MOLECULES are in constant MOTION

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and Cornell NanoScale Science & Technology Facility

ISSUE 12 • 2012

NANOOZE

Emily Maletz / Nanooze

THE MOVEMENT OF MOLECULES

ABSOLUTE ZERO

SIMULATIONS

MOVING ATOMS ONE BY ONE

nanooze.org

International Year of CHEMISTRY 2011

NANOOZE

ALL ABOUT THE THINGS TOO SMALL TO SEE

Welcome to Nanooze!

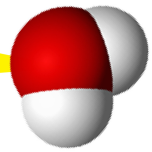
What is a Nanooze? (Sounds like nah-news.) Nanooze is not a thing, Nanooze is a place to hear about the latest exciting stuff in science and technology. What kind of stuff? Mostly discoveries about the part of our world that is too small to see and making tiny things using nanotechnology. Things like 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****.*

A project of the National Nanotechnology Infrastructure Network (NNIN) with support from the National Science Foundation.

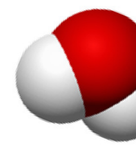
At the nanometer scale molecules are in constant motion!



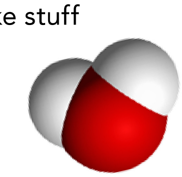
All things are made of atoms. That is a pretty easy concept, anything (outside of energy, like sunlight) is made up of tiny things called atoms. Atoms bond together to form molecules.

Molecules are in constant motion. That is a pretty hard concept to get your head around since when you look at something it might or might not be moving. Molecular motion is a property of all matter; molecules in a gas move a lot quicker than molecules in liquids. But even molecules in a solid still move.

This issue is all about moving molecules and what it means for scientists who want to make stuff at the molecular scale. The story begins a long time ago when the idea that molecules are in constant motion was first discovered. Part of the evidence that you can see in everyday life was discovered by Robert Brown about 150 years ago when he used a microscope to watch how tiny dust particles move.



So how fast do molecules move? It all depends upon the molecule and its state: molecules in a solid state move slower than in a liquid state, and much slower than gas molecules. One estimate puts gas molecules in the range of 1,100 mph at room temperature. Cool them down to almost absolute zero and they slow down to less than 0.1 mph (slower than the average couch potato). The fact that they are always moving makes it a challenge to see molecules and make stuff out of them, but it's a challenge that scientists work hard to figure out.



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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!!**

iStockphoto

Q&A with Scientist Aurora Clark

How did you get into science? I have always been interested in why things happen and how they work. At first I was interested only in animals so I wanted to be a veterinarian when I grew up. But the more I learned about science, the more I knew that I wanted to understand much more basic things… like why is my chair hard when atoms are mostly empty space? And why is ice slippery? Luckily I had some very good teachers that talked with me about these things and encouraged me to go to the library and learn more and to start doing science as part of my everyday life.

What was your first recollection of doing science as a kid? I remember watching the insects called water skippers and wondering how they could stand on water. So I started poking the top of water with various objects to see if I could make them stand on water too. Something even as simple as this is scientific, especially if you gather enough information to start making hypotheses about why some things can stand on water.

You work on doing chemistry on computers. Do you have a lab with beakers and stuff? No, I do not have any beakers or real "chemicals" in my laboratory. Instead, we use software programs that predict how a real chemical will behave. This is actually very neat because we can sometimes prevent the need for doing an expensive or very dangerous experiment by using a computer to predict the results. Also, computers can help scientists to understand why they are getting a specific result from an experiment because computers can examine the more basic reason why they are getting the result that they do.

What's it like to be a professor? Do you like to teach? A professor has to do lots of different things. We teach classes, but we also train new scientists who are learning how to do research. I love teaching, but it is only a part of what I do. I also have to pay for my research (computers can be expensive), so I write grants that describe the research I want to do and ask for money from the government or companies to help pay for my equipment. Finally, I do research, which hopefully has a positive impact on our day-to-day lives, makes the world a better place, and helps to understand the world around us.

Molecules are in constant motion. Can you explain that? Just think about how hyper and goofy you may act on Halloween night after you have eaten a bunch of candy. That candy has given you a lot of energy, which you use up by running around. Molecules are so much smaller than us that what gives them energy is actually heat. At room temperature there is enough heat energy around us that molecules constantly move. When molecules are in the gas phase, like in the air we breathe, they move around a lot. When molecules are in a liquid, like water, they move less, and when molecules are in a solid, like ice, they don't move around very much at all.

