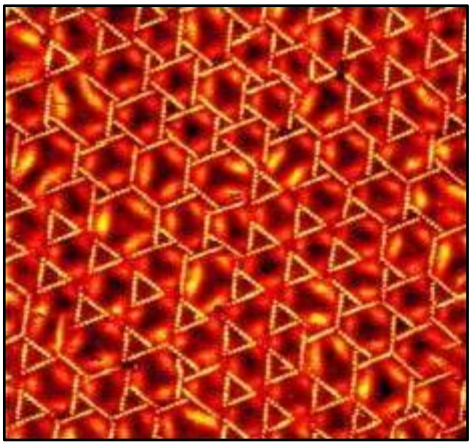
Nanotechnology: An Overview

http://www.explainthatstuff.com/nanotechnologyforkids.html
by Chris Woodford. Last updated: May 19, 2014.

1 Imagine if you climbed out of the shower only to discover you'd shrunk in the wash by about 1500 million times! If you stepped into your living room, what you'd see around you would not be chairs, tables, computers, and your family but atoms, molecules, proteins, and cells. Shrunk down to the "nanoscale," you'd not only see the atoms that everything is made from—you'd actually be able to move them around! Now suppose you started sticking those atoms together in interesting new ways, like tiny LEGO® bricks of nature. You could build all kinds of fantastic materials, everything from brand new medicines to ultra-fast computer chips. Making new things on this incredibly small scale is called "nanotechnology" and it's one of the most exciting and fast-moving areas of science and technology today.



Looking into the nanoworld: Sulfur atoms arranged on a layer of copper deposited onto a crystal of ruthenium. By courtesy of US Department of Energy/Brookhaven National Laboratory

How big is "nano"?

2 We live on a scale of meters and kilometers (thousands of meters), so it's quite hard for us to imagine a world that's too small to see. You've probably looked at amazing photos in science books of things like dust mites and flies photographed with electron microscopes. These powerful scientific instruments make images that are "microscopic", which means on a scale millionths of a meter wide. "Nanoscopic" involves shrinking things down to a whole new level. "Nano" means "billionth", so a "nanometer" is one billionth of a meter. In other words, the nanoscale is 1000 times smaller than the microscopic scale and a billion (1000 million) times smaller than the world of meters that we live in.

The Nanoscale

Ordinary objects are absolutely huge measured on what scientists call the nanoscale:

- Atom: ~0.1 nanometers.
- Atoms in a molecule: ~0.15 nanometers apart.
- DNA double-helix: ~2 nanometers in diameter.
- Typical protein: ~10 nanometers long.
- Computer transistor (switch): ~100-200 nanometers wide.
- Typical bacteria: ~200 nanometers long.
- Human hair: 50,000–100,000 nanometers in diameter.
- One piece of paper: ~100,000 nanometers thick.
- Girl 1.2 m (4ft) tall: ~1200 million nanometers tall.
- Man 2m (6.5 ft) tall ~ 2000 million nanometers tall.
- Empire State Building: 381m (1250 ft) tall: ~381,000 million nanometers tall.

Can you figure out how tall you are in nanometers?

From nanoscience to nanotechnology

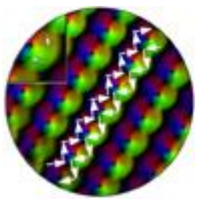
3 This is all very interesting and quite impressive, but what use is it? Our lives have some meaning on a scale of meters, but it's impossible to think about ordinary, everyday existence on a scale 1000 times smaller than a fly's eye. We can't really think about problems like AIDS, world poverty, or global warming, because they lose all meaning on the nanoscale. Yet the nanoscale—the world where atoms, molecules (atoms joined together), proteins, and cells rule the roost—is a place where science and technology gain an entirely new meaning.

4 By zooming in to the nanoscale, we can figure out how some of the puzzling things in our world actually work by seeing how atoms and molecules make them happen. You've probably seen that trick TV programs do with satellite photos, where they start off with a picture of the green and blue Earth and zoom in really fast, at ever-increasing scale, until you're suddenly staring at someone's back garden. You realize Earth is green because it's made from a patchwork of green grass. Keep zooming in and you'll see the chloroplasts in the grass: the green capsules inside the plant cells that make energy from sunlight. Zoom in some more and you'll eventually see molecules made from carbon, hydrogen, and oxygen being split apart and recombined inside the chloroplasts. So the nanoscale is good because it lets us do nanoscience: it helps us understand why things happen by studying them at the smallest possible scale. Once we understand nanoscience, we can do some nanotechnology: we can put the science into action to help solve our problems. That's what the word "technology" means and it's how technology (applied science) differs from pure "science", which is about studying things for their own sake.

