Stronger than Steel: Carbon Nanotubes

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How small is nano?

I need to be managing a sexier project to boost my career.

It only has to sound good and not fail until I get a better job.

How about a nanotechnology stem cell for fighting terrorists?

0-0-okay.

My boss wants me to invent nanotechnology stem cells because it sounds good.

Try pointing to your empty hand and saying, “You can’t see them but they’re almost done!”

Then trick him into giving you a high-five and yell, “You crushed them! Aaag!!!”

Nano-hype!
Today’s Nanotube Workshop

• The Chemistry of Carbon
  - A New Form of Carbon: Nanotubes
  - Activity: Building Nanotube Models

• Nanotubes in Biology and Medicine
  - Biosensors
  - Filtration of Biocontaminants

• Carbon Nanotubes – Stronger than steel
  - Tensile strength of Carbon Nanotubes
  - Composite Materials
  - Applications
Chemistry of Carbon

Carbon Atoms

Outer Electrons

Nucleus

Diamond

Graphite

Nanotube
• Carbon was discovered in prehistory and was known to the ancients

• The allotropes of carbon are the different molecular configurations that pure carbon can take.

• The three relatively well-known allotropes of carbon are amorphous carbon, graphite and diamond.

• Several exotic allotropes have also been synthesized or discovered, including fullerenes and carbon nanotubes.
Graphite

• Graphite is a conductor, and can be used as the material in the electrodes of an electrical arc lamp, or as the lead in pencils.

• Each carbon atom is covalently bonded to three other surrounding carbon atoms.

• Each carbon atom possesses an sp² orbital hybridization. The pi orbital electrons delocalized across the hexagonal atomic sheets of carbon contribute the graphite's conductivity.
Diamonds

• Diamonds typically crystallize in the cubic crystal system and consist of tetrahedrally bonded carbon atoms.

• The tetrahedral arrangement of atoms in a diamond crystal is the source of many of diamond's properties; graphite, has a rhombohedral crystal structure and as a result shows dramatically different physical characteristics—contrary to diamond, graphite is a very soft, dark grey, opaque mineral.
History of Carbon Nanotubes

• In 1985 a new class of molecules consisting of purely carbon was discovered, the Fullerenes.

• In 1990 Dr. Richard Smalley recognized that tubular Fullerenes should be possible.

• It was not until 1991 that Sumio Ijima of the NEC Laboratory in Tsukuba, Japan, observed that these fibers were hollow.
Fullerenes

- The Fullerenes are a recently discovered allotrope of carbon.
- Fullerenes are not very reactive due to the stability of the graphite-like bonds
Carbon Nanotubes

- Carbon nanotubes are cylindrical carbon molecules with novel properties that make them potentially useful in a wide variety of applications.
- Nanotubes are composed entirely of $sp^2$ bonds, similar to graphite.
What makes nanotubes different from one another?
Inquiry Activity

Buckyballs

Nanotubes
Ideal sensor molecule

• Remarkable Properties of CNTs
  - Carbon Nanotubes “glow”
  - Excited in the near-IR range of the EM spectrum
  - Different than almost all other dyes
  - Continuous fluorescence- no photobleaching

• Ideal for sensor applications in the body

http://www.jobinyvon.com/usadivisions/fluorescence/carbon_nanotubes.htm
Nanotubes and medicine

- Fluorescence of nanotubes can be used to make biosensors
- Light and the human body
  - Different wavelengths interact with tissue differently
  - Familiar with X-rays

http://pbskids.org/lions/words/xray.html
“There is a window in which light can penetrate into tissue: the near-IR wavelengths, from approximately 700 to 900 nm.”

(http://www.spie.org/web/oer/may/may00/cover2.html)
Lesson engagement

• How would you choose to test your blood?