We are surrounded by molecules. Do you sometimes see things as a bunch of molecules? Sometimes. One of the things I am interested in is how the molecules interact with one another, and how that influences what we experience when we interact with billions and billions of molecules all put together. So sometimes I imagine what all of those molecules must be doing when I sit on a chair, or drink a glass of water.

Courtesy Aurora Clark

iStockphoto

MOLECULES ARE ALWAYS MOVING

Molecules are really small. How small? A nanometer is one-billionth of a meter and molecules are measured in nanometers.

"SEEING" THE MOTION

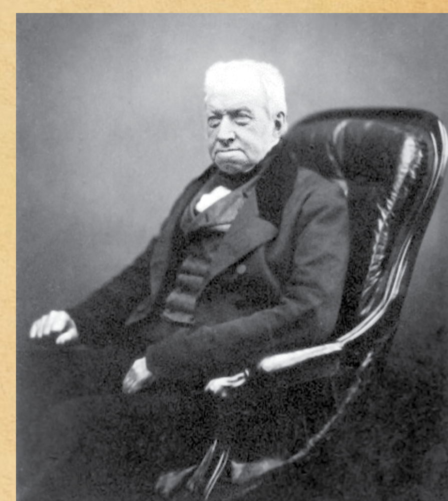
Not only are molecules really small but they are in constant motion. The motion is called "thermal motion" because it's caused by temperature. Increase the temperature around them and the molecules move faster. That is easy to "see" if you have a balloon full of air and put it in the freezer. The temperature in the freezer is much lower than the outside temperature so the air molecules slow down a bit. They don't bump into the sides of the balloon as much and the balloon shrinks. Take it out of the freezer and the balloon will gradually expand as it warms up again.

BROWNIAN MOTION

The first scientist to discover that molecules are always moving was Robert Brown back in 1872 and to this day we refer to the movement of particles as Brownian motion. You can do the same experiment that Brown did almost 150 years ago. Look under a microscope at pollen or some dust, or even some cells. Notice how they seem to be jiggling around? That is thermal motion and, if you can, imagine how fast something might move if it were 1,000 or 10,000 times smaller.

TWO BIG PROBLEMS

Molecules constantly moving is a problem for us if we want to see them. We can see molecules using very powerful microscopes called "scanning tunneling microscopes," but there are two big problems to overcome. First, molecules are always moving and that makes it tough to see them. Kind of like a mosquito, if it lands on your arm it's easy to see (and squish) it, but when it's zipping around it's hard to see. The other problem is that there are a lot of molecules, so to see just one, or some, you need to get rid of a lot of them.



Wikipedia / Public domain

By permission of the Linnean Society of London

Moving around atoms is tough because they are really small—less than a nanometer in size. That means that about a half-million atoms can fit across the width of a hair. Plus, molecules are in constant motion.

Robert Brown (above) was the first to observe this molecular motion using an optical microscope like this one (left).

VERY, EXTREMELY, UTTERLY COLD

Molecules are too small to see except by using very powerful microscopes. But even then, scientists need to cool them down in order to see them, otherwise they move too much to get a good picture. Everything looks fuzzy. So they cool down the molecules to absolute zero, which is cold, cold, cold.

HOW COLD IS COLD?

The record at the South Pole is something like -89°C (1983, Vostok Station, Antarctica). That is pretty cold. But things can get a lot colder. Temperature is just a measure of how much energy is in a system.

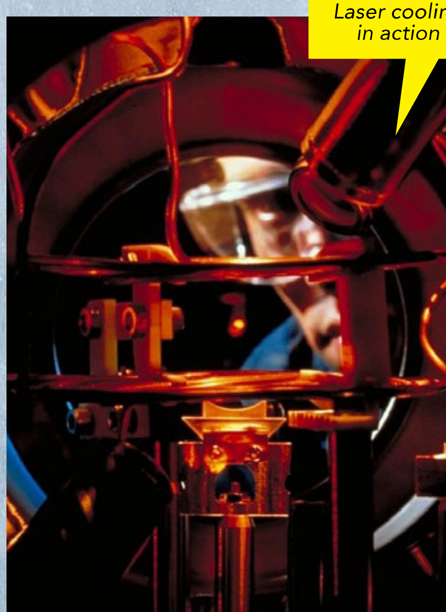
ABSOLUTE ZERO

Absolute zero is the lowest temperature ever. It is measured on the Kelvin scale, which starts at 0°K—that's about -273°C or -459.67°F. Room temperature is about 293°K (20°C or 68°F). At absolute zero there is no heat and nobody has actually ever reached that temperature in the laboratory. In fact, it is impossible to reach absolute zero. The closest that anyone has come is to within 700 nK (an nK is one-billionth of a °K).

