON

Slippery or Sticky?

Nanotechnology, like a lot of things in life, is about whatever is new. The new "it" material is graphene. Graphene follows in a long line of other carbon materials, like buckyballs and carbon nanotubes.

Carbon? That's the fourth most abundant element in the universe (after hydrogen, helium and oxygen). The thing that most life is built on? Yup, *that* carbon. And who knew it was sitting right under our noses—or *was* our noses—all this time?

Graphene is a flat sheet of carbon atoms and each carbon atom is bound to three other carbon atoms. That simple. Kind of looks like chicken wire except a lot smaller. Each carbon atom is separated from the other carbon atom by less than a nanometer. It is related to graphite, which is the stuff found in pencils. Graphene is a single layer of carbon atoms, while graphite is a lot of layers stacked on each other.

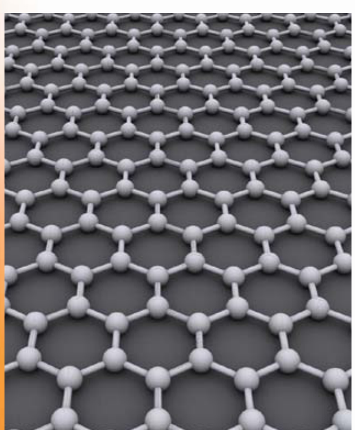
If you write with a pencil, one of the things you might notice is that it feels smooth as it moves across paper. The mark left by a pencil is actually tiny sheets of graphite that peel off the pencil and get stuck to the paper. Try writing on a sheet of wax paper with a pencil. The graphite sheets don't stick to the wax very easily. Wax paper doesn't like water (hydrophobic) and neither does graphite, so they don't stick to each other very easily.

Scientists are really interested in graphene because it can act as an electrical insulator and can also carry electrons. It is slippery, meaning it could be a lubricant. It is also sometimes sticky. The sticky part was unexpected and just discovered in 2012. When scientists took a sheet of graphene and stuck it to a piece of glass they discovered that the graphene stuck stronger than any normal sticky stuff, like Scotch tape, chewing gum or even a gecko's foot. The wonder material graphene continues to amaze scientists because at the nanometer scale, molecules like graphene have unexpected properties.

If you could peel off a tiny layer from the graphite on the pencil tip that was only one atom thick, you would have a sheet of graphene.

If you took a pencil and could draw a single line of just graphene it would be 35 miles long.

iStockphoto



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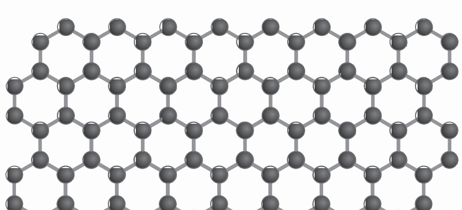
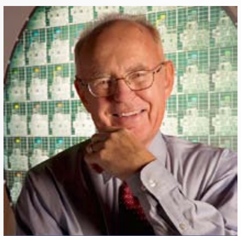


Graphene: a wonder material with unexpected properties
Graphene is a single layer of carbon atoms arranged in a hexagonal pattern like tiny nanoscale chicken wire. It is a semiconductor, can be slippery or sticky and is very lightweight.

How Small Can We Go?

Back in 1965, a guy by the name of Gordon Moore (who founded a little company called Intel) predicted that the number of circuits (transistors) in a computer chip would have to double every two years or so. Now maybe you could just make larger computer chips or maybe you might just make the transistors smaller. Moore's law then became the road map for making transistors smaller and smaller and making computers more and more powerful.



Gordon Moore
The founder of Intel. *Moore's Law* was named after him.

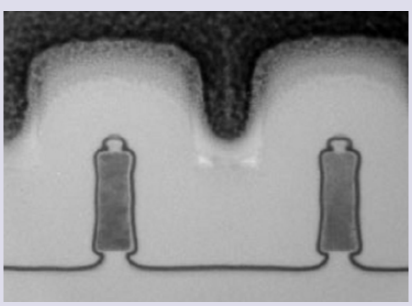
Today, some parts of a computer chip are smaller than 50 nano-meters. That means 2,000 of them could fit across the width of a hair. That is pretty small! Today's computer chips pack about 1,000,000,000 transistors or more.

Can we make things even smaller? The current technology is 32 nanometers—that means these parts are only 32 nanometers or a few hundred atoms across. Smaller yet? How about a single atom? A number of researchers have made transistors out of a single molecule or even a single atom.

A transistor is a little switch that is either on or off.

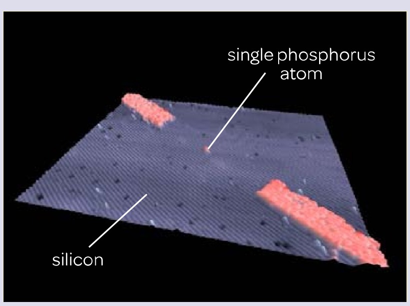
Scientists have made transistors by inserting a phosphorus atom into a bunch of silicon atoms. They used a very powerful microscope called a *scanning tunneling microscope* that can put atoms in very precise spots. When you apply voltage to the phosphorus atom, it switches back and forth.

While it is possible to make single-atom transistors, it will take a lot of work to make it practical and economical enough to produce on a large scale. But it proves that even just a *single* atom can function as a transistor, something totally unexpected even just 20 years ago.



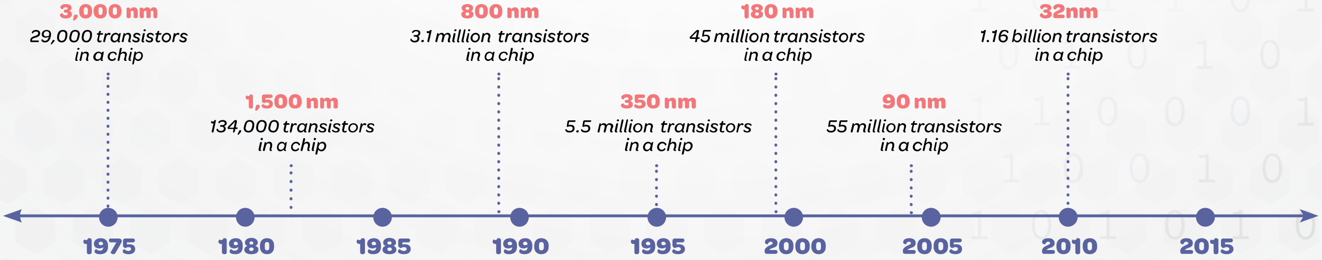
NIST

A 32nm transistor
Today's computer chips contain 32nm transistors. These transistors can switch on and off over 300 billion times in one second.



University of New South Wales

A single-atom transistor
Scientists at the University of New South Wales and Purdue University have built a transistor from a single atom.



Transistor Size Timeline

Intel