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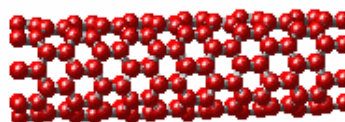
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# NANOTUBES & BUCKYBALLS

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## Nanotube:



Copyright [Prof. Vincent H. Crespi](#) Department of Physics Pennsylvania State University.  
And an excellent description of [Nanotubes](#)

A one dimensional fullerene (a convex cage of atoms with only hexagonal and/or pentagonal faces). Carbon nanotubes discovered in 1991 by Sumio Iijima resemble rolled up graphite, although they can be rolled in two different ways. Depending on the direction that the tubes appear to have been rolled (quantified by the 'chiral vector'), they can act as conductors or semiconductors. Nanotubes are proving to be useful as molecular components. [[Encyclopedia Nanotech](#)]

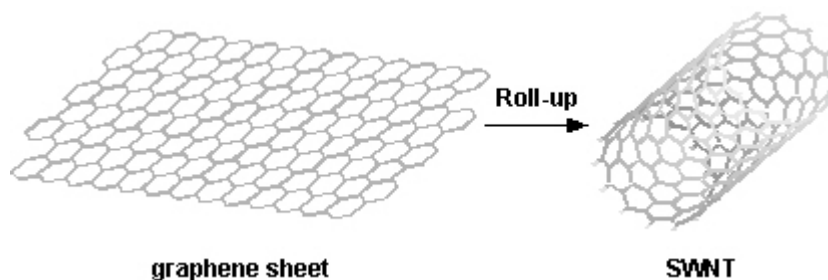
Strictly speaking, any tube with nanoscale dimensions, but generally used to refer to carbon nanotubes. Graphite rolled up to make a tube. A commonly mentioned non-carbon variety is made of boron nitride. These noncarbon nanotubes are most often referred to as *nanowires*. The dimensions are variable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

Nanotubes can be either electrically conductive or semiconductive, depending on their helicity, leading to their use as electrical components. These one-dimensional fibers exhibit electrical conductivity as high as copper, strength 100 times greater than steel at one sixth the weight, and high strain to failure. [[Nanotubes](#)]

A nanotube's chiral angle--the angle between the axis of its hexagonal pattern and the axis of the tube.

tube is metallic or semiconducting. [Nanotubes Under Stress](#)

A graphene sheet can be rolled more than one way, producing different types of carbon nanotubes, armchair, zig-zag, and chiral. [Examples](#)



Copyright [Professor Charles M. Lieber Group](#)

And an excellent description of [Carbon Nanotube Tips for Atomic Force Microscopy](#)

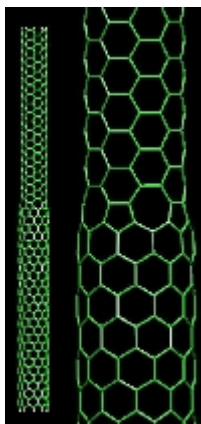
Carbon nanotubes possess many unique properties which make them ideal AFM probes. Their faithful imaging of deep trenches, while good resolution is retained due to their nanometer-scale diameter factors also lead to reduced tip-sample adhesion, which allows gentler imaging. Nanotubes elastically deform when deformed, which results in highly robust probes. They are electrically conductive, which allows for EFM (electric force microscopy), and they can be modified at their ends with specific chemical or functional 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. Its estimated tensile strength is 200 Giga Pascal. These properties are ideal for reinforced composite systems (NEMS). [Center for Nanotechnology | Gallery](#)

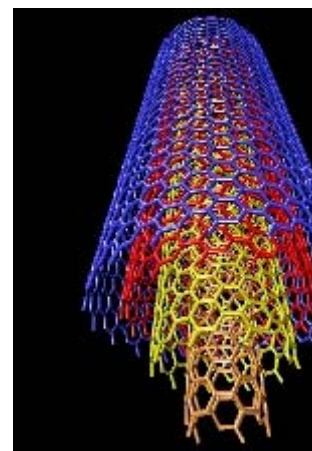
Carbon Nanotube Transistors exploit the fact that nm-scale nanotubes (NT) are ready-made molecules that can be rendered into a conducting, semiconducting, or insulating state, which make them valuable for future nanotechnology. Carbon nanotubes are quite popular now for their prospective electrical, thermal, and even selective-catalytic properties. [Physics News 590, May 21, 2002](#)

