Biodistribution of C60(Nanom Purple) in male Wistar rats (5 rats/time point) after tail vein administration (5 mg/kg bw/injection x 4 times) was examined using LC-MS/MS (Kubota et al.2011). C60 was detected in various tissues, such as brain, kidneys, liver, lungs, and spleen of male Wistar rats. On the other hand, no C60 was found in blood. The highest C60 concentration was observed in the lungs, followed by spleen, liver, kidneys and brain. These results suggested that C60 injected in the tail vein could be filtered by lung capillary vessels and accumulate in the lungs prior to being distributed to other tissues. Furthermore, C60 not being detected in the blood indicated that clearance of C60 from the blood by filtration might effectively occur in the lungs. The time-dependent variation in the biodistribution of C60 was evaluated. A time-dependent decrease in C60 concentrations was observed in all tissues, except spleen. Moreover, a decreasing trend of C60 levels differed among tissues, which could be due to differences in accumulation.

Figure 3. Effect of G or SWCNT on (A) mitochondrial toxicity and (B) LDH release (cell membrane damage marker) (C) Morphology change of PC12 cells: left, control; middle, G; right, SWCNT. Bar 10 m.
Figure 1. (A) Low-magnification TEM image of graphene sheets. (B) High magnification TEM image of few-layer graphene sheets overlaid side-by-side. (C) SEM image of the semitransparent graphene sheets synthesized in large quantities. (D) High-pass filtered AFM scan of graphene sheets overlaid on the Si surface. (E) AFM image of the few-layer graphene sheets, with (F) a corresponding AFM height image. (G) High-resolution TEM image of the single-wall carbon nanotubes used for this study. (H) AFM images of the nanotubes used for this study. The diameter of the nanotubes ranged from 0.8 to 1.2 nm.

Ken Donaldson is a respiratory toxicologist at the University of Edinburgh and he and his colleagues are among the first to raise the warning flag on graphene, at least for nanoscopic platelets of the material. It is not too great a leap of the imagination to imagine how such tiny flakes of carbon might be transported deep within the lungs similar to asbestos fibres and coal dust. Once lodged within, there is no likely mechanism for the removal or break down of such inert particles and they might reside on these sensitive tissues triggering a
chronic inflammatory response or interfering with the normal cellular functions.

Translocation and protein uptake influences biodistribution and toxicity

Toxicity of nanosilver -Surface effect- Nanosilver (silver nanopowder, SN; silver– copper nanopowder, SCN; and colloidal silver, CS) was found to interfere with DNA replication Wenjuan Yang et al Food storage material silver nanoparticles interfere with DNA replication fidelity and bind with DNA. 2009 Nanotechnology 20

Nanogold as contrast agent Micro-CT planar X-ray (upper images): Kidneys in live mouse 60 minutes after intravenous injection of (a) gold nanoparticles or (b) iodine contrast medium (Omnipaque H). Arrow: 100 nm ureter (Bar = 51 mm). (c) Cancer imaging: X-ray of mouse hind legs showing accumulation of gold and significant contrast (white, arrow) in tumor growing on leg on left, compared with normal contra-lateral leg. Much of gold is in vasculature, illustrating angiogenic effect of tumor. Longer residence time in blood results in a significantly higher tumor : non-tumor ratio than is possible with iodine reagents (Bar = 51 mm). (d) Micro-CT showing resolution available with gold nanoparticle contrast agents: 3 nm section of mouse abdomen after gold nanoparticle injection, showing branching of inferior vena cava and 25 µm blood vessels (bar = 1 mm)

http://www.nanoprobes.com/ImgGold.html Toxicity of pure gold nanoparticles Gold clusters (Au 55 ) have been shown to interact with DNA (see image). Armed with this knowledge, experiments have shown that such clusters are shown to have significant toxicity towards many types of human cells, both healthy and cancerous, in contrast to previously studied larger gold nanoparticles. It is hoped, therefore, that there is a future for Au 55
clusters in the treatment of certain cancers. Tsoli et al. 2005, 1, 8-9, 841–844, DOI: 10.1002/smll.200500104

**Toxicity of QD** Small size causes oxidative stress -> surface effect

**Classical toxicity of the heavy metal compounds** (Se, As, Cd etc.) -> material effect

**Cell toxicity of carbon nanotubes** Alexandra E. Porter, Mhairi Gass, Karin Muller, Jeremy N. Skepper, Paul A. Midgley and Mark Well Nature Nanotechnology advance online publication, 28 October 2007


**Toxicity of polymers or polyions** Depending of the functional groups, polycations are more cytotoxic than polyanions

Charge pattern

Interaction with the cell

**Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study**

*Nature Nanotechnology volume 3*, pages 423–428 (2008) | Download Citation

**Abstract**

Carbon nanotubes have distinctive characteristics, but their needle-like fibre shape has been compared to asbestos, raising concerns that widespread use of carbon nanotubes may lead to mesothelioma, cancer of the lining of the lungs caused by exposure to asbestos. Here we show that exposing the mesothelial lining of the body cavity of mice, as a surrogate for the mesothelial lining of the chest cavity, to long multiwalled carbon nanotubes results in asbestos-like, length-dependent, pathogenic behaviour. This includes inflammation and the formation of lesions known as granulomas. This is of considerable importance, because research and business communities continue to invest heavily in carbon nanotubes for a wide range of products under the assumption that they are no more hazardous than graphite. Our results suggest the need for further research and great caution before introducing such products into the market if long-term harm is to be avoided.
Carbon NanoTubes--will not be detected in water bodies using currently available monitoring equipment and hence will not be identified as a pollutant, were they to be present.

C60 impacts
Bioaccumulation--C60
Patras et al.11 studied on the bioaccumulation of fullerenes from MER Corp. The crustacean Thamnocephalus platyurus was exposed to aqueous suspensions of fullerenes C 60. **Aqueous fullerene suspensions were formed by stirring C 60 in deionized water (termed aqu/C60) for 100 days.** The Z-average (mean hydrodynamic) diameters of aqu/C60 aggregates as measured by DLS was 517 ± 21 nm. **Exposure of fullerene suspensions to T. platyurus resulted in the formation of dark masses in the digestive track visible under a stereo microscope (×40 magnification).** Fullerene ingestion over 1 h of exposure was quantitatively determined after extraction and analysis by high-performance liquid chromatography-mass spectrometry (HPLC-MS). The uptake of aqu/C60 between 0 and 10 minutes was rapid for both concentrations of 3 mg/L and 6 mg/L. However, after the initial uptake period, the C60 concentration per unit mass of organism did not change significantly over the remaining 1 hour time period. One-hour exposures (at 3 mg/L and 6 mg/L) resulted in aqu/C60 burdens of 2.7 ± 0.4 μg/mg and 6.8 ± 1.5 μg/mg.
Comment [i]: this is indicating that it is not coming out but accumulating in the system what is leaving and what is remaining is considerably more than what is being lead to believe.

