From: McCauley, Brendan

Sent: 8/18/2014 8:13:58 PM

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Subject: U.S. TRADEMARK APPLICATION NO. 79129484 - GRAPHENE TUBE - 130376 - Request for Reconsideration Denied - Return to TTAB - Message 3 of 6

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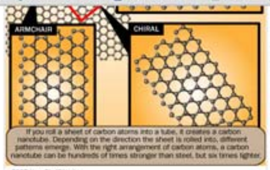
Count: 15

Files: How Stuff Works- Nanotechnology3.jpg, How Stuff Works- Nanotechnology4.jpg, How Stuff Works- Nanotechnology5.jpg, How Stuff Works- Nanotechnology6.jpg, How Stuff Works- Nanotechnology7.jpg, Nanocyl- nanotubes are tubes1.jpg, Nanocyl- nanotubes are tubes2.jpg, Nanotech Now- Intro to nanotubes, defined1.jpg, Nanotech Now- Intro to nanotubes, defined2.jpg, Nanotech Now- Intro to nanotubes, defined3.jpg, Nanotech Now- Intro to nanotubes, defined4.jpg, Nanotech Now- Intro to nanotubes, defined5.jpg, Nanotechnology for Dummies- Carbon Nanotubes.jpg, Nanotechnology for Dummies- Graphene.jpg, Nanotechnology for Dummies- Title.jpg



If you roll a sheet of carbon atoms into a tube, it creates a carbon nanotube. Depending on the direction the sheet is rolled into, different patterns emerge. With the right arrangement of carbon atoms, a carbon nanotube can be hundreds of times stronger than steel, but six times lighter.

2007 HowStuffWorks

A carbon nanotube is a nano-size cylinder of carbon atoms. Imagine a sheet of carbon atoms, which would look like a sheet of hexagons. If you roll that sheet into a tube, you'd have a carbon nanotube. Carbon nanotube properties depend on how you roll the sheet. In other words, even though all carbon nanotubes are made of carbon, they can be very different from one another based on how you align the individual atoms.

With the right arrangement of atoms, you can create a carbon nanotube that's hundreds of times stronger than steel, but six times lighter [source: The Ecologist]. Engineers plan to make building material out of carbon nanotubes, particularly for things like cars and airplanes. Lighter vehicles would mean better fuel efficiency, and the added strength translates to increased passenger safety.

Carbon nanotubes can also be effective semiconductors with the right arrangement of atoms. Scientists are still working on finding ways to make carbon nanotubes a realistic option for transistors in microprocessors and other electronics.

In the next section, we'll look at products that are taking advantage of nanotechnology.

GRAPHITE VS. DIAMONDS

What's the difference between graphite and diamonds? Both materials are made of carbon, but both have vastly different properties. Graphite is soft; diamonds are hard. Graphite conducts electricity, but diamonds are insulators and can't conduct electricity. Graphite is opaque; diamonds are usually transparent. Graphite and diamonds have these properties because of the way the carbon atoms bond together at the nanoscale.


Ingredients like zinc oxide can leave a white sheen behind. But sunscreens with zinc oxide nanoparticles rub on clear.
Greg Wood/AFP/Getty Images

Products with Nanotechnology

You might be surprised to find out how many products on the market are already benefiting from nanotechnology.

- **Sunscreen** - Many sunscreens contain nanoparticles of zinc oxide or titanium oxide. Older sunscreen formulas use larger particles, which is what gives most sunscreens their whitish color. Smaller particles are less visible, meaning that when you rub the sunscreen into your skin, it doesn't give you a whitish tinge.
- **Self-cleaning glass** - A company called Pilkington offers a product they call Activ Glass, which uses nanoparticles to make the glass **photocatalytic** and **hydrophilic**. The photocatalytic effect means that when UV radiation from light hits the glass, nanoparticles become energized and begin to break down and loosen organic molecules on the glass (in other words, dirt). Hydrophilic means that when water makes contact with the glass, it spreads across the glass evenly, which helps wash the glass clean.
- **Clothing** - Scientists are using nanoparticles to enhance your clothing. By coating fabrics with a thin layer of zinc oxide nanoparticles, manufacturers can create clothes that give better protection from UV radiation. Some clothes have nanoparticles in the form of little hairs or whiskers that help repel water and other materials, making the clothing stain-resistant.
- **Scratch-resistant coatings** - Engineers discovered that adding aluminum silicate nanoparticles to scratch-resistant polymer coatings made the coatings more effective, increasing resistance to chipping and scratching. Scratch-resistant coatings are common on everything from cars to eyeglass lenses.
- **Antimicrobial bandages** - Scientist Robert Burrell created a process to manufacture antibacterial bandages using nanoparticles of silver. Silver ions block microbes' cellular respiration [source: Burnsurgery.org]. In other words, silver smothers harmful cells, killing them.