Many potential applications have been proposed for carbon nanotubes, including conductive and high energy storage and energy conversion devices; sensors; field emission displays and radiation sources; and nanometer-sized semiconductor devices, probes, and interconnects. Some of these applications are already commercial products. Others are demonstrated in early to advanced devices, and one, hydrogen storage, is under development. Nanotube cost, polydispersity in nanotube type, and limitations in processing and assembly methods are some of the challenges for some applications of single-walled nanotubes. [Carbon Nanotubes—the Route Toward Applications](#) Ray Zakhidov, Walt A. de Heer

AKA: Multi-wall Carbon Nanotubes (MWNTs), Single-wall Carbon Nanotubes (SWCNTs), (5, 5) armchair nanotube, and (10, 5) chiral nanotube. Also, single-wall carbon nanotube field-effect transistors (SWCNT-FETs), Nanocones, and Nanosheets: an applet that lets you control in 3D the components and form elements of a nanotube. Also [carbon nanowalls](#).



carbon nanotube with metal-semiconductor junction



structure of a multi-walled nan

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Copyright [Alain Rochefort](#) Assistant Professor Engineering Physics Department, Nanostructure Group, Center for Research on Computation and its Applications (CERCA)

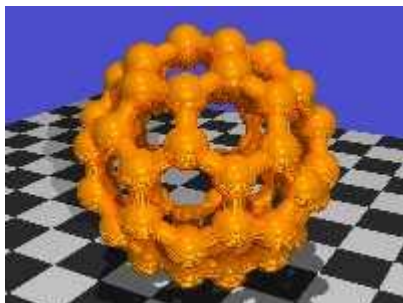
## Bucky Ball:

"It is the roundest and most symmetrical large molecule known to man. Buckminsterfullerene contains amazing properties after another. Named after American architect R. Buckminster Fuller who designed the same fundamental symmetry, C<sub>60</sub> is the third major form of pure carbon; graphite and diamond  
[Balls - Andy Gion](#).

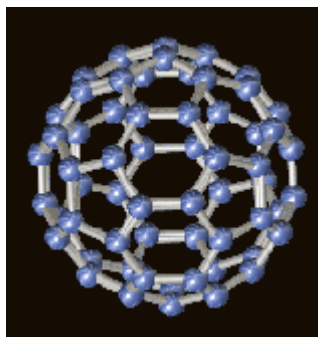
AKA: C<sub>60</sub> molecules & buckminsterfullerene. Molecules made up of 60 carbon atoms arranged in hexagons and pentagons, forming a structure that looks similar to a [soccer ball](#) [[Steffen Weber](#), "truncated icosahedron", consisting of 12 pentagons and 20 hexagons. It was discovered in 1985 by [Kroto](#) and two Rice University professors, chemists Dr. Richard E. Smalley and Dr. Robert F. Curl Jr., [for which they were awarded the 1996 Nobel Prize in Chemistry] and is the only molecule composed of a single spheroid [which gives the potential for filling it, and using it for novel drug-delivery systems. See [S Buckyballs Created](#)].

"The buckyball, being the roundest of round molecules, is also quite resistant to high speed collisions. It can withstand slamming into a stainless steel plate at 15,000 mph, merely bouncing back, unharmed. In fact, 10 percent of its original size, the buckyball becomes more than twice as hard as its cousin, diamond."  
[Almeida Siqueira](#).

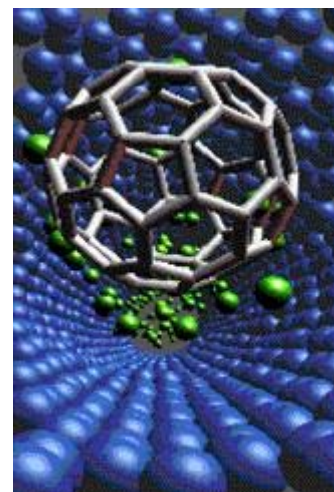
AKA: Endohedral fullerenes, carbon cages.



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Copyright Dr. **Roger C. Wagner**, Dept. of Biological Sciences, University of Delaware.