From http://www.vitrex.dk/images/lancets.jpg

http://sci-toys.com/scitoys/scitoys/light/cliplead_transmitter.jpg
Nanotubes as Biosensors

• Carbon nanotubes can be modified to detect many molecules found in the blood
• Small size means that encapsulated nanotubes can be implanted at any site
• Researchers at University of Illinois led by Dr. Michael Strano have already constructed a glucose sensor from carbon nanotubes ([http://www.sciencedaily.com/releases/2004/12/041219153804.htm](http://www.sciencedaily.com/releases/2004/12/041219153804.htm))
• New glucose detector that takes advantage of CNT fluorescence and small size
Example: Glucose Sensor

This glass capillary tube, shown here on a fingertip, has been loaded with glucose-sensitive nanotubes. The capillary tube keeps the nanotubes confined, but has porous walls so that glucose molecules can get to them. (Credit: Michael S. Strano)

From http://www.sciencedaily.com/releases/2004/12/041214081957.htm

- Carbon nanotube modified with “sensor” molecules
- RESULT: More glucose \(\rightarrow\) More fluorescence
Another Exciting Property of CNTs

- Nanotubes make excellent filters
  - Small pore size
  - High Surface Area to Volume Ratio
  - Easy to Modify
- Seldon, Technologies (Windsor, VT) has created several nanotube filters
  http://www.seldontech.com/
- Removes chemicals
- Kills and removes bio-contaminants
Carbon Nanotube “Kill-zone”

- Seldon Technologies created a CNT-based filter:
  - Don’t need high pressure
  - “Kill-zone” that is an absolute barrier to biocontaminants
- Monolayer nanomesh blocks debris without stopping water flow
Making Your Own Monolayer

<table>
<thead>
<tr>
<th>Nanotubes</th>
<th>Bacteria</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 nm</td>
<td>2 μm</td>
<td>0.03</td>
</tr>
<tr>
<td>Sticks</td>
<td>Marbles</td>
<td>Ratio</td>
</tr>
<tr>
<td>1 mm</td>
<td>1.25 cm</td>
<td>0.08</td>
</tr>
</tbody>
</table>

TUMBLE game ($9.99)
http://www.pressmantoy.com/
Antibacterial Properties
Applications for the Military

- Prototype built as a "backpack"

- United States Air Force currently testing the device

- Can filter large volumes of water from dirty sources (EVEN URINE!)

(c) 2005 Seldon Laboratories, LLC
Safe Water Available Anywhere

(c) 2005 Seldon Laboratories, LLC
Physics of Carbon Nanotubes

• Maximum Tensile Strength
  ~ 30 GPa

• Density normalized strength of a carbon nanotube is ~56 times that of steel wire

• CNT can carry large currents with little heating

What are Composite Materials?

- Composite materials are materials made from two or more components.
- A composite material usually consists of a strong fiber and a matrix (which surrounds the fiber).
- The fiber carries the load while the matrix keeps fibers in the correct position and protects the fibers from environmental damage.
- Examples of fibers: fiberglass, Kevlar.
- Examples of a matrix: polyester, epoxy.
Carbon Nanotubes in Composite Materials

- CNT can act as a strong fiber to improve the strength, elasticity, and conductivity of a material.
- Challenges
  - Dispersing the nanotubes uniformly throughout the matrix
  - Reducing intratube sliding in MWNT
  - Creating adhesion between the carbon nanotube and the matrix that results in an effective stress transfer
Mechanical Properties and applications of Carbon nanotubes (CNTs)

- Mechanical properties: (1nm to 100s nm)
  - Light weight, sustains extremely high tension force; 130 GPa compared to steel at <5 GPa
  - Highly flexible, even under low temperature.
- Applications: AFM tips, super-strong fabrics, polymer composites and space elevator
CNT in Action
Applications of CNT Composites

- Babolat Tennis Rackets
- Easton uses CNT in baseball bats
- Nissan’s X-Trail SUV has bumpers that are reinforced with CNT
- Wings on NASA’s Morphing Glider
In an older TV (CRT) a cathode emits electrons towards an anode and onto a phosphor screen.

One electron beam serves the entire screen and the direction of the beam was manipulated by magnetic coils.

How does a Field Emission Display differ from a CRT?

*An FED has electron emitters behind every pixel.*

Source (both images): howstuffworks. [www.howstuffworks.com](http://www.howstuffworks.com)
Field Emission Displays

Why are carbon nanotubes a good choice in an FED?

Nanotubes are able to generate a high electric field due to their small tip. They are stable emitters with a long lifetime.

How is an FED different from an LCD?

Lower power consumption, higher brightness, wider viewing angle.

Source (diagram):
http://materials.ecn.purdue.edu/~mdasilva/other.shtml
Nanoscale electronics

- Transport properties:
  - High thermal conductivities w/o electrical conductivity,
    Semiconducting or metallic tubes,
  - High current density (1000X Cu).
- Applications:
  - field emission devices => field emission flat panel.
  - single molecular transistors
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The Space Elevator