Why is absolute zero important? At 0°K, atoms and molecules stop moving—their thermal energy is zero, so they stop dead in their tracks. To try to reach these temperatures, scientists use instruments that are similar to refrigerators because they need to extract the heat and put it somewhere else.

LASER COOLING

Scientists can also use lasers to cool down atoms. The trick is to tune the wavelength of the laser to correspond to the specific atom you are trying to cool down. Discovered in the 1970s, laser cooling of *atoms* became possible and more recently it has been possible to cool *molecules* with lasers. Laser cooling is used for things like building an atomic clock that is so accurate it is off by less than a second in 30 million years.



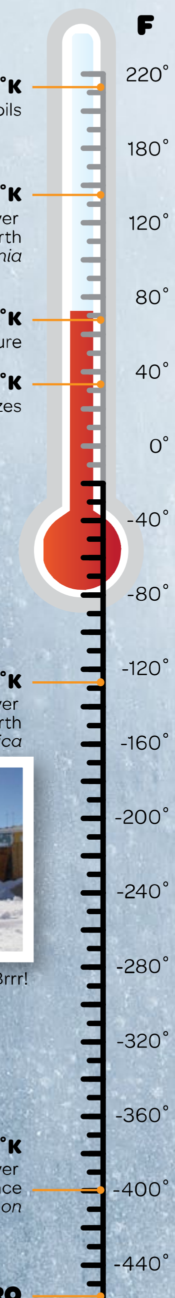
Laser cooling in action

H. M. Helfer / NIST

Steven Chu

Laser cooling and the Nobel Prize

In 1997, the Nobel Prize in Physics was awarded to three scientists for their work on laser cooling, including Steven Chu, who would become the head of the U.S. Department of Energy.



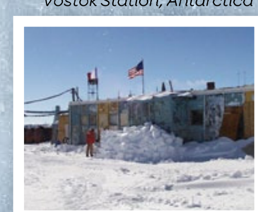
212°F / 100°C / 373°K
water boils

134°F / 57°C / 330°K
Hottest temperature ever recorded on Earth
Death Valley, California

68°F / 20°C / 293°K
room temperature

32°F / 0°C / 273°K
water freezes

-128°F / -89°C / 184°K
Coldest temperature ever recorded on Earth
Vostok Station, Antarctica



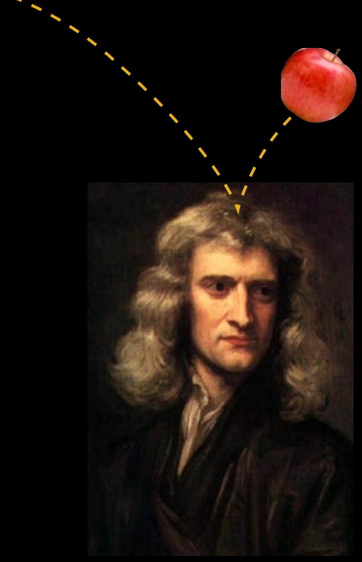
Vostok Station – Brrr!

-400°F / -240°C / 33°K
Coldest temperature ever recorded in space
In a crater on the Moon

ABSOLUTE ZERO
-459.67°F / -273°C / 0°K

Steven Chu: Wikipedia / Public Domain, Vostock Station: NSF/Josh Landis / Wikimedia Commons / Public domain

SIMULATING MOLECULAR DYNAMICS



Thank you, Sir Isaac Newton, for figuring out a lot of those important rules we still use today.

Wikipedia / Public Domain

Cooling atoms to absolute zero helps you see them, but then you can't really learn much about they way they behave and interact.

Scientists can figure out how molecules behave without even making them or testing them for real. The forces that hold atoms together into molecules and how molecules interact with each other are pretty well known and can be written as mathematical equations, some of which are based upon work done a couple hundred years ago by Isaac Newton (the guy who saw an apple fall from a tree and figured out gravity).

A NANO VIDEO GAME

Scientists use computers to solve these equations and create simulations of millions and millions of molecules all put together in different chemical environments. These computer simulations are like a video game, but one whose characters are molecules. Just like a video game, these characters do things over the course of time, except only about a nanosecond of time can be looked at in any one simulation.

There are a billion nanoseconds in a second, so scientists often do lots of simulations one right after another to understand how millions of molecules behave. When you look at that many molecules at once you can calculate and predict the same properties that are measured in "real" experiments, and this information can be used to make sure that the simulations are mimicking the real world.