[source: The Ecologist]

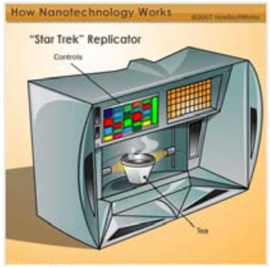

Bridgestone engineers developed this Quick Response Liquid Powder Display, a flexible digital screen, using nanotechnology.
Yoshikazu Tsuno/AFP/Getty Images

New products incorporating nanotechnology are coming out every day. Wrinkle-resistant fabrics, deep-penetrating cosmetics, liquid crystal displays (LCD) and other conveniences using nanotechnology are on the market. Before long, we'll see dozens of other products that take advantage of nanotechnology ranging from Intel microprocessors to **bio-nanobatteries**, capacitors only a few nanometers thick. While this is exciting, it's only the tip of the iceberg as far as how nanotechnology may impact us in the future.

In the next section, we'll look at some of the incredible things that nanotechnology may hold for us.

TENNIS, ANYONE?

Nanotechnology is making a big impact on the tennis world. In 2002, the tennis racket company Babolat introduced the VS Nanotube Power racket. They made the racket out of carbon nanotube-infused graphite, meaning the racket was very light, yet many times stronger than steel. Meanwhile, tennis ball manufacturer Wilson introduced the Double Core tennis ball. These balls have a coating of clay nanoparticles on the inner core. The clay acts as a sealant, making it very difficult for air to escape the ball.



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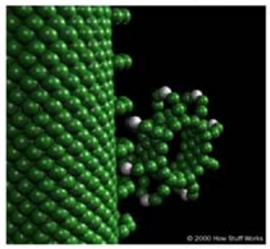
The Future of Nanotechnology

In the world of "Star Trek," machines called **replicators** can produce practically any physical object, from weapons to a steaming cup of Earl Grey tea. Long considered to be exclusively the product of science fiction, today some people believe replicators are a very real possibility. They call it **molecular manufacturing**, and if it ever does become a reality, it could drastically change the world.

Atoms and molecules stick together because they have complementary shapes that lock together, or charges that attract. Just like with magnets, a positively charged atom will stick to a negatively charged atom. As millions of these atoms are pieced together by nanomachines, a specific product will begin to take shape. The goal of molecular manufacturing is to manipulate atoms individually and place them in a pattern to produce a desired structure.

The first step would be to develop nanoscopic machines, called **assemblers**, that scientists can program to manipulate atoms and molecules at will. Rice University Professor Richard Smalley points out that it would take a single nanoscopic machine millions of years to assemble a meaningful amount of material. In order for molecular manufacturing to be practical, you would need trillions of assemblers working together simultaneously. Eric Drexler believes that assemblers could first replicate themselves, building other assemblers. Each generation would build another, resulting in exponential growth until there are enough assemblers to produce objects [source: Ray Kurzweil].



Assemblers might have moving parts like the nanogears in this concept drawing.

Trillions of assemblers and replicators could fill an area smaller than a cubic millimeter, and could still be too small for us to see with the naked eye. Assemblers and replicators could work together to automatically construct products, and could eventually replace all traditional labor methods. This could vastly decrease replicators could work together to automatically construct products, and could eventually replace all traditional labor methods. This could vastly decrease manufacturing costs, thereby making consumer goods plentiful, cheaper and stronger. Eventually, we could be able to replicate anything, including diamonds, water and food. Famine could be eradicated by machines that fabricate foods to feed the hungry.