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Copyright ORNL. See [Materials by Design and Atomistic Simulation](#) presents a visualization of piston. The model consist nanotube (blue), Helium & a "Buckyball" molecule. I explore the stability of the

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### **Nanotube, nanowiskers, nanofibres, and buckyball NEWS:**

#### ● **Nanowires within nanowires**

**Physicsweb November 08, 2002** Semiconductor nanowires are increasingly used in electronic devices transistors, sensors, detectors and light-emitting diodes. More complicated devices are expected soon, improved ways of growing such wires.

#### ● **Scientists shell out on nanowires**

**Nanotechweb November 08, 2002** Researchers from Harvard University, US, have used chemical-vap multiple shells around nanowires of silicon and germanium. Charles Lieber and his team also demons transistor based on a nanowire with a silicon core coated with layers of germanium and silicon oxide.

- **Spongy carbon**

\* [Nature November 07, 2002](#) The high surface area and porosity of carbon-based materials such as carbon nanotubes produce a great number of potential applications including hydrogen storage and catalysis. By turning their structure to produce a carbon microstructure with a negative curvature, the properties of these materials could be

- **Researchers stamp out polymer nanowires**

[Nanotechweb November 07, 2002](#) A team of scientists has used micromoulding in capillaries and soft lithography to produce polymer nanowires and nanodots from conducting and semiconducting polymers.

- **NEC uses nanotubes in DNA-sorting biochip**

[Asahi.com November 06, 2002](#) NEC Corp. has applied the techniques of nanotechnology to create a biochip that can identify DNA and protein molecules.

- **Pulling nanotubes makes thread**

[TRNNews October 30, 2002](#) Pulling strands from several silkworm cocoons at once makes the thin silk thread. Researchers at Tsinghua University in China have hit upon a similar method for making three-dimensional microscopic carbon nanotubes.

- **Duke Researchers Report Advance in Nanotube Production**

[NanoelectronicsPlanet October 30, 2002](#) By growing nanotubes with diameters that varied by about 10 percent, Duke University chemists may have made a significant advance toward producing nanotubes with electronic properties uniform enough to use in molecular-sized circuits. ... [More](#)

- **Making 'Buckytubes' More Uniform**

[DukeNews October 28, 2002](#) Duke University chemists report they have made a significant advance in producing hollow tubes of carbon atoms, called "nanotubes," with electronic properties reliable enough to use in molecular-sized circuits. More details from 10/30 story.

- **University of Surrey Electronic Engineers' Revolutionary Discovery**

[AlphaGalileo October 27, 2002](#) A University of Surrey team led by Professor Ravi Silva has demonstrated a new method for growing carbon nanofibres at room temperature.

- **Ripping yarns**

\* [Nature October 24, 2002](#) Because of their size, the use of carbon nanotubes has largely been limited to applications such as field emission displays. But now, researchers have succeeded in drawing carbon nanotube yarns to lengths of up to several centimeters.

- **Report Projects Size of Global Nanotube Market**

[PR Newswire October 23, 2002](#) According to the report, the global market for nanotubes in 2002 will be worth \$1.5 billion and this number is expected to grow substantially over the next three years.

- **Thread spun from pure carbon nanotubes**

[NewScientist October 23, 2002](#) A way of making a thread purely from carbon nanotubes has been developed by researchers in China. They say the super-strong, electrically-conducting threads "should eventually be able to be woven into bullet-proof clothing and materials that block electromagnetic waves".

- **Purdue researchers build made-to-order nanotubes**

[EETimes October 24, 2002](#) Using a more complex system of atoms than carbon nanotubes, scientists at Purdue University have devised a tunable approach to nanotube creation that allows them to build application-specific varieties.

- **Nanotubes lined to order**

\* [Nature October 17, 2002](#) By chemically modifying template-cast nanotubes inside and out, researchers have

perform many useful tricks.

● **Applied Nanotech announces carbon-nanotube composites**

**Nanotechweb October 17, 2002** Applied Nanotech, US, has created carbon-nanotube composites for applications that it says have significantly improved properties.

● **ANI Says Nanotube Composites Improve Electron Emission Properties**

**NanoelectronicsPlanet October 15, 2002** By combining the new, proprietary carbon nanotube composites and non-conductive nanoparticles, ANI's scientists claim they were able to significantly lower the voltage of electron emission.

