Stronger than Steel: Carbon Nanotubes

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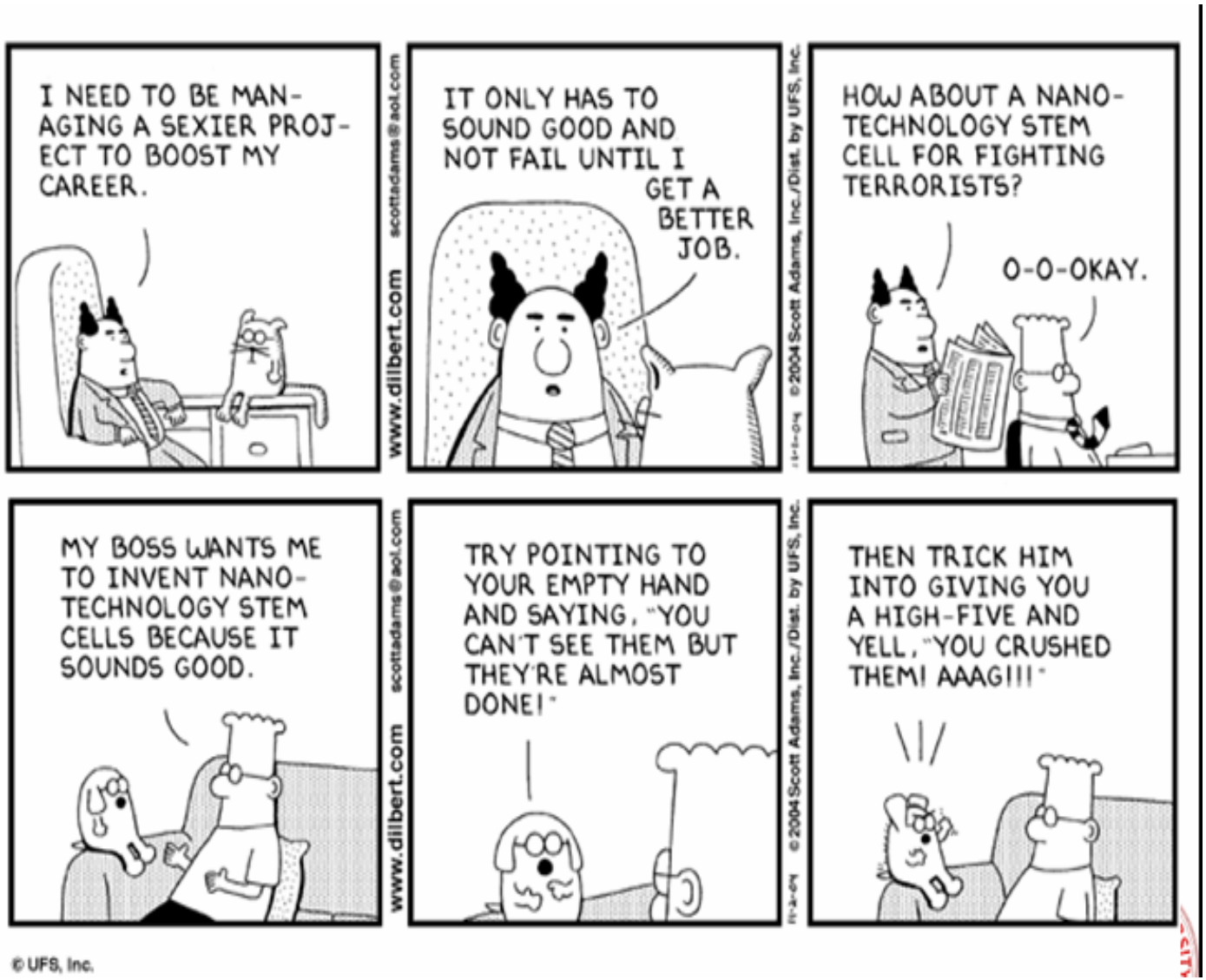
How small is nano?



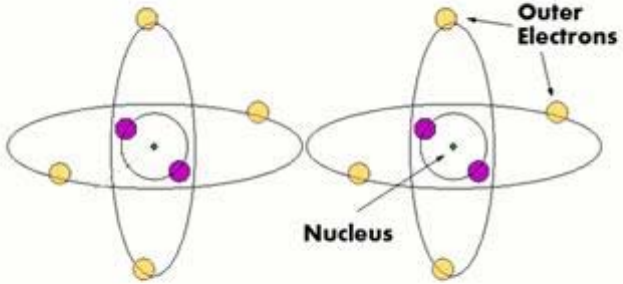
Nano-hype!

Today's Nanotube Workshop