Nanotechnology may have its biggest impact on the medical industry. Patients will drink fluids containing nanorobots programmed to attack and reconstruct the molecular structure of cancer cells and viruses. There's even speculation that nanorobots could slow or reverse the aging process, and life expectancy could increase significantly. Nanorobots could also be programmed to perform delicate surgeries -- such **nanosurgeons** could work at a level a thousand times more precise than the sharpest scalpel [source: International Journal of Surgery]. By working on such a small scale, a nanorobot could operate without leaving the scars that conventional surgery does. Additionally, nanorobots could change your physical appearance. They could be programmed to perform cosmetic surgery, rearranging your atoms to change your ears, nose, eye color or any other physical feature you wish to alter.

Nanotechnology has the potential to have a positive effect on the environment. For instance, scientists could program airborne nanorobots to rebuild the thinning ozone layer. Nanorobots could remove contaminants from water sources and clean up oil spills. Manufacturing materials using the **bottom-up method** of nanotechnology also creates less pollution than conventional manufacturing processes. Our dependence on non-renewable resources would diminish with nanotechnology. Cutting down trees, mining coal or drilling for oil may no longer be necessary -- nanomachines could produce those resources.

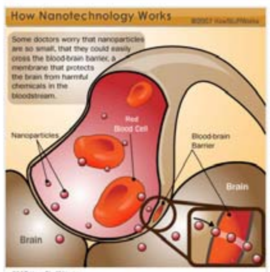
Many nanotechnology experts feel that these applications are well outside the realm of possibility, at least for the foreseeable future. They caution that the more exotic applications are only theoretical. Some worry that nanotechnology will end up like virtual reality -- in other words, the hype surrounding nanotechnology will continue to build until the limitations of the field become public knowledge, and then interest (and funding) will quickly dissipate.

In the next section, we'll look at some of the challenges and risks of nanotechnology.

HOW NEW IS NANOTECHNOLOGY?

In 1959, physicist and future Nobel prize winner Richard Feynman gave a lecture to the American Physical Society called "There's Plenty of Room at the Bottom." The focus of his speech was about the field of miniaturization and how he believed man would create increasingly smaller, powerful devices.

In 1986, K. Eric Drexler wrote "Engines of Creation" and introduced the term nanotechnology. Scientific research really expanded over the last decade. Inventors and corporations aren't far behind -- today, more than 13,000 patents registered with the U.S. Patent Office have the word "nano" in them [source: U.S. Patent and Trademark Office]



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Nanotechnology Challenges, Risks and Ethics

The most immediate challenge in nanotechnology is that we need to learn more about materials and their properties at the nanoscale. Universities and corporations across the world are rigorously studying how atoms fit together to form larger structures. We're still learning about how quantum mechanics impact substances at the nanoscale.

Because elements at the nanoscale behave differently than they do in their bulk form, there's a concern that some nanoparticles could be toxic. Some doctors worry that the nanoparticles are so small, that they could easily cross the **blood-brain barrier**, a membrane that protects the brain from harmful chemicals in the bloodstream. If we plan on using nanoparticles to coat everything from our clothing to our highways, we need to be sure that they won't poison us.

Closely related to the knowledge barrier is the technical barrier. In order for the incredible predictions regarding nanotechnology to come true, we have to find ways to mass produce nano-size products like transistors and nanowires. While we can use nanoparticles to build things like tennis rackets and make wrinkle-free fabrics, we can't make really complex microprocessor chips with nanowires yet.

There are some hefty social concerns about nanotechnology too. Nanotechnology may also allow us to create more powerful weapons, both lethal and non-lethal. Some organizations are concerned that we'll only get around to examining the ethical implications of nanotechnology in weaponry after these devices are built. They urge scientists and politicians to examine carefully all the possibilities of nanotechnology before designing increasingly powerful weapons.