● **Nanotubes hang tough**

**Nature October 14, 2002** By sandwiching tiny but super-tough carbon nanotubes between layers of polycarbonate, researchers have created a revolutionary material that is six times stronger than conventional carbon-fibre composites and as tough as ultrahard ceramic materials used in engineering.

● **Cetek, Motorola Sign Pact for Display Technology**

**NanoelectronicsPlanet October 14, 2002** Cetek Technologies Inc. has secured a license from Motorola for carbon nanotube triode (CNT) technology, which Cetek will use to produce flat-panel displays.

● **Wired for success**

\* **Nature October 10, 2002** Nanowires, nanorods or nanowhiskers. It doesn't matter what you call them, they have a special property in nanotechnology.

● **Cetek and Motorola team up on nanotube-based displays**

**Nanotechweb October 09, 2002** US ceramics specialist Cetek Technologies, US, has secured a license to produce and use carbon nanotube triode technology, which has applications in flat-panel displays.

● **Big Future in Tiny Spaces**

**MSNBC October 07, 2002** Nanotechnology is moving from labs to businesses

● **Nanosys Licenses Nanolaser Technology from Cal**

**NanoelectronicsPlanet October 01, 2002** Nanosys Inc. continues to add to its impressive intellectual property portfolio, announcing this week it received exclusive license to semiconductor nanowire-based nanolasers developed in California.

● **E-beam welding eyed for dense nanoscale circuits**

**EETimes September 30, 2002** An international consortium of researchers believes its electron-beam welding of carbon nanotubes could be applied to the construction of ultradense circuits. | [More on the story from Sept 16](#)  
**Creates Tiny Junctions**

● **Investors make leap of faith when it comes to nanotubes**

**SmallTimes September 30, 2002** It could well be the ultimate test of faith for investors – betting on something you can't see. But in the world of nanotubes, where technology is grown rather than fabricated, that is the

● **IBM grows nanotube patterns on silicon wafers**

**EETimes September 30, 2002** IBM Corp. has grown catalyst-free nanotube networks on silicon carbide wafers, the company said last week.

● **Exohydrogenated single-wall carbon nanotubes**

**NIST** Carbon nanotubes exhibit very unusual structural and electronic properties, suggesting a wide variety of

applications, including the storage of hydrogen where the large effective surface area promises a large

- **Leap Of Faith**

**Electronic News September 23, 2002** It could well be the ultimate test of faith for investors—betting literally can't see. But in the world of nanotubes, where technology is grown rather than fabricated, th

- **Can Nanotubes Be Engineered to Superconduct?**

**NIST September 20, 2002** Superconducting nanotubes may lie on the technology horizon, suggests a published by researchers from the Commerce Department's National Institute of Standards and Techn University of Pennsylvania, and Bilkent University in Turkey.

- **CNI Improves on Nanotubes with BuckyPearls**

**NanoelectronicsPlanet September 17, 2002** Houston-based Carbon Nanotechnologies Inc. (CNI) has an improved form of single-wall carbon nanotubes.

- **Nanotubes could reduce CO2 emissions**

**WashTimes September 16, 2002** A team led by scientists at Carnegie Mellon University said Monday which are straw-like structures with walls a single atom thick, could filter gases much more quickly th

- **Nimble Nanoswitch May Win Info Relay Race**

**NewsFactor September 13, 2002** Carbon nanotube circuits may provide a powerful new supplement t electronic freeways, enhancing every occupant of the digital domain, from gaming gadgets to the infc

- **Important contacts**

\* **Nature September 12, 2002** The demonstration and refinement of switching in carbon nanotube fiel been a promising development on the road towards commercial nanoelectronics. But new research su properties of the nanotubes themselves may have only minimal effect of the characteristics of these d

- **Just Two Words: Carbon Nanotubes**

**Business 2.0 September 11, 2002** Mass production of these super-strong, super-versatile structures is means lower prices -- and new opportunities.

- **Atoms Light Up Very Rapidly Near Nanotubes**

**Physics News September 09, 2002** Just as the sharp point of a lightning rod modifies the electrical pr building, so too will certain highly curved (on a nanoscopic scale) surfaces modify the electromagnet vacuum in their vicinity.

- **Purdue Creates Self-Generating Nanotubes With 'Dial-Up' Properties**

**SpaceDaily September 10, 2002** Nanotubes, stringy supermolecules already used to create fuel cell ba circuits, could find myriad new applications ranging from disease treatment to plastics manufacturing reports a Purdue University research team.