Thin-section TEM images of aqu/C60-exposed T. platyurus showed the formation in the gut of fullerene agglomerates (5–10 μm) that were an order of magnitude larger than the suspended fullerene agglomerates. Upon excretion, the observed fullerene agglomerates were in the 10–70 μm size range and settled to the bottom of the incubation wells. In contrast to the control polystyrene microspheres, which dispersed after depuration, the aqu/C60 agglomerates remained agglomerated for up to six months. When exposed to fullerenes, T. platyurus shows the potential to influence agglomerate size and may facilitate movement of these nanoparticles from the water column into sediment.
Nano Toxicity and Translocation Effects

Purified Carbon Nano Tube

The outcome

Granuloma is a medical term for a ball-like collection of immune cells which forms when the immune system attempts to wall off substances that it perceives as foreign but is unable to eliminate.

<table>
<thead>
<tr>
<th>Dose (mg)</th>
<th>Type of lung lesion</th>
<th>Carbon black</th>
<th>RNT</th>
<th>PNT</th>
<th>CNT</th>
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<td>Inflammation</td>
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<td>Granuloma</td>
<td>0</td>
<td>0</td>
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</table>

*Mice (5/group) were each instilled with 0.1 or 0.5 μg of a test material and euthanized 90 d after the single treatment. Lungs were microscopically examined by a pathologist who had no knowledge of the treatment of each animal.

**Including 3 mice that died in the first week.

PNT: purified carbon nanotubes
RNT: raw carbon nanotubes
From HiPro™
CNT: From CarboLex, Inc. (Lexington, KY)
Translocation and protein uptake influences biodistribution and toxicity

Table 1 Chemical and physical properties of inorganic–organic hybrid nanoparticles (IoHNs) and organic nanoparticles (OnPs)

<table>
<thead>
<tr>
<th>Nanoparticle</th>
<th>Core/shell</th>
<th>Organic coating</th>
<th>In PBS</th>
<th>In serum</th>
<th>Surface charge</th>
<th>Emission max. (nm)</th>
<th>LNS (%IDg)</th>
<th>NLRg in body + other</th>
<th>Toxicity at 1 h</th>
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</table>

Rapid translocation of nanoparticles from the lung airspaces to the body

Huk Sook Choi, Yoshihito Ashitabe, Jeong Hoon Lee, Soon Hee Kim, Aya Matsui, Nampy Imnmu, Mounqi G Bawendi, Manuela Gommer-Roheke, John V Fettinger & Akira Tada

Nanoparticles in the lung

Wolfgang G Kremls, Stephanie Hirm & Carsten Schlech
Fig. 2 Principal nanocarrier internalization pathways in mammalian cells. a Phagocytosis is an actin-based mechanism occurring primarily in professional phagocytes, such as macrophages, and closely associated with opsonization. b Clathrin-mediated endocytosis is a widely shared pathway of nanoparticle internalization, associated with the formation of a clathrin lattice and depending on the GTPase dynamin. c Caveola-mediated endocytosis occurs in typical flask-shaped invaginations of the membrane coated with caveolin dimers, also depending on dynamin. d Macropinocytosis is an actin-based pathway, engulfing nanoparticles and the extracellular milieu with a poor selectivity. e Other endocytosis pathways can be involved in the nanoparticle internalization, independent of both clathrin and caveolae.

Nanoparticle Transformation

Product size distribution

Ions/complexes Nanoclusters Nanoparticles Agglomerates

Increasing Risk?

1st: Passive nanostructures (1st generation products)
   a. Dispersed and contact nanostructures. Ex: aerosols, colloids
   b. Products incorporating nanostructures. Ex: coatings; nanoparticle reinforced composites; nanostructured metals, polymers, ceramics
   ~ 2000

2nd: Active nanostructures
   a. Bio-active, health effects. Ex: targeted drugs, biodevices
   b. Physico-chemical active. Ex: 3D transistors, amplifiers, actuators, adaptive structures
   ~ 2005

3rd: Systems of nanosystems
   Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary
   ~ 2010

4th: Molecular nanosystems
   Ex: molecular devices 'by design'; atomic design, emerging functions
   ~ 2015-2020
Gold Nano particles have been shown to be toxic to DNA and healthy cells as well as other...
Quantum dots are microscopic semiconductor crystals that are made of clusters of cadmium selenide, cadmium sulfide, indium arsenide, or indium phosphide and they radiate colors when are exposed to ultraviolet light. They are typically between two to ten nanometers long in diameter. Their small size allows for the visible emission of photons as they are excited, which produces wavelengths of color that people can see. They are used to visualize and track individual molecules and their movements inside cells. They are also known as “artificial atoms” because their behavior is analogous to that of single atom.
Carbon Nanotube Multi Walled

Fig. 1: Principal types of nanocarriers for drug delivery. A: Liposomes are formed by one (or several) phospholipid bilayers surrounding an aqueous core. They can be PEGylated and decorated with targeting ligands. B: Polymeric nanoparticles are designed using biodegradable polymers or polyalkylcyanoacrylate), or natural polymers, like albumin. They can also be PEGylated and decorated with targeting ligands. C: Polymeric nanocapsules are formed by a polymer membrane (same materials as for nanoparticles) surrounding either an oily or an aqueous core. D: Polymeric micelles are formed by the assembly of amphiphilic polymers, generally exhibiting a PEG shell that can be functionalized by targeting ligands.
Cell toxicity of carbon nanotubes

Another problem:

Alexandra E. Porter, Mhairi Gess, Karin Muller, Jeremy N. Skepper, Paul A. Midgley and Mark Well. Nature Nanotechnology advance online publication, 26 October 2007
Radio, made out of a single carbon nanotube about 10,000 times thinner than a human hair, runs on batteries and requires headphones.

University of California at Berkeley's nanoradio might be a 100 billion times smaller than the first commercial radios, but it plays the hits that never die.