EXPERIMENTING

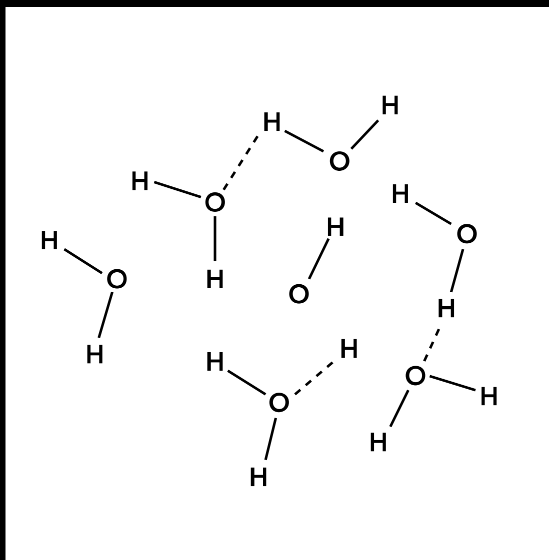
Temperature and pressure can be changed in the simulations just like in a "real" experiment so scientists can be incredibly creative and look at a lot of different processes, from how molecules might behave in extreme environments like the center of the sun or an alien planet, to how water flows through the ground, to why water freezes into such different shapes when it forms a snowflake. Sometimes scientists force the molecules to do certain things, just like you might make a character in a video game climb a wall. This information can be used to predict new chemical reactions and make new materials, like a stronger steel or better plastic.

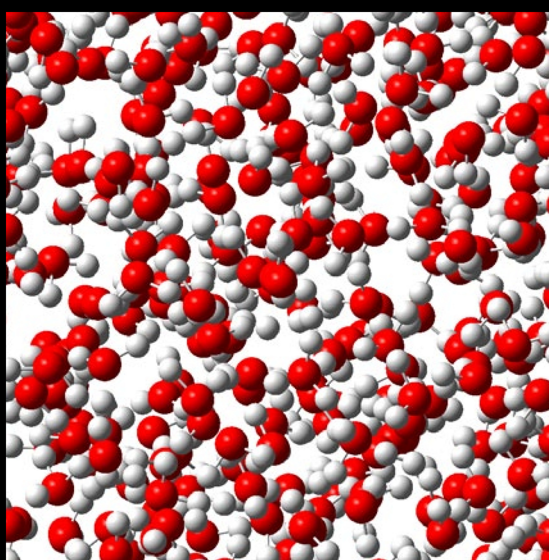
Companies, universities and national laboratories are using computer simulations more and more, so much so that scientific computing is used almost as much as experiments done at a lab bench. In turn, this is causing computer scientists to design faster and bigger computers, so that more complex chemical systems can be studied and simulation data can be used to predict the types of "real" experiments that are done and how to conduct them in safer and cheaper ways. In the end, the combination of computer simulations and laboratory experiments are helping to understand new aspects of our world and make new discoveries at a faster pace than ever before.

Scientists can figure out how molecules behave without even making them or testing them for real.

Simulation Examples

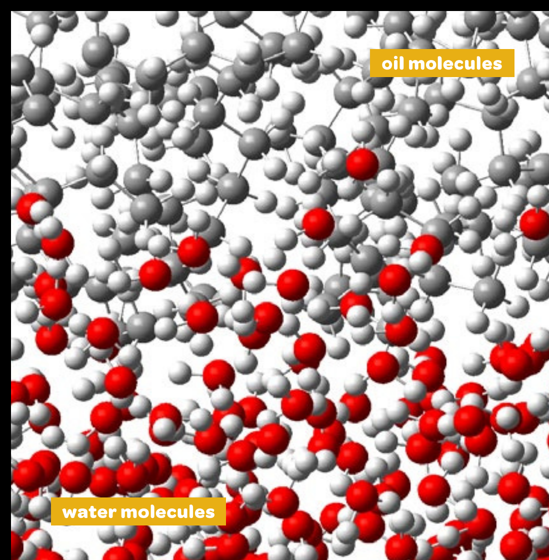
Provided by Aurora Clark





Water behavior

Water molecules are made up of two parts hydrogen and one part oxygen (H_2O). Oxygen is a more electronegative element, which means that it has a small negative charge, while hydrogen is partially positive. Individual molecules are attracted to one another by hydrogen bonds, where the partially positive hydrogen atoms of one molecule are attracted to the partially negative charge of the oxygen atom of a different molecule. Computer simulations keep track of these hydrogen bonds, how they break and form, in order to predict the behavior of water in extreme conditions, as in the deep ocean or an alien planet.