If nanotechnology in medicine makes it possible for us to enhance ourselves physically, is that ethical? In theory, medical nanotechnology could make us smarter, If nanotechnology in medicine makes it possible for us to enhance ourselves physically, is that ethical? In theory, medical nanotechnology could make us smarter, stronger and give us other abilities ranging from rapid healing to night vision. Should we pursue such goals? Could we continue to call ourselves human, or would we become transhuman -- the next step on man's evolutionary path? Since almost every technology starts off as very expensive, would this mean we'd create two races of people -- a wealthy race of modified humans and a poorer population of unaltered people? We don't have answers to these questions, but several organizations are urging nanoscientists to consider these implications now, before it becomes too late.

Not all questions involve altering the human body -- some deal with the world of finance and economics. If molecular manufacturing becomes a reality, how will that impact the world's economy? Assuming we can build anything we need with the click of a button, what happens to all the manufacturing jobs? If you can create anything using a replicator, what happens to currency? Would we move to a completely electronic economy? Would we even need money?

Whether we'll actually need to answer all of these questions is a matter of debate. Many experts think that concerns like grey goo and transhumans are at best premature, and probably unnecessary. Even so, nanotechnology will definitely continue to impact us as we learn more about the enormous potential of the nanoscale.

To learn more about nanotechnology and other subjects, follow the links on the next page.

APOCALYPTIC GOO

Eric Drexler, the man who introduced the word nanotechnology, presented a frightening apocalyptic vision -- self-replicating nanorobots malfunctioning, duplicating themselves a trillion times over, rapidly consuming the entire world as they pull carbon from the environment to build more of themselves. It's called the **"grey goo"** scenario, where a synthetic nano-size device replaces all organic material. Another scenario involves nanodevices made of organic material wiping out the Earth -- the **"green goo"** scenario.

Lots More Information

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- Foresight Nanotech Institute
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- PhysOrg.com: Nanotechnology

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nanocyl
THE CARBON NANOTUBE SPECIALIST

Carbon Nanotubes

Talk to an Expert

What is a Carbon Nanotube?

A Carbon Nanotube is a tube-shaped material, made of carbon, having a diameter measuring on the nanometer scale. A nanometer is one-billionth of a meter, or about one ten-thousandth of the thickness of a human hair. The graphite layer appears somewhat like a rolled-up chicken wire with a continuous unbroken hexagonal mesh and carbon molecules at the apexes of the hexagons.

Carbon Nanotubes have many structures, differing in length, thickness, and in the type of helicity and number of layers. Although they are formed from essentially the same graphite sheet, their electrical characteristics differ depending on these variations, acting either as metals or as semiconductors.

As a group, Carbon Nanotubes typically have diameters ranging from <1 nm up to 50 nm. Their lengths are typically several microns, but recent advancements have made the nanotubes much longer, and measured in centimeters.

Carbon Nanotubes can be categorized by their structures:

- Single-wall Nanotubes (SWNT)
- Multi-wall Nanotubes (MWNT)
- Double-wall Nanotubes (DWNT)

What are the Properties of a Carbon Nanotube?

The intrinsic mechanical and transport properties of Carbon Nanotubes make them the ultimate carbon fibers. The following tables (Table 1 and Table 2) compare these properties to other engineering materials.

Overall, Carbon Nanotubes show a unique combination of stiffness, strength, and tenacity compared to other fiber materials which usually lack one or more of these properties. Thermal and electrical conductivity are also very high, and comparable to other conductive materials.

Table 1. Mechanical Properties of Engineering Fibers

Fiber Material	Specific Density	E (TPa)	Strenght (GPa)	Strain at Break (%)
Carbon Nanotube	1.3 - 2	1	10 - 60	10
HS Steel	7.8	0.2	4.1	< 10
Carbon Fiber - PAN	1.7 - 2	0.2 - 0.6	1.7 - 5	0.3 - 2.4
Carbon Fiber - Pitch	2 - 2.2	0.4 - 0.96	2.2 - 3.3	0.27 - 0.6
E/S - glass	2.5	0.07 / 0.08	2.4 / 4.5	4.8
Kevlar* 49	1.4	0.13	3.6 - 4.1	2.8

Kevlar is a registered trademark of DuPont.