Alex Zettl, a professor of physics at the university, has made a radio out of a single carbon nanotube that's about 10,000 times thinner than a human hair. It runs on batteries and you need headphones to use it, but it tunes in stations on the FM dial. Zettl and his team last year received their first FM broadcast, which turned out to be "Layla" from Derek and the Dominoes. They also caught "Good Vibrations." In homage to the 100th anniversary of the first voice and music transmission, they transmitted (and tuned in to) a recording
of "Largo," from the Handel opera Xerxes. It was the first successful radio transmission of music in 1906. The \textit{nanotube serves as the antenna, tuner, amplifier, and demodulator in the radio}. In an ordinary radio, these are all separate components. The nanotube vibrates thousands to millions of times per second in tune with the radio wave. Carbon nanotubes are the miracle material of the chemistry world. Stronger than steel yet very light, nanotubes can also transmit electricity faster than metals as well as emit light. Scientists speculate that nanotubes one day could be incorporated into silicon chips, power lines, medicines, bridges, and aircraft parts. Nanotubes are essentially cylinders made completely from carbon atoms; the incredibly strong bonds that can be formed between carbon atoms are what give nanotubes their unusual properties. Right now, though, nanotubes are mostly used to make things like tennis rackets and car panels stronger without adding weight. \textit{The nanotube radio may lead to radical new applications, such as radio-controlled devices small enough to exist in a human’s bloodstream}," wrote Zettl and his team in a paper that was released online Wednesday and will be published November 6 in \textit{Nano Letters}.

\begin{quote}
The nanoradio could also be used to measure the mass of atoms.
\end{quote}

\textbf{Organic crystals twist, bend, and heal}

\begin{quote}
Thermally twistable, photobendable, elastically deformable, and self-healable soft crystal gives a multifunctional, all-in-one material
\end{quote}

Crystals are brittle and inelastic? A novel class of \textit{smart, bendable crystalline organic materials has challenged this view}. Now, scientists have engineered a molecular soft cocrystalline structure that bends and twists reversibly and without disintegration when stimulated by high temperature, mechanical force, or under UV light. This multifunctional quality makes it a robust candidate for advanced molecular electronics and other new materials, as the authors reported in the journal \textit{Angewandte Chemie}.

\begin{quote}
Crystal structures can be quite elastic. This notion has emerged only recently, after the first dynamic and adaptive molecular crystals were reported ten years ago. \textit{Crystals that can bend without disintegration are attractive materials in microrobotics, flexible electronics, and optical devices}. Now, a team of scientists led by Naba Kamal Nath at the National Institute of Technology, Meghalaya, India, and Panče Naumov at New York University, Abu Dhabi, United Arab Emirates \textit{have pushed the boundaries of single crystals a bit further}. They developed a molecular soft crystal that twists and untwists upon heating and cooling, bends reversibly under UV light, and deforms and reforms
\end{quote}
responding to mechanical force. Moreover, cracks in the crystals heal themselves over thermal cycling, the scientists noted. The crystallinity of molecular organic crystals arises from the packing of the molecule layers. These layers are held in place by intermolecular interactions such as hydrogen bonding, hydrophobic interaction, or interactions between aromatic rings. The crystals Naumov and Nath prepared contained two different molecules, probenecid, a drug compound prescribed to enhance uric acid excretion, and 4,4’-azopyridine, a heteroaromatic azo compound that is known to change from an elongated to a more bent conformation when irradiated by UV light. The single crystals formed from these two molecules consist of stacked 2D layers in crisscross arrangement. Heating, so the authors found, caused a phase change in this structure, a slight rearrangement leading to different packing angles. The long, thin crystal fibrous sheet twisted. But not for ever. Cooling brought back its original molecular order, and the sheet straightened again. In addition, mechanical bending was possible without cracking, and irradiation with UV light caused rapid, reversible bending. Not only had the material combined three functionalities -- reversible twisting upon heating, elastic bending induced by mechanical force, and rapid, reversible bending under UV light -- but it also healed itself: The authors reported that splits and small cracks disappeared when the crystal was cycled between room temperature and elevated temperatures. These effects amount to a remarkable multifunctionality of the organic crystal. It is thus recommended as a valuable candidate for next-generation solid-state semiconductors, flexible electronics, and other technologies where a combination of apparently contradictory mechanical properties is desired.-Story Source-Journal Reference-Poonam Gupta, Durga Prasad Karothu, Ejaz Ahmed, Panče Naumov, Naba K. Nath. Thermally Twistable, Photobendable, Elastically Deformable, and Self-Healable Soft Crystals. Angewandte Chemie International Edition, 2018; DOI: 10.1002/anie.201802785-Wiley. "Organic crystals twist, bend, and heal: Thermally twistable, photobendable, elastically deformable, and self-healable soft crystal gives a multifunctional, all-in-one material." ScienceDaily. ScienceDaily, 18 June 2018. <www.sciencedaily.com/releases/2018/06/180618141844.htm>.

C₆₀ impacts
Bioaccumulation--C₆₀
Patras et al. studied on the bioaccumulation of fullerenes from MER Corp. The crustacean Thamnocephalus platyurus was exposed to aqueous suspensions of fullerenes C₆₀. Aqueous fullerene suspensions were formed by stirring C₆₀ in deionized water (termed aqu/C₆₀) for 100 days. The Z-average (mean hydrodynamic) diameters of aqu/C₆₀ aggregates as measured by DLS was 517 ± 21 nm. Exposure of fullerene suspensions to T. platyurus resulted in the formation of dark masses in the digestive track visible under a stereo microscope (×40 magnification). Fullerene ingestion over 1 h of exposure was quantitatively determined after extraction and analysis by high-performance liquid
chromatography-mass spectrometry (HPLC-MS). The uptake of aqu/C$_{60}$ between 0 and 10 minutes was rapid for both concentrations of 3 mg/L and 6 mg/L. However, after the initial uptake period, the C$_{60}$ concentration per unit mass of organism did not change significantly over the remaining 1 hour time period. One-hour exposures (at 3 mg/L and 6 mg/L) resulted in aqu/C$_{60}$ burdens of 2.7 ± 0.4 μg/mg and 6.8 ± 1.5 μg/mg wet weight, respectively. Thin-section TEM images of aqu/C$_{60}$-exposed T. platyurus showed the formation in the gut of fullerene agglomerates (5 – 10 μm) that were an order of magnitude larger than the suspended fullerene agglomerates. Upon excretion, the observed fullerene agglomerates were in the 10 – 70 μm size range and settled to the bottom of the incubation wells. In contrast to the control polystyrene microspheres, which dispersed after depuration, the aqu/C$_{60}$ agglomerates (greater than two orders of magnitude larger than the suspended fullerenes) remained agglomerated for up to six months. When exposed to fullerenes, T. platyurus shows the potential to influence agglomerate size and may facilitate movement of these nanoparticles from the water column into sediment.