Oil and water

Ever wonder why oil and water don't mix? When olive oil is poured into a glass of water, it floats on top of the water. At the molecular level, this occurs because the water molecules (in red and white) and oil molecules (grey and white) don't like each other very much. The forces of attraction between water and oil are much weaker than the forces of attraction between individual water molecules, so water would rather keep to itself than mix with oil molecules. Computer simulations clearly reveal the oil-water separation.

Simulations Courtesy Aurora Clark, Oil and water: iStockphoto

MOVING MOLECULES ONE BY ONE

Don Eigler and his dogs

Wikipedia / Public Domain

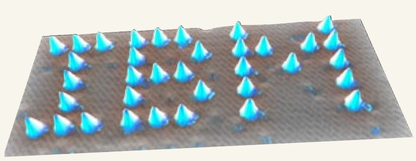
In 1989, a group of scientists led by Don Eigler astounded the world by using just a few atoms—35 in all—to spell out I-B-M.

This simple demonstration of moving atoms would become an icon for nanotechnology. The real challenge of moving individual atoms is that everyday objects are so big compared to an atom. How would you move a single atom…with your fingers, or even tiny tweezers?

But that's not the hard part. The hard part is that there are a lot of atoms… everywhere. Even in deep space where it is a vacuum with no air, there are a lot of atoms floating around. So to create an environment to work in, the first thing you need to do is make a really good vacuum and try to remove all of the atoms. To do that you need really powerful pumps that can suck all of the air (and the atoms) out of the space that you use to move atoms around. 10^{-13} atmospheres.

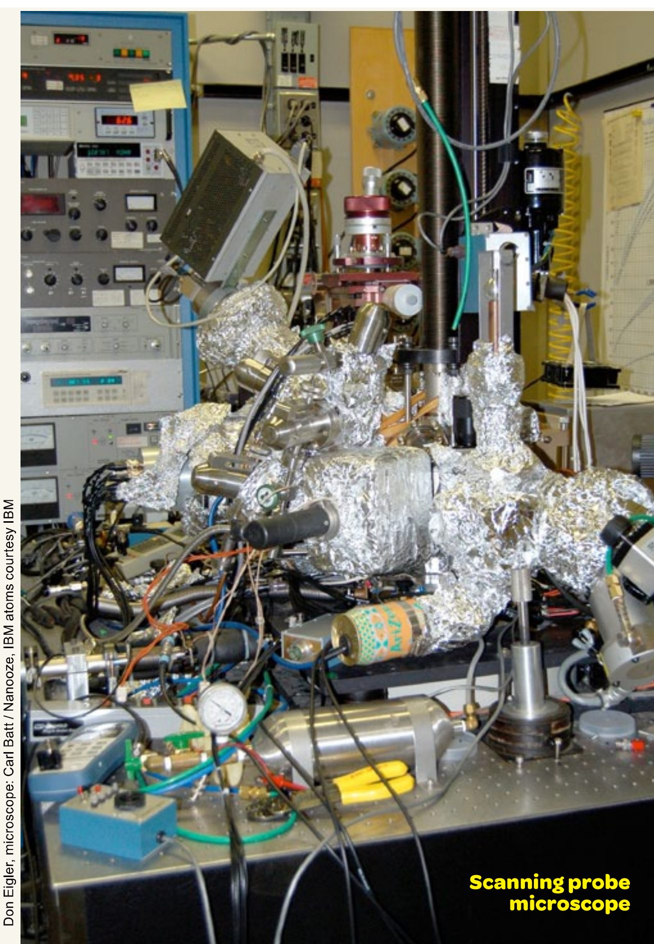
Eigler also needed to have a special kind of atom that could be moved with his microscope needle, so he chose an element called xenon. Xenon is a gas at room temperature but when you cool it down it turns solid.

So how did Eigler move an atom? With a very special instrument called a scanning probe microscope. It is not like a regular microscope—it "sees" by using a tiny needle as a probe. This special needle is used to "feel" the contours of the surface and, if you're careful, you can "see" atoms. Even more exciting is that a scanning probe microscope can also be used to move atoms one at a time.



IBM logo made from xenon atoms

The iconic IBM logo was created from individual xenon atoms. Eigler moved the atoms into place one by one using this scanning probe microscope that he built himself. The foil and iced tea can aren't just for looks, they help insulate the scope.



Scanning probe microscope

Don Eigler, microscope: Carl Batt / Nanooze, IBM atoms courtesy IBM