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Kevlar is a registered trademark of DuPont.

Table 2. Transport Properties of Conductive Materials

Material	Thermal Conductivity (W/m.k)	Electrical Conductivity
Carbon Nanotubes	> 3000	106 - 107
Copper	400	6 x 107
Carbon Fiber - Pitch	1000	2 - 8.5 x 106
Carbon Fiber - PAN	8 - 105	6.5 - 14 x 106

What are the Potential Applications for Carbon Nanotubes?

Carbon Nanotube Technology can be used for a wide range of new and existing applications:

- Conductive plastics
- Structural composite materials
- Flat-panel displays
- Gas storage
- Antifouling paint
- Micro- and nano-electronics
- Radar-absorbing coating
- Technical textiles
- Ultra-capacitors
- Atomic Force Microscope (AFM) tips
- Batteries with improved lifetime
- Biosensors for harmful gases
- Extra strong fibers

How Does Nanocyl Produce Carbon Nanotubes?

Nanocyl uses the "Catalytic Carbon Vapor Deposition" method for producing Carbon Nanotube Technologies. This proven industrial process is well known for its reliability and scalability. It involves growing nanotubes on substrates, thus enabling uniform, large-scale production of the highest-quality carbon nanotubes worldwide.

Which Carbon Nanotube Technology is Right for Your Application? Choose by:

- Sectors
- Materials
- Products

Home > Introduction > Nanotubes and Buckyballs

Nanotubes and Buckyballs

Last Updated: Tuesday, 29-May-2012 06:53:42 PDT

Go directly to Websites

Nanotube:

"Conceptually, single-wall carbon nanotubes (SWCNTs) can be considered to be formed by the rolling of a single layer of graphite (called a graphene layer) into a seamless cylinder. A multiwall carbon nanotube (MWCNT) can similarly be considered to be a coaxial assembly of cylinders of SWCNTs, like a Russian doll, one within another; the separation between tubes is about equal to that between the layers in natural graphite. Hence, nanotubes are one-dimensional objects with a well-defined direction along the nanotube axis that is analogous to the in-plane directions of graphite."
—M. S. Dresselhaus, Department of Physics and the Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

Copyright Prof. Vincent H. Crespi Department of Physics Pennsylvania State University.

A one dimensional fullerene (a convex cage of atoms with only hexagonal and/or pentagonal faces) with a cylindrical shape. Carbon nanotubes discovered in 1991 by Sumio Iijima resemble rolled up graphite, although they can not really be made that way. Depending on the direction that the tubes appear to have been rolled (quantified by the 'chiral vector'), they are known to act as conductors or semiconductors. Nanotubes are a proving to be useful as molecular components for nanotechnology. [Encyclopedia Nanotech]

Strictly speaking, any tube with nanoscale dimensions, but generally used to refer to carbon nanotubes, which are sheets of graphite rolled up to make a tube. A commonly mentioned non-carbon variety is made of boron nitride, another is silicon. These noncarbon nanotubes are most often referred to as nanowires. The dimensions are variable (down to 0.4 nm in diameter) and you can also get nanotubes within nanotubes, leading to a distinction between multi-walled and single-walled nanotubes. Apart from remarkable tensile strength, nanotubes exhibit varying electrical properties (depending on the way the graphite structure spirals around the tube, and other factors, such as doping), and can be superconducting, insulating, semiconducting or conducting (metallic). [CMP]

Nanotubes can be either electrically conductive or semiconductive, depending on their helicity, leading to nanoscale wires and electrical components. These one-dimensional fibers exhibit electrical conductivity as high as copper, thermal conductivity as high as diamond, strength 100 times greater than steel at one sixth the weight, and high strain to failure. NASA JSC - Carbon Nanotubes

A nanotube's chiral angle--the angle between the axis of its hexagonal pattern and the axis of the tube--determines whether the tube is metallic or semiconducting. Nanotubes Under Stress

A graphene sheet can be rolled more than one way, producing different types of carbon nanotubes. The three main types are armchair, zig-zag, and chiral. Examples