- **Nantero's Next-Gen Memory Turns to Nanotubes**

**Nanoelectronics Planet September 03, 2002** Their plan is diabolically simple: build a memory chip th all other technologies placing Nantero at the pinnacle of memory chip design, research and developm

- **Purdue creates self-generating nanotubes with 'dial-up' properties**

**Purdue August 26, 2002** "Nanotubes, stringy supermolecules already used to create fuel cell batteries circuits, could find myriad new applications ranging from disease treatment to plastics manufacturing

- **Complementary nanotubes**

\* [Nature August 22, 2002](#) One of the barriers to nanotube electronics becoming a viable alternative to silicon is the difficulty of forming both p-type and n-type transistors on a single chip. New research suggests that this has now been overcome.

● [Carbon nanotube networks fall into line](#)

[Nanotechweb August 20, 2002](#) Researchers at Rensselaer Polytechnic Institute, US, have used carbon nanotubes for growing networks of aligned carbon nanotubes.

● [Duke Chemists Describe Progress At Making 'Buckytubes' Suitable For Nanoelectronic Devices](#)

[Duke News August 18, 2002](#) Duke University chemists are producing increased quantities of single walled carbon nanotubes, sometimes called "buckytubes," in forms suitable for use in futuristic molecular scale electronic devices.

● [NEC shares rise as carbon nanotubes draw interest](#)

[EV World August 18, 2002](#) Shares in chips-to-computers conglomerate NEC Corp <6701.T> rose on news of plans to mass-produce carbon nanotubes.

● [Nanotubes speed up](#) [Nanotechweb August 16, 2002](#)

● [Nanotubes grown in place](#) [TRN August 07, 2002](#)

● [Nanotubes seen emitting near-IR light](#) [EE Times August 06, 2002](#)

● [Scientists convert alcohol into carbon nanofibres](#) [Nanotechweb August 06, 2002](#)

● [PATENTS ARE GOING DOWN THE 'TUBES'; STUDY MAY PREDICT ECONOMIC GROWTH](#) [Small Business July 29, 2002](#)

● [Molecular Junctions by Joining Single-Walled Carbon Nanotubes](#) [APS July 29, 2002](#)

● [CARBON NANOTUBES FOUND TO FLUORESCENCE](#) [Rice U. July 29, 2002](#). More [Carbon nanotubes fluoresce](#) [Nanotechweb July 26, 2002](#)

● [CNI HAS THE BRAINS, THE CASH, NOW ALL IT NEEDS IS THE MARKET](#) [Small Times July 29, 2002](#)

● [Nanowires self-assemble from individual particles](#) [EE Times July 26, 2002](#)

● [The Next Wave](#) More on Burlington using nanowiskers [Business 2.0 July 18, 2002](#)

● [CdTe nanowires make themselves up](#) [NanotechWeb July 17, 2002](#)

● [It Slices! It Dices! Nanotube Struts Its Stuff](#) \* [NYTimes July 16, 2002](#)

● [Self-Assembly vs. Electron Beam Lithography](#) [Hoover's July 09, 2002](#)

● [NANOTUBE CATHODE BREAKTHROUGH MAY MAKE PORTABLE X-RAYS POSSIBLE](#) [Small Business July 09, 2002](#)

● [Memories of nanotubes](#) \* [Nature July 04, 2002](#)

● [Splitting Up Cooper Pairs](#) [APS June 28, 2002](#)

● [William E. Buhro Interview](#) [Nanotechnology Now June 20, 2002](#). [Chemists make first boron nanowiskers](#)

● [The Tinkertoys of Nanotechnology](#) [Lab Notes UC Berkeley June 20, 2002](#)