What's so good about the nanoscale?

5 It turns out there are some very interesting things about the nanoscale. Lots of substances behave very differently in the world of atoms and molecules. For example, the metal copper is transparent on the nanoscale while gold, which is normally unreactive, becomes chemically very active. Carbon, which is quite soft in its normally occurring form (graphite), becomes incredibly hard when it's tightly packed into a nanoscopic arrangement called a nanotube. In other words, materials can have different physical properties on the nanoscale even though they're still the same materials! On the nanoscale, it's easier for atoms and molecules to move around and between one another, so the chemical properties of materials can also be different. Nanoparticles have much more surface area exposed to other nanoparticles, so they are very good as catalysts (substances that speed up chemical reactions).

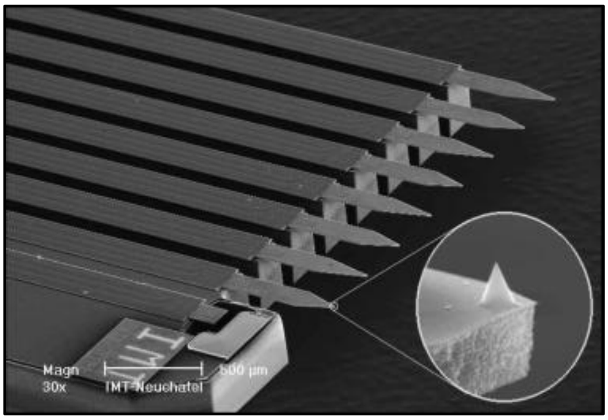
6 One reason for these differences is that different factors become important on the nanoscale. In our everyday world, gravity is the most important force we encounter: it dominates everything around us, from the way our hair hangs down around our head to the way Earth has different seasons at different times of year. But on the nanoscale, gravity is much less important than the electromagnetic forces between atoms and molecules. Factors like thermal vibrations (the way atoms and molecules store heat by jiggling about) also become extremely significant. In short, the game of science has different rules when you play it on the nanoscale.



Looking at the nanoscale with electron holography.
By courtesy of US Department of Energy/Brookhaven National Laboratory

How do you work on the nanoscale?

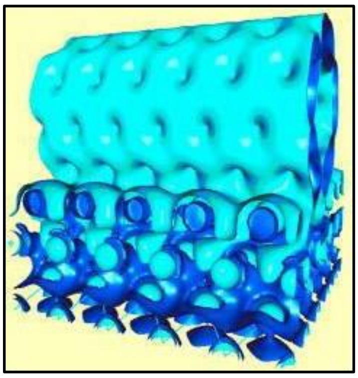
7 Your fingers are millions of nanometers long, so it's no good trying to pick up atoms and molecules and move them around with your bare hands. That would be like trying to eat your dinner with a fork 300 km (186 miles) long! Amazingly, scientists have developed electron microscopes that allow us to "see" things on the nanoscale and also manipulate them. They're called atomic force microscopes (AFMs), scanning probe microscopes (SPMs), and scanning tunneling microscopes (STMs).



The eight tiny probe tips on the Atomic Force Microscope (AFM) built into NASA's Phoenix Mars Lander. The tip enlarged in the circle is the same size as a smoke particle at its base (2 microns). Photo by courtesy of NASA Jet Propulsion Laboratory (NASA-JPL).

8 The basic idea of an electron microscope is to use a beam of electrons to see things that are too small to see using a beam of light. A nanoscopic microscope uses electronic and quantum effects to see things that are even smaller. It also has a tiny probe on it that can be used to shift atoms and molecules around and rearrange them like tiny building blocks. In 1989, IBM researcher Don Eigler used a microscope like this to spell out the word I-B-M by moving individual atoms into position. Other scientists have used similar techniques to draw pictures of nanoscopic guitars, books, and all kinds of other things. These are mostly frivolous exercises, designed to wow people with nanopower. But they also have important practical applications. There are lots of other ways of working with nanotechnology, including “molecular beam epitaxy”, which is a way of growing single crystals one layer of atoms at a time.

What can we use nanotechnology for?