Copyright Professor Charles M. Lieber Group
And an excellent description of **Carbon Nanotube Tips for Atomic Force Microscopy**

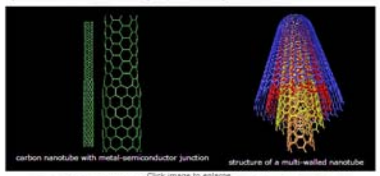
Carbon nanotubes possess many unique properties which make them ideal AFM probes. Their high aspect ratio provides faithful imaging of deep trenches, while good resolution is retained due to their nanometer-scale diameter. These geometrical factors also lead to reduced tip-sample adhesion, which allows gentler imaging. Nanotubes elastically buckle rather than break when deformed, which results in highly robust probes. They are electrically conductive, which allows their use in STM and EFM (electric force microscopy), and they can be modified at their ends with specific chemical or biological groups for high resolution functional imaging. Professor Charles M. Lieber Group

CNT exhibits extraordinary mechanical properties: the Young's modulus is over 1 Tera Pascal. It is stiff as diamond. The estimated tensile strength is 200 Giga Pascal. These properties are ideal for reinforced composites, nanoelectromechanical systems (NEMS). Center for Nanotechnology | Gallery

Carbon Nanotube Transistors exploit the fact that nm- scale nanotubes (NT) are ready-made molecular wires and can be rendered into a conducting, semiconducting, or insulating state, which make them valuable for future nanocomputer design. ... Carbon nanotubes are quite popular now for their prospective electrical, thermal, and even selective-chemistry applications. Physics News 590, May 21, 2002

Many potential applications have been proposed for carbon nanotubes, including conductive and high-strength composites; energy storage and energy conversion devices; sensors; field emission displays and radiation sources; hydrogen storage media; and nanometer-sized semiconductor devices, probes, and interconnects. Some of these applications are now realized in products. Others are demonstrated in early to advanced devices, and one, hydrogen storage, is clouded by controversy. Nanotube cost, polydispersity in nanotube type, and limitations in processing and assembly methods are important barriers for some applications of single-walled nanotubes. Carbon Nanotubes—the Route Toward Applications Ray H. Baughman, Anvar A. Zakhidov, Walt A. de Heer

AKA: Multi-wall Carbon Nanotubes (MWNTs), Single-wall Carbon Nanotubes (SWCNs), (5, 5) armchair nanotube, (9, 0) zigzag nanotube, and (10, 5) chiral nanotube. Also, single-wall carbon nanotube field-effect transistors (CNFETs). See Nanotubes, Nanocones, and Nanosheets: an applet that lets you control in 3D the components and form elements. [Steffen Weber, PhD. See his VRML gallery of Fullerenes]. Also carbon nanowalls.



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Bucky Ball:

"It is the roundest and most symmetrical large molecule known to man. Buckminsterfullerine continues to astonish with one amazing property after another. Named after American architect R. Buckminister Fuller who designed a geodesic dome with the same fundamental symmetry, C60 is the third major form of pure carbon; graphite and diamond are the other two." Bucky Balls - Andy Gion.

AKA: C60 molecules & buckminsterfullerene. Molecules made up of 60 carbon atoms arranged in a series of interlocking hexagons and pentagons, forming a structure that looks similar to a soccer ball [Steffen Weber, PhD.]. C60 is actually a "truncated icosahedron", consisting of 12 pentagons and 20 hexagons. It was discovered in 1985 by Professor Sir Harry Kroto, and two Rice University professors, chemists Dr. Richard E. Smalley and Dr. Robert F. Curl Jr., [for which they were jointly awarded the 1996 Nobel Lauriate for chemistry] and is the only molecule composed of a single element to form a hollow spheroid [which gives the potential for filling it, and using it for novel drug-delivery systems. See Structure of a New Family of Buckyballs Created].

"The buckyball, being the roundest of round molecules, is also quite resistant to high speed collisions. In fact, the buckyball can withstand slamming into a stainless steel plate at 15,000 mph, merely bouncing back, unharmed. When compressed to 70 percent of its original size, the buckyball becomes more than twice as hard as its cousin, diamond." The Buckyball - Rodrigo de Almeida Siqueira.