**Synthetic 'tissues' build themselves**

**Biologists program cells to self-organize into 3D-structures in a first step towards tissues that regrow and self-repair**

How do complex biological structures -- an eye, a hand, a brain -- emerge from a single fertilized egg? This is the fundamental question of developmental biology, and a mystery still being grappled with by scientists who hope to one day apply the same principles to heal damaged tissues or regrow ailing organs.

Now, in a study published May 31, 2018 in *Science*, researchers have demonstrated the ability to program groups of individual cells to self-organize into multi-layered structures reminiscent of simple organisms or the first stages of embryonic development. "What is amazing about biology is that DNA allows all the instructions required to build an elephant to be packed within a tiny embryo," said study senior author Wendell Lim, PhD, chair and Byers Distinguished Professor in the Department of Cellular and Molecular Pharmacology at UCSF, director of the NIH-funded Center for Systems and Synthetic Biology, and co-director of the National Science
Foundation-funded Center for Cellular Construction. "DNA encodes an algorithm for growing the organism -- a series of instructions that unfolds in time in a way we still don't really understand. It's easy to get overwhelmed by the complexity of natural systems, so here we set out to understand the minimal set of rules for programming cells to self-assemble into multicellular structures." A critical part of development is that, as biological structures form, cells communicate with one another and make coordinated, collective decisions about how to structurally organize themselves. To mimic this process, the new research -- led by UCSF postdoctoral researcher Satoshi Toda, PhD, in Lim's lab -- relied on a powerfully customizable synthetic signaling molecule called synNotch (for "synthetic Notch receptor") recently developed in Lim's lab, which allowed the researchers to program cells to respond to specific cell-cell communication signals with bespoke genetic programs. For example, using synNotch, the researchers engineered cells to respond to specific signals from neighboring cells by producing Velcro-like adhesion molecules called cadherins as well as fluorescent marker proteins. Remarkably, just a few simple forms of collective cell communication were sufficient to cause ensembles of cells to change color and self-organize into multi-layered structures akin to simple organisms or developing tissues. These evolutions represent a field to interact with other cells or other synthetic structure.

Comment [i]: Pay attention here this is synthetic biology forming using DNA as the conductor and the syn notch as the program and director here--the means to weaponized this is infinitive~ this makes using all forms of current tech that is nuclear totally obsolete.

Comment [i]: Polarity in other words governing not only signals but a field to interact with other cells or other synthetic structure.

Comment [i]: Synthetic life evolutions.
in half with a micro-guillotine developed by co-authors Lucas R. Blauch and Sindy Tang, PhD, of Stanford University, the remaining cells quickly re-formed and reorganized themselves according to their intrinsic program. SynNotch was originally developed in the Lim lab by co-author Kole Roybal, PhD, now an assistant professor of microbiology and immunology at UCSF, and Leonardo Morsut, PhD, now an assistant professor of stem cell biology and regenerative medicine at the University of Southern California and co-corresponding author on the new paper. In the future, Lim imagines programming ever more complex tissue-like cellular structures through multiple layers of synNotch signaling. For example, activation of one synNotch receptor by cell-cell contact or chemical signaling could trigger cells to produce additional distinct synNotch receptors, leading to a cascade of engineered signaling steps. In this way, Lim envisions programming the self-organization of the elaborate structures that would eventually be needed for growing tissues for wound repair or transplant.

"People talk about 3D-printing organs, but that is really quite different from how biology builds tissues. Imagine if you had to build a human by meticulously placing every cell just where it needs to be and gluing it in place," said Lim, who is a Howard Hughes Medical Institute investigator and member of the UCSF Helen Diller Family Comprehensive Cancer Center. "It's equally hard to imagine how you would print a complete organ, then make sure it was hooked up properly to the bloodstream and the rest of the body. The beauty of self-organizing systems is that they are autonomous and compactly encoded. You put in one or a few cells, and they grow and organize, taking care of the microscopic details themselves." Lim says he hopes his lab's work will help guide scientists towards being able to program stem cells to repair damaged tissue, or even build new organs that grow with the right connections to the rest of the body. "Wouldn't it be great," Lim said, "if we could grow a new organ directly in the body so that it specifically grows connected to the right places, where it's supposed to be?" Materials provided by University of California - San Francisco. Original written by Nicholas Weiler - Journal Reference - Satoshi Toda, Lucas R. Blauch, Sindy K. Y. Tang, Leonardo Morsut, Wendell A. Lim. Programming self-organizing multicellular structures with synthetic cell-cell signaling. Science, 2018; eaat0271 DOI: 10.1126/science.aat0271 University of California - San Francisco. "Synthetic 'tissues' build themselves: Biologists program cells to self-organize into 3D-structures in a first step towards tissues that regrow and self-repair." ScienceDaily. ScienceDaily, 31 May 2018. <www.sciencedaily.com/releases/2018/05/180531143006.htm>.

Immune cells don't always ward off carbon nano invaders

Scientists at the University of Michigan have found evidence that some carbon nanomaterials can enter into immune cell membranes, seemingly going undetected by the cell's built-in mechanisms for engulfing and disposing of foreign material, and then escape through
some unidentified pathway.-- The researchers from the School of Public Health and College of Engineering say their findings of a more passive entry of the materials into cells is the first research to show that the normal process of endocytosis-phagocytosis isn't always activated when cells are confronted with tiny Carbon 60 (C60) molecules. Their research is reported in the current issue of Nanoscale. Nanomaterials are small accumulations of atoms, usually measuring from 1-100 nanometers. As reference, a human hair is about 75,000 nanometers wide. This study examined nanomaterials known as carbon fullerenes, in this case C60, which has a distinct spherical shape. Over the last decade, scientists have found these carbon-based materials useful in a number of commercial products, including drugs, medical devices, cosmetics, lubricants, antimicrobial agents and more. Fullerenes also are produced in nature through events like volcanic eruptions and wildfires. The concern is that however exposed, commercially or naturally, little is known about how inhaling these materials impacts health. "It's entirely possible that even tiny amounts of some nanomaterials could cause altered cellular signaling," said Martin Philbert, dean and professor of toxicology at the U-M School of Public Health. Philbert said much of the previously published research bombarded cells with large amounts of particle clusters, unlike a normal environmental exposure. The U-M researchers examined various mechanisms of cell entry through a combination of classical biological, biophysical and newer computational techniques, using models developed by a team led by Angela Violi to determine how C60 molecules find their way into living immune cells of mice. They found that the C60 particles in low concentrations were entering the membrane individually, without perturbing the structure of the cell enough to trigger its normal response. "Computational modeling of C60 interacting with lipid bilayers, representative of the cellular membrane, show that particles readily diffuse into biological membranes and find a thermodynamically stable equilibrium in an eccentric position within the bilayer," said Violi, U-M professor of mechanical engineering, chemical engineering, biomedical engineering, and macromolecular science and engineering. "The surprising contribution of passive modes of cellular entry provides new avenues for toxicological research, as we still don't know exactly what are the mechanisms that cause this crossing."--Story Source--The above post is reprinted from materials provided by University of Michigan. --Journal Reference--K. A. Russ, P. Elvati, T. L. Parsonage, A. Dews, J. A. Jarvis, M. Ray, B. Schneider, P. J. S. Smith, P. T. F. Williamson, A. Violi, M. A. Philbert. C60fullerene localization and membrane interactions in RAW 264.7 immortalized mouse macrophages. Nanoscale, 2016; 8 (7): 4134 DOI: 10.1039/C5NR07003A --University of Michigan. "Immune cells don't always

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Why carbon nanotubes spell trouble for cells

It's been long known that asbestos spells trouble for human cells. Scientists have seen cells stabbed with spiky, long asbestos fibers, and the image is gory: Part of the fiber is protruding from the cell, like a quivering arrow that's found its mark. -- But scientists had been unable to understand why cells would be interested in asbestos fibers and other materials at the nanoscale that are too long to be fully ingested. Now a group of researchers at Brown University explains what happens. Through molecular simulations and experiments, the team reports in Nature Nanotechnology that certain nanomaterials, such as carbon nanotubes, enter cells tip-first and almost always at a 90-degree angle. The orientation ends up fooling the cell; by taking in the rounded tip first, the cell mistakes the particle for a sphere, rather than a long cylinder. By the time the cell realizes the material is too long to be fully ingested, it's too late. "The research is important because nanomaterials like carbon nanotubes have promise in Biotech, such as acting as vehicles to transport nanobio( synthetic biology) to specific cells or to specific locations in the human body. If scientists can fully understand how nanomaterials interact with cells, then they can conceivably design products that help cells rather than harm them. "If we can fully understand (nanomaterial-cell dynamics), we can make other tubes that can control how cells interact with nanomaterials and not be toxic," Gao said. "We ultimately want to stop the attraction between the nanotip and the cell. Like asbestos fibers, commercially available carbon nanotubes and gold nanowires have rounded tips that often range from 10 to 100 nanometers in diameter. Size is important here; the diameter fits well within the cell's parameters for what it can handle. Brushing up against the nanotube, special proteins called receptors on the cell spring into action, clustering and bending the membrane wall to wrap the cell around the nanotube tip in a sequence that the authors call "tip recognition." As this occurs, the nanotube is tipped to a 90-degree angle, which reduces the amount of energy needed for the cell to engulf the particle. Once the engulfing -- endocytosis -- begins, there is no turning back. Within minutes, the cell senses it can't fully engulf the nanostructure and essentially dials 911. "At this stage, it's too late," Gao said. "It's in trouble and calls for help, triggering an immune response that can cause repeated inflammation." The team hypothesized the interaction using coarse-grained molecular dynamic simulations and capped multiwalled carbon nanotubes. In experiments involving nanotubes and gold nanowires and mouse liver cells and human mesothelial cells, the nanomaterials entered the cells tip-first and at a 90-degree angle about 90 percent of the time, the researchers report. "We thought the tube was going to lie on the cell membrane to obtain more binding
Endocytosis is a form of bulk transport in which a cell transports molecules (such as proteins) into the cell (endo- + cytosis) by engulfing them in an energy-using process. Endocytosis and its counterpart, exocytosis, are used by all cells because most chemical substances important to them are large polar molecules that cannot pass through the hydrophobic plasma or cell membrane by passive means.

Researchers clarify cellular uptake mechanisms for carbon nanotubes

November 30, 2005

They look like the tiniest of needles and have the potential to channel pharmaceutical agents into targeted living cells: carbon nanotubes are long, thin nanoscale tubes made of one (or more) layers of carbon atoms in a graphite-like arrangement. Drugs can be hooked on to their exteriors and can thus be carried into the cell along with the nanotube. But how? Hongjie Dai and his team at Stanford University have systematically examined the cellular uptake mechanism for nanotubes with various biological cargos including DNA and proteins. In order to develop tailored nano-transporters that duly deliver their cargo, it is important to know which route they take through the cell membrane. Molecules can get into the interior of a cell by various means. First, the researchers needed to determine if this is a case of active or passive transport. The passive transport mechanisms do not consume energy; molecules just pass the membrane. Regarding active mechanisms, nanotubes might enter the cell by so-called endocytosis: Parts of the cell membrane include the molecules and migrate into
the interior. This requires energy in the form of ATP and sufficiently high temperatures. Dai and his colleagues cooled some cell cultures and reacted others with an inhibitor that stops ATP production. In both cases the cells were no longer able to absorb nanotubes. “We conclude that this is an energy-dependent endocytosis mechanism,” says Dai. For the nanotubes, among the different types of endocytosis pathways the researchers thought two mechanisms in particular seemed likely: caveolae-mediated and clathrin-dependent endocytosis. -Caveolae are little indentations made of lipids in the cell membrane. Molecules from the medium enter the indentation, which then closes itself off into a bubble that migrates into the cell interior. By means of inhibitors, the researchers disrupted the lipid distribution in the cell membrane, thus disrupting the caveolae—this did not prevent intake of the nanotubes. The clathrin-dependent mechanism involves the docking of molecules from the medium at special docking stations on the exterior of the membrane. Tripod-shaped protein molecules, clathrin, are bound to the docking site inside the membrane. The clathrin molecules aggregate into a two-dimensional network that forms an arch that results in a cavity in the membrane. This again results in a bubble that closes itself off and wanders into the interior of the cell. Sugar-containing or potassium-free media destroy clathrin sheets. The cell cultures were thus placed under these conditions and were no longer able to absorb the nanotubes. Says Dai, “This clearly indicates clathrin-dependent endocytosis for carbon nanotubes used in our work.” This result contradicts the results of another group who propose a non-endocytotic mechanism. The reasons for the discrepancy have yet to be determined.

Graphene becomes superconductive- Electrons with 'no mass' flow with 'no resistance'

Graphene is a single-atomic carbon sheet with a hexagonal honeycomb network. Electrons in graphene take a special electronic state called Dirac-cone where they behave as if they have no mass. This allows them to flow at very high speed, giving graphene a very high level of electrical conductivity. This is significant because electrons with no mass flowing with no resistance in graphene could lead to the realization of an ultimately high-speed nano electronic device. The collaborative team of Tohoku University and the University of Tokyo has developed a method to grow high-quality graphene on a silicon carbide (SiC) crystal by controlling the number of graphene sheets. The team fabricated bilayer graphene with this method and then inserted calcium (Ca) atoms between the two graphene layers like a sandwich. They...
measured the electrical conductivity with the micro four-point probe method and found that the electrical resistivity rapidly drops at around 4 K (-269 °C), indicative of an emergence of superconductivity. The team also found that neither genuine bilayer graphene nor lithium-intercalated bilayer graphene shows superconductivity, indicating that the superconductivity is driven by the electron transfer from Ca atoms to graphene sheets. The success in fabricating superconducting graphene is expected to greatly impact both the basic and applied researches of graphene.

It is currently not clear what phenomenon takes place when the Dirac electrons with no mass become superconductive with no resistance.

But based on the latest study results, further experimental and theoretical investigations would help to unravel the properties of superconducting graphene. The superconducting transition temperature (Tc) observed in this study on Ca-intercalated bilayer graphene is still low (4 K). This prompts further studies into ways to increase Tc, for example, by replacing Ca with other metals and alloys, or changing the number of graphene sheets. From the application point of view, the latest results pave the way for the further development of ultrahigh-speed superconducting nano devices such as a quantum computing device, which utilizes superconducting graphene in its integrated circuit.

**Story Source**-The above post is reprinted from materials provided by Tohoku University.


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**Carbon Nanotube**---Equilibrium Structure

Much research has been devoted to the study of the equilibrium structure of carbon nanotubes. Currently, some information is still begin disputed, but I have compiled recent data on the most basic and necessary aspects of single-walled carbon nanotubes (SWNT).

**Basic Structure:**

Simply put, carbon nanotubes exist as a macro-molecule of carbon, analogous to a sheet of graphite (the pure, brittle form of carbon in your pencil lead) rolled into a cylinder. Graphite looks like a sheet of chicken wire—a tessellation of hexagonal rings of carbon. Sheets of graphite in your pencil lay stacked on top on one another, but they slide past each other and can be separated easily, which is how it is used for writing. However, when coiled, the carbon arrangement becomes very strong. In fact, nanotubes have been known to be up to one hundred times as strong as steel and almost two millimeters long! These nanotubes have a hemispherical "cap" at each end of the cylinder. They are light, flexible, thermally...
stable, and are chemically inert. They have the ability to be either metallic or semi-conducting depending on the "twist" of the tube.

Types of SWNTs

Nanotubes form different types, which can be described by the chiral vector \((n, m)\), where \(n\) and \(m\) are integers of the vector equation \(R = na_1 + ma_2\). The chiral vector is determined by the diagram at the left. Imagine that the nanotube is unraveled into a planar sheet. Draw two lines (the blue lines) along the tube axis where the separation takes place. In other words, if you cut along the two blue lines and then match their ends together in a cylinder, you get the nanotube that you started with. Now, find any point on one of the blue lines that intersects one of the carbon atoms (point A). Next, draw the Armchair line (the thin yellow line), which travels across each hexagon, separating them into two equal halves. Now that you have the armchair line drawn, find a point along the other tube axis that intersects a carbon atom nearest to the Armchair line (point B). Now connect A and B with our chiral vector, \(R\) (red arrow). The wrapping angle \(\theta\) (not shown) is formed between \(R\) and the Armchair line. If \(R\) lies along the Armchair line (\(\theta = 0^\circ\)), then it is called an "Armchair" nanotube. If \(\theta = 30^\circ\), then the tube is of the "zigzag" type. Otherwise, if \(0^\circ < \theta < 30^\circ\) then it is a "chiral" tube. The vector \(a_1\) lies along the "zigzag" line. The other vector \(a_2\) has a different magnitude than \(a_1\), but its direction is a reflection of \(a_1\) over the Armchair line. When added together, they equal the chiral vector \(R\). [Adapted from 23]

The values of \(n\) and \(m\) determine the chirality, or "twist" of the nanotube. The chirality in turn affects the conductance of the nanotube, its density, its lattice structure, and other properties. A SWNT is considered metallic if the value \(n - m\) is divisible by three. Otherwise, the nanotube is semiconducting. Consequently, when tubes are formed with random values of \(n\) and \(m\), we would expect that two-thirds of nanotubes would be semi-conducting, while the other third would be metallic, which happens to be the case. [23]

Given the chiral vector \((n,m)\), the diameter of a carbon nanotube can be determined using the relationship

\[
d = (n^2 + m^2 + nm)^{1/2} \times 0.0783 \text{ nm}
\]

Detailed Structure

The average diameter of a SWNT is 1.2 nm. [1] However, nanotubes can vary in size, and they aren’t always perfectly cylindrical. The larger nanotubes, such as a \((20, 20)\) tube, tend to bend under their own weight. [12] The diagram at right shows the average bond length and carbon separation values for the hexagonal lattice. The carbon bond length of 1.42 \(\tilde{\sigma}\) was measured by Spires and Brown in 1996 [1] and later confirmed by Wilder et al. in 1998. [23] The C-C tight
bonding overlap energy is in the order of 2.5 eV. Wilder et al. estimated it to be between 2.6 eV - 2.8 eV [23] while at the same time, Odom et al. estimated it to be 2.45 eV [24]. A (10, 10) Armchair tube was found to have C5v symmetry [2] which has the following character table:

![Character Table Image]

**Electrical Conductivity**

**CNTs can be highly conducting, and hence can be said to be metallic.** Their conductivity has been shown to be a function of their chirality, the degree of twist as well as their diameter. **CNTs can be either metallic or semi-conducting in their electrical behavior.** Conductivity in MWNTs is quite complex. Some types of “armchair”-structured CNTs appear to conduct better than other metallic CNTs. Furthermore, interwall reactions within multi walled nanotubes have been found to redistribute the current over individual tubes non-uniformly. However, there is no change in current across different parts of metallic single-walled nanotubes. **The behavior of the ropes of semi-conducting single walled nanotubes is different, in that the transport current changes abruptly at various positions on the CNTs.** The conductivity and resistivity of ropes of single walled nanotubes has been measured by placing electrodes at different parts of the CNTs. The resistivity of the single walled nanotubes ropes was of the order of 10–4 ohm-cm at 27°C. This means that single walled nanotube ropes are the most conductive carbon fibers known. The current density that was possible to achieve was 10-7 A/cm2, however in theory the single walled nanotube ropes should be able to sustain much higher stable current densities, as high as 10-13 A/cm2. It has been reported that individual single walled nanotubes may contain defects. Fortuitously, these defects allow the single walled nanotubes to act as transistors. **Likewise, joining CNTs together may form transistor-like devices.** A nanotube with a natural junction (where a straight metallic section is joined to a chiral semiconducting section) behaves as a rectifying diode – that is, a half-transistor in a single molecule. It has also recently been reported that single walled nanotubes can route electrical signals at speeds up to 10 GHz when used as interconnects on semi-conducting devices.

**Strength and Elasticity**
The carbon atoms of a single sheet of graphite form a planar honeycomb lattice, in which each atom is connected via a strong chemical bond to three neighboring atoms. Because of these strong bonds, the basal plane elastic modulus of graphite is one of the largest of any known material. For this reason, CNTs are expected to be the ultimate high-strength fibers. Single walled nanotubes are stiffer than steel, and are very resistant to damage from physical forces. Pressing on the tip of a nanotube will cause it to bend, but without damage to the tip. When the force is removed, the nanotube returns to its original state. This property makes CNTs very useful as probe tips for very high-resolution scanning probe microscopy. Quantifying these effects has been rather difficult, and an exact numerical value has not been agreed upon. Using atomic force microscopy, the unanchored ends of a freestanding nanotube can be pushed out of their equilibrium position, and the force required to push the nanotube can be measured. The current Young’s modulus value of single walled nanotubes is about 1 TeraPascal, but this value has been widely disputed, and a value as high as 1.8 TPa has been reported. Other values significantly higher than that have also been reported. The differences probably arise through different experimental measurement techniques. Others have shown theoretically that the Young’s modulus depends on the size and chirality of the single walled nanotubes, ranging from 1.22 TPa to 1.26 TPa. They have calculated a value of 1.09 TPa for a generic nanotube. However, when working with different multi walled nanotubes, others have noted that the modulus measurements of multi walled nanotubes using AFM techniques do not strongly depend on the diameter. Instead, they argue that the modulus of the multi walled nanotubes correlates to the amount of disorder in the nanotube walls. Not surprisingly, when multi walled nanotubes break, the outermost layers break first.

Thermal Conductivity and Expansion

CNTs have been shown to exhibit superconductivity below 20°K (approximately -253°C). Research suggests that these exotic strands, already heralded for their unparalleled strength and unique ability to adopt the electrical properties of either semiconductors or perfect metals, may someday also find applications as miniature heat conduits in a host of devices and materials. The strong in-plane graphitic carbon-carbon bonds make them exceptionally strong and stiff against axial strains. The almost zero in-plane thermal expansion but large inter-plane expansion of single walled nanotubes implies strong in-plane coupling and high flexibility against non-axial strains. Many applications of CNTs, such as in nanoscale molecular electronics, sensing and actuating devices, or as reinforcing additive fibers in functional composite materials, have been proposed. Reports of several recent experiments on the preparation and mechanical characterization of CNT-polymer composites have also appeared. These measurements suggest modest enhancements in strength characteristics of CNT-embedded matrixes as compared to bare polymer matrixes. Preliminary experiments and...
Simulation studies on the thermal properties of CNTs show very high thermal conductivity. It is expected, therefore, that nanotube reinforcements in polymeric materials may also significantly improve the thermal and thermomechanical properties of the composites.

Field Emission

Field emission results from the tunneling of electrons from a metal tip into vacuum, under application of a strong electric field. The small diameter and high aspect ratio of CNTs is very favorable for field emission. Even for moderate voltages, a strong electric field develops at the free end of supported CNTs because of their sharpness. This was observed by de Heer and co-workers at EPFL in 1995. He also immediately realized that these field emitters must be superior to conventional electron sources and might find their way into all kind of applications, most importantly flat-panel displays. It is remarkable that after only five years Samsung actually realized a very bright color display, which will be shortly commercialized using this technology. Studying the field emission properties of multi walled nanotubes, Bonard and co-workers at EPFL observed that together with electrons, light is emitted as well. This luminescence is induced by the electron field emission, since it is not detected without applied potential. This light emission occurs in the visible part of the spectrum, and can sometimes be seen with the naked eye.

High Aspect Ratio

CNTs represent a very small, high aspect ratio conductive additive for plastics of all types. Their high aspect ratio means that a lower loading of CNTs is needed compared to other conductive additives to achieve the same electrical conductivity. This low loading preserves more of the polymer resins’ toughness, especially at low temperatures, as well as maintaining other key performance properties of the matrix resin. CNTs have proven to be an excellent additive to impart electrical conductivity in plastics. Their high aspect ratio, about 1000:1 imparts electrical conductivity at lower loadings, compared to conventional additive materials such as carbon black, chopped carbon fiber, or stainless steel fiber.

Highly Absorbent

The large surface area and high absorbency of CNTs make them ideal candidates for use in air, gas, and water filtration. A lot of research is being done in replacing activated charcoal with CNTs in certain ultra high purity applications. In certain ultra high purity applications. The special nature of carbon combined with the molecular perfection of single-walled nanotubes to endow them with exceptional material properties, such as very high electrical and thermal conductivity, strength, stiffness, and toughness. No other element in the
periodic table bonds to itself in an extended network with the strength of the carbon-carbon bond. The delocalized pi-electron donated by each atom is free to move about the entire structure, rather than remain with its donor atom, giving rise to the first known molecule with metallic-type electrical conductivity. Furthermore, the high-frequency carbon-carbon bonds vibrations provide an intrinsic thermal conductivity higher than even diamond. In most conventional materials, however, the actual observed material properties - strength, electrical conductivity, etc. - are degraded very substantially by the occurrence of defects in their structure. For example, high-strength steel typically fails at only about 1% of its theoretical breaking strength. CNTs, however, achieve values very close to their theoretical limits because of their molecular perfection of structure. This aspect is part of the unique story of CNTs. CNTs are an example of true nanotechnology: they are under 100 nanometers in diameter, but are molecules that can be manipulated chemically and physically in very useful ways. They open an incredible range of applications in materials science, electronics, chemical processing, energy management, and many other fields. CNTs have extraordinary electrical conductivity, heat conductivity, and mechanical properties. They are probably the best electron field-emitter possible. They are polymers of pure carbon and can be reacted and manipulated using the well-known and the tremendously rich chemistry of carbon. This provides opportunity to modify their structure, and to optimize their solubility and dispersion. Very significantly, CNTs are molecularly perfect, which means that they are normally free of property-degrading flaws in the nanotube structure. Their material properties can therefore approach closely the very high levels intrinsic to them. These extraordinary characteristics give CNTs potential in numerous applications.

Energy Storage

CNTs have the intrinsic characteristics desired in material used as electrodes in batteries and capacitors, two technologies of rapidly increasing importance. CNTs have a tremendously high surface area, good electrical conductivity, and very importantly, their linear geometry makes their surface highly accessible to the electrolyte. Research has shown that CNTs have the highest reversible capacity of any carbon material for use in lithium ion batteries. In addition, CNTs are outstanding materials for super capacitor electrodes and are now being marketed for this application. CNTs also have applications in a variety of fuel cell components. They have a number of properties, including high surface area and thermal conductivity, which make them useful as electrode catalyst supports in PEM fuel cells. Because of their high electrical conductivity, they may also be used in gas diffusion layers, as well as current collectors. CNTs' high strength and toughness-to-weight characteristics may also prove valuable as part of composite components in fuel
cells that are deployed in transport applications, where durability is extremely important.

**Conductive Adhesives and Connectors**

The same properties that make CNTs attractive as conductive fillers for use in electromagnetic shielding, ESD materials, etc., make them attractive for electronics packaging and interconnection applications, such as adhesives, potting compounds, coaxial cables, and other types of connectors.

**Molecular Electronics**

The idea of building electronic circuits out of the essential building blocks of materials - molecules - has seen a revival the past few years, and is a key component of nanotechnology. In any electronic circuit, but particularly as dimensions shrink to the nanoscale, the interconnections between switches and other active devices become increasingly important. Their geometry, electrical conductivity, and ability to be precisely derived, make CNTs the ideal candidates for the connections in molecular electronics. In addition, they have been demonstrated as switches themselves.

**Thermal Materials**

The record-setting anisotropic thermal conductivity of CNTs is enabling many applications where heat needs to move from one place to another. Such an application is found in electronics, particularly heat sinks for chips used in advanced computing, where uncooled chips now routinely reach over 100°C. The technology for creating aligned structures and ribbons of CNTs [D.Walters, et al., *Chem. Phys. Lett.* 338, 14 (2001)] is a step toward realizing incredibly efficient heat conduits. In addition, composites with CNTs have been shown to dramatically increase their bulk thermal conductivity, even at very small loadings.

**Structural Composites**

The superior properties of CNTs are not limited to electrical and thermal conductivities, but also include mechanical properties, such as stiffness, toughness, and strength. These properties lead to a wealth of applications.
exploiting them, including advanced composites requiring high values of one or more of these properties.

Fibers and Fabrics

Fibers spun of pure CNTs have recently been demonstrated and are undergoing rapid development, along with CNT composite fibers. Such super-strong fibers will have many applications including body and vehicle armor, transmission line cables, woven fabrics and textiles.

Catalyst Support

CNTs intrinsically have an enormously high surface area; in fact, for single walled nanotubes every atom is not just on one surface - each atom is on two surfaces, the inside and the outside of the nanotube! Combined with the ability to attach essentially any chemical species to their sidewalls this provides an opportunity for unique catalyst supports. Their electrical conductivity may also be exploited in the search for new catalysts and catalytic behavior.

CNT Ceramics

A ceramic material reinforced with carbon nanotubes has been made by materials scientists at UC Davis. The new material is far tougher than conventional ceramics, conducts electricity and can both conduct heat and act as a thermal barrier, depending on the orientation of the nanotubes. Ceramic materials are very hard and resistant to heat and chemical attack, making them useful for applications such as coating turbine blades, but they are also very brittle. The researchers mixed powdered alumina (aluminum oxide) with 5 to 10 percent carbon nanotubes and a further 5 percent finely milled niobium. The researchers treated the mixture with an electrical pulse in a process called spark-plasma sintering. This process consolidates ceramic powders more quickly and at lower temperatures than conventional processes. The new material has up to five times the fracture toughness -- resistance to cracking under stress -- of conventional alumina. The material shows electrical conductivity seven times that of previous ceramics made with nanotubes. It also has interesting thermal properties, conducting heat in one direction, along the alignment of the nanotubes, but reflecting heat at right angles to the nanotubes, making it an attractive material for thermal barrier coatings.

Biomedical Applications

The exploration of CNTs in biomedical applications is just underway, but has significant potential. Since a large part of the human body consists of carbon, it is generally thought of as a very biocompatible material. Cells have been shown...
to grow on CNTs, so they appear to have no toxic effect. The cells also do not adhere to the CNTs, potentially giving rise to applications such as coatings for prosthetics and surgical implants. The ability to functionalize the sidewalls of CNTs also leads to biomedical applications such as vascular stents, and neuron growth and regeneration. It has also been shown that a single strand of DNA can be bonded to a nanotube, which can then be successfully inserted into a cell; this has potential applications in gene therapy.

Air, Water and Gas Filtration

Many researchers and corporations have already developed CNT based air and water filtration devices. It has been reported that these filters can not only block the smallest particles but also kill most bacteria. This is another area where CNTs have already been commercialized and products are on the market now. Someday CNTs may be used to filter other liquids such as fuels and lubricants as well. A lot of research is being done in the development of CNT based air and gas filtration. Filtration has been shown to be another area where it is cost effective to use CNTs already. The research I’ve seen suggests that 1 gram of MWNTs can be dispersed onto 1 sq ft of filter media. Manufacturers can get their cost down to 35 cents per gram of purified MWNTs when purchasing ton quantities.

Other Applications

Some commercial products on the market today utilizing CNTs include stain resistant textiles, CNT reinforced tennis rackets and baseball bats. Companies like Kraft foods are heavily funding cnt based plastic packaging. Food
will stay fresh longer if the packaging is less permeable to atmosphere. **Coors Brewing company has developed new plastic beer bottles that stay cold for longer periods of time.** Samsung already has CNT based flat panel displays on the market. A lot of companies are looking forward to being able to produce transparent conductive coatings and phase out ITO coatings. Samsung uses align SWNTs in the transparent conductive layer of their display manufacturing process.