- [Custom nanotubes from a wet template](#) EE Times June 19, 2002
- [Chemists make first boron nanowhiskers](#) WUSL June 19, 2002
- [Cagey chemistry](#) ACS June 18, 2002
- [ALIGNING POLYMER NANOTUBES, EASILY](#) C&EN June 17, 2002
- [APPLIED NANOTECH INC. ANNOUNCES THE USE OF ITS CARBON NANOTUBE COLD CATHODE APPLICATIONS](#) SI Diamond June 17, 2002
- [DNA parts make versatile nanotubes](#) TRN News June 06, 2002
- [Onions in action](#) Nanostructured carbon has found a new use: concentric-shelled graphitic 'bucky on important industrial reaction. \* Nature May 30, 2002
- [Nanotubes self-assemble into circuit elements](#) EE Times March 26, 2002
- [Single-Walled Carbon Nanotube Electronics](#) PDF. Paul McEuen's group, Cornell University, Laboratory of Physical Science, Department of Physics

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### WebSites:

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Leiber Group - a Physical Chemistry research group in the Department of Chemistry and Chemical Biology at Harvard University. See also [Carbon Nanotube Based Molecular/Nano Electronics](#)
- [Sussex Fullerene Research Centre | The Buckyball Workshops | Buckminsterfullerene, C60, the Celestial Vega Science Trust program featuring Sir Harold Kroto](#), Sussex University
- [Carbon Nanotube Introduction](#) from Nanoledge. Includes: Properties & Potential Applications
- [The Nanotube Site](#) Dr. David Tomanek
- [Carbon nanotubes](#) Great introductory article, with images and technical explanations. PhysicsWeb, JPL
- [The smallest revolution](#) a simple introduction to the science behind using nanowires and nanotubes in electronics
- [Recent Developments \(Buckyballs\)](#) Buckminster Fuller Institute
- [Fullerenes to Nanotubes](#) Center for Nanoscale Science and Technology, Rice Quantum Institute, and Department of Chemistry and Physics, Dr. Richard E. Smalley
- [Prof. Vincent H. Crespi - Nanotubes](#) Department of Physics The Pennsylvania State University.  
And an excellent description of **Nanotubes**
- [Interlinking, Band Gap Engineering, Tunable Adsorption and Functionalization of Carbon Nanotubes](#) Dr. J. Kong

- [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 Phy 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 y not without the aid of an electron microscope..."
- [Nanotechnology Team Video Gallery](#) Carbon Nanotube Gears, Carbon Nanotubes - Compression, Be Carbon Nanotube Hole Punch, and MBE Simulation of GaAs Growth via Quantum Wavefunctions.
- [Carbon Nanotube Gear Simulations](#) These are datasets associated with the simulation runs from the st Simulation of Carbon Nanotube Based Gears".
- [IBM Scientists Develop Breakthrough Transistor Technology with Carbon Nanotubes](#) IBM Research Ne
- [Cluster Science Collaboration](#) an academic interest group at Michigan State University promoting fu atomic clusters.
- [Physical Properties of Nanotubes](#) A compendium of the currently accepted physical properties of Car
- [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
- [VRML gallery of chiral Nano-Tubes](#) generated with JSV1.08, © S.Weber, 1999
- [VRML gallery of Nano-Cones](#) generated with JSV1.08, © S.Weber, 1999
- [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
- [Project 26: JNanoTube](#) This applet generates the atom positions for nano-tubes and nano-cones. Stef written for Dr. Jeremy Sloan
- [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 si
- [Carbon nanotubes](#) IBM Nanoscale Science Department

- [C<sub>1,000,000</sub> 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<sub>60</sub> Molecule](#) Images from Boris Pevzner MIT
- [Fullerene Patent Database](#)
- [Hydrogen implantation into C<sub>60</sub>](#) Molecular Dynamics simulations of 10 to 50 eV hydrogen atom in room temperature fullerenes. CNLS LANL
- [Buckyball, Diamond, Graphite](#) Describes how Buckminsterfullerene was discovered, its structure and Chemistry, University of Wisconsin-Madison
- [Fullerenes](#) - a little history and description. TECHNISCHE UNIVERSITÄT DARMSTADT
- [Chemical Functionalisation of Carbon Nanotubes](#) FUNCARS is a Research Training Network funded by the Commission under the Improving Human Research Potential and the Socio-Economic Knowledge Based Programme.
- [Gallery of Molecular Artwork](#) by Keith Beardmore, with the Computational Materials Group, Motorola 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 modeler
- [Nanotubulites](#) An International Cooperative Research Project, with Gallery [including first experimental images published]
- [Sunysb](#) home page of Laszlo Mihaly's laboratory at the Physics Department in SUNY @ Stony Brook
- [CMU Buckyball Project](#)



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