AKA: Endohedral fullerenes, carbon cages.

AKA: Endohedral fullerenes, carbon cages.

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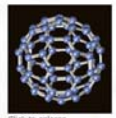

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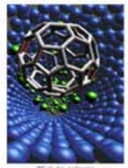

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Copyright ORNL. See Materials by Computational Design and Atomistic Simulations. This figure presents a visualization of a nanohydraulic piston. The model consists of a Carbon nanotube (blue), Helium atoms (green), and a "Buckyball" molecule. It is used to explore the stability of the system.

Below you will find a selection of sites whose main theme is **Nanotubes & carbon buckyballs**. If you have another favorite, please email us.

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Nanotube, nanowhiskers, nanofibres, and buckyball links:

Best Sites:

An excellent description of Nanotubes

Physical Properties of Carbon Nanotubes

VRML Gallery of Fullerene Geometries

Basic Properties of Carbon Nanotubes

Nanotube Images

More Nanotube Images

Nanotube Modeler

The Nanotube Site Dr. David Tomanek

Project 26: JNanoTube

Organoclays and Carbon Nanotubes

More Information:

NASA/Johnson Space Center Nano Materials Project
"NASA and the Johnson Space Center (JSC) have made a commitment to pursue and drive breakthrough technologies to expand human exploration of space. The very future of space exploration depends on advanced technologies such as nanotechnology and biomimetics. Toward this goal, JSC is focusing on the development of nanotechnology based on single-wall carbon nanotubes."

Sussex Fullerene Research Centre | The Buckyball Workshops | Buckminsterfullerene, C60, the Celestial Sphere that Fell to Earth: Vega Science Trust program featuring Sir Harold Kroto, Sussex University

- Carbon Nanotube Introduction from Nanoledge. Includes: Properties & Potential Applications
- Carbon nanotubes Great introductory article, with images and technical explanations. PhysicsWeb, January 1998
- The smallest revolution a simple introduction to the science behind using nanowires and nanotubes in electronics.
- C 60 Molecule - Buckminsterfullerene Buckminster Fuller Institute
- Fullerenes to Nanotubes Center for Nanoscale Science and Technology, Rice Quantum Institute, and Departments of Chemistry and Physics, Dr. Richard E. Smalley
- Prof. Vincent H. Crespi - Nanotubes Department of Physics The Pennsylvania State University.
- Interlinking, Band Gap Engineering, Tunable Adsorption and Functionalization of Carbon Nanotubes Dr. Taner Yildirim (NIST)
- Delft University of Technology Molecular Biophysics Group - Carbon nanotubes.
- Stony Brook Buckyball Home Page Virtual tour of fullerenes in Laszlo Mihaly's laboratory at the Physics Department at SUNY, Stony Brook.
- A Fullerene Structure Library Images from the Department of Chemistry at SUNY Stony Brook
- Berkeley Lab Research Review Fall 2001: Nanotubes "Alex Zettl makes the most incredible devices you'll never see - at least not without the aid of an electron microscope..."
- IBM Scientists Develop Breakthrough Transistor Technology with Carbon Nanotubes IBM Research News, April 2001
- Cluster Science Collaboration an academic interest group at Michigan State University promoting fundamental research in atomic clusters.
- Science & Application of Nanotubes Edited by: David Tománek & Richard Enbody
- Nanotube Publications (33) David Tománek's Group
- Nanotube Publications (151 : ~68 of which are online) David Tománek
- A Timeline David Tománek "a first iteration of my subjective opinion regarding the key events and publications."
- VRML gallery of chiral Nano-Tubes generated with JSV1.08, © S.Weber, 1999
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- Nitrogen makes buckyballs strong and springy EETimes article by Sara Sowah 11.21.2001
- The Buckyball Collection Molecular Expressions Photo Gallery
- Crossed nanowires compute TRN News article by Eric Smalley 11.14.2001
- 1st 4Å SWC Nanotubes Article by Hong Kong University of Science and Technology 11.02.2000
- Artificial Muscles Made From Nanotubes BBC article 12.31.2001
- Carbon Nanotubes as Molecular Quantum Wires Cees Dekker, Delft Univ of Tech - Real Audio and slide show
- Carbon nanotubes IBM Nanoscale Science Department
- $C_{1,000,000}$ and Beyond. American Scientist Article by Boris I. Yakobson and Richard E. Smalley 07.1997
- What are fullerenes? Institute for Solid State and Materials Research Dresden 04.2000
- Buckyball: a C_{60} Molecule Images from Boris Pevzner MIT
- Fullerene Patent Database
- Hydrogen implantation into C_{60} Molecular Dynamics simulations of 10 to 50 eV hydrogen atom impact with zero K and room temperature fullerenes. CNLS LANL
- Buckyball, Diamond, Graphite Describes how Buckminsterfullerene was discovered, its structure and research. Dept. of Chemistry, University of Wisconsin-Madison
- **Chemical Functionalisation of Carbon Nanotubes FUNCARS** is a Research Training Network funded by the European Commission under the Improving Human Research Potential and the Socio-Economic Knowledge Base 5th Framework Programme.
- Gallery of Molecular Artwork by Keith Beardmore, with the Computational Materials Group, Motorola Semiconductor Products Sector.
- Production of Single Walled Carbon Nanotubes In a Reduced Gravity Environment - 1999 Project Final Report
- Bucky Animation Richard Loftin. Using a freeware buckminsterfullerene molecule collision modeling program.
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Glossary