9 Most of nanotechnology's benefits will happen decades in the future, but it's already helping to improve our world in many different ways. We tend to think of nanotechnology as something new and alien, perhaps because the word "technology" implies artificial and human-made, but life itself is an example of nanotechnology: proteins, bacteria, viruses, and cells all work on the nanoscopic scale.

Nanomaterials

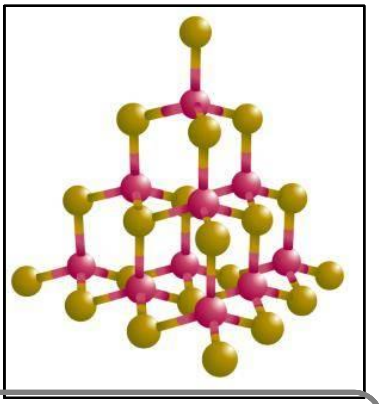
10 It could be you're already using nanotechnology. You might be wearing nanotechnology pants (that's "trousers" to you in the UK), walking on a nanotechnology rug, sleeping on nanotechnology sheets, or hauling nanotechnology luggage to the airport. All these products are made from fabrics coated with "nanowhiskers." These tiny surface fibers are so small that

dirt cannot penetrate into them, which means the deeper layers of material stay clean. Some brands of sunscreens use nanotechnology in a similar way: they coat your skin with a layer of nanoscopic titanium dioxide or zinc oxide that blocks out the Sun's harmful ultraviolet rays. Nano-coatings are also appearing on scratch-resistant car bumpers, anti-slip steps on vans and buses, corrosion resistant paints, and wound dressings.

11 Carbon nanotubes are among the most exciting of nanomaterials. These rod-shaped carbon molecules are roughly one nanometer across. Although they're hollow, their densely packed structure makes them incredibly strong and they can be grown into fibers of virtually any length. NASA scientists have recently proposed carbon nanotubes could be used to make a gigantic elevator stretching all the way from Earth into space. Equipment and people could be shuttled slowly up and down this "carbon ladder to the stars," saving the need for expensive rocket flights.

Nanochips

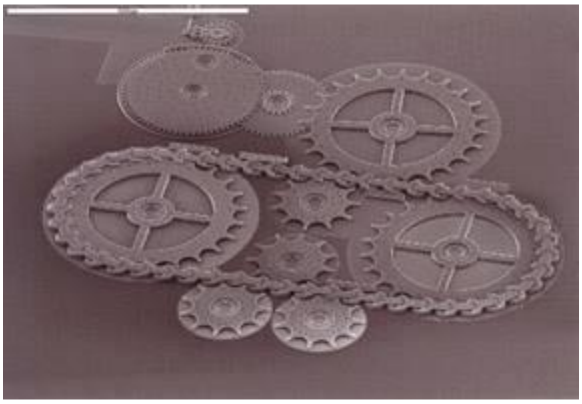
12 One form of nanotechnology we all use is microelectronics. The "micro" part of that word suggests computer chips work on the microscopic scale—and they do. But since terms like "microchip" were coined in the 1970s, electronic engineers have found ways of packing even more transistor switches into integrated circuits to make computers that are smaller, faster, and cheaper than ever before. This constant increase in computing power goes by the name of Moore's Law, and nanotechnology will ensure it continues well into the future. Everyday transistors in the early 21st-century are just 100–200 nanometers wide, but cutting-edge experiments are already developing much smaller devices. In 1998, scientists made a transistor from a single carbon nanotube. And it's not just the chips inside computers that use nanotechnology. The displays on everything from iPods and cellphones to laptops and flat screen TVs are shifting to organic light-emitting diodes (OLEDs), made from plastic films built on the nanoscale.



Creatures of the nanoworld? This is what a single molecule of the semiconductor material cadmium sulfide looks like. Nanoparticles like this could be used to make improved electronic displays and lasers. Picture by courtesy of NASA Marshall Space Flight Center (NASA-MSFC).

Nanomachines

The world's smallest chain drive. An example of a nanomachine, this nanotechnology "bike chain" and gear system was developed by scientists at Sandia National Laboratory. By courtesy of US Department of Energy/Sandia National Laboratory.



13 One of the most exciting areas of nanotechnology is the possibility of building incredibly small machines—things like gears, switches, pumps, or engines—from individual atoms. Nanomachines could be made into nanorobots (sometimes called nanobots) that could be injected into our bodies to carry out repairs or sent into hazardous or dangerous environments, perhaps to clean up disused nuclear power plants. As is so often the case,

nature leads humans here. Scientists have already found numerous examples of nanomachines in the natural world. For example, a common bacteria called E.coli can build itself a little nanotechnology tail that it whips around like a kind of propeller to move it closer to food. Making “nanomachines” is also known as molecular manufacturing and molecular nanotechnology (MNT).

History of nanotechnology

14 Natural examples like this tell us that nanotechnology is as old as life itself, but the concept of the nanoscale, nanoscience we can study, and nanotechnology we can harness are all relatively new developments. The brilliant American physicist Richard Feynman (1918–1988) is widely credited with kick-starting modern interest in nanotechnology. In 1959, in a famous after-dinner speech called "There's plenty of room at the bottom," the ever-imaginative Feynman speculated about an incredibly tiny world where people could use tiny tools to rearrange atoms and molecules. By 1974, Japanese engineering professor Norio Taniguchi had named this field "nanotechnology."

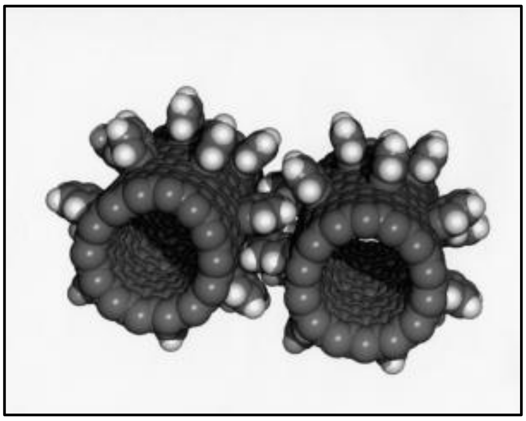
15 Nanotechnology really took off in the 1980s. That was when nanotech-evangelist Dr K. Eric Drexler first published his groundbreaking book Engines of Creation: The Coming Era of Nanotechnology. It was also the decade when microscopes appeared that were capable of manipulating atoms and molecules on the nanoscale. In 1991, carbon nanotubes were discovered by another Japanese scientist, Sumio Iijima, opening up huge interest in new engineering applications. The graphite in pencils is a soft form of carbon. In 1998, some American scientists built themselves another kind of pencil from a carbon nanotube and then used it, under a microscope, to write the words "NANOTUBE NANOPENCIL" with letters only 10 nanometers across.

16 Stunts like this captured the public imagination, but they also led to nanotechnology being recognized and taken seriously at the highest political levels. In 2000, President Bill Clinton sealed the importance of nanotechnology when he launched a major US government program called the National Nanotechnology Initiative (NNI), designed to fund groundbreaking research and inspire public interest.

The future of nanotechnology: nanodream or nano-nightmare?

17 Engineers the world over are raving about nanotechnology. This is what scientists at one of America's premier research institutions, the Los Alamos National Laboratory, have to say: *"The new concepts of nanotechnology are so broad and pervasive, that they will influence every area of technology and science, in ways that are surely unpredictable.... The total societal impact of nanotechnology is expected to be greater than the combined influences that the silicon integrated circuit, medical imaging, computer-aided engineering, and man-made polymers have had in this century."* That's a pretty amazing claim: 21st-century nanotechnology will be more important than all the greatest technologies of the 20th century put together!

18 Nanotechnology sounds like a world of great promise, but there are controversial issues too that must be considered and resolved. Some people have raised concerns that nanoscale organisms or machines could harm human life or the environment. One problem is that tiny particles can be extremely toxic to the human body. No-one really knows what harmful effect new nanomaterials or substances could have. Chemical pesticides were not considered harmful when they were first used in the early decades of the 20th century; it wasn't until the 1960s and 1970s that their potentially harmful effects were properly understood. Could the same happen with nanotechnology?



These nanogears were made by attaching benzene molecules (outer white blobs) to the outsides of carbon nanotubes (inner gray rings). By courtesy of Great Images in NASA

19 The ultimate nano-nightmare, the problem of "gray goo," was first highlighted by Eric Drexler. What happens if well-meaning humans create nanobots that run riot through the biosphere, gobbling up all living things and leaving behind nothing but a chewed-up mass of "gray goo"? Critics of nanotechnology argue humans shouldn't meddle with worlds they don't understand, but if we took that argument to its logical conclusion, we'd have no inventions at all—no medicines, no transportation, no agriculture, and no education—and we'd still be living in the Stone Age. The real question is whether the promise of nanotechnology is greater than any potential risks that go with it. And that will determine whether our nano-future becomes dream—or nightmare.