Aerogels: An insulating foam of silica nanoparticles separated by nanopores containing air.

Armchair quantum wire: An electrically conducting wire constructed of metallic carbon nanotubes.

Atomic force microscope (AFM): A scanning probe device producing extremely high-resolution images of surfaces at the atomic scale.

Autonomous nanotechnology swarms (ANTS): Collections of very small robots that can collectively change their shape, communicate with each other, and act as sensors.

Bionanorobot: Robots approximately the size of the cells in our bodies that can perform tasks on nanoscale objects. The term *bio* refers to the fact that biological molecules are part of the nanorobot mechanism.

Bottom up: An approach to manufacturing that uses nanotechnology to build structures atom by atom.

Buckyball: Also called Fullerene. Molecules composed of carbon atoms arranged on the surface of a nearly spherical shape, in a pattern of pentagons and hexagons that looks like a soccer ball. Buckyballs are named after Buckminster Fuller, who introduced the geodesic dome. C60, indicating the number of carbon atoms in a single sphere, is the most common type of buckyball.

Carbon nanotubes: Molecules composed of carbon atoms arranged on the surface of a cylindrical shape in a pattern of hexagons as seen in buckyballs.

Covalent bonding: A type of chemical bonding in which electrons are shared between atoms.

Diamondoid: A very strong structure consisting of carbon atoms in a three-dimensional lattice joined by covalent bonds.

Dip-pen nanolithography: A technique for applying nano-sized patterns on surfaces using the tip of an atomic force microscope.

E-beam nanolithography: A technique for applying nano-sized patterns on surfaces using an electron beam.

Electron microscope: A type of microscope that uses a beam of electrons to produce an image.

Extreme ultraviolet nanolithography: A type of optical lithography that uses extremely short wavelengths of light.

Fullerene: *See* buckyball.

Functionalization: To attach sets of molecules to a nanoparticle to create a specific result, such as allowing a nanoparticle to bond to polymers to create a strong, lightweight composite material.

Graphene: Molecules composed of carbon atoms in a pattern of hexagons like that seen in buckyballs, arranged in a planar sheet one atom thick.

Mechanosynthesis: The use of mechanical tools to build a covalently bonded structure by depositing atoms or molecules at desired locations with atomic precision.

Metal-organic framework (MOF): Metal oxides linked by organic molecules in a porous crystalline structure that can be used to store gases.

Molecular assembler: *See* molecular fabricators.

Nanotechnology FOR DUMMIES®

2ND EDITION

by Earl Boysen and Nancy Boysen

Foreword by Desiree Dudley and Christine Peterson
Foresight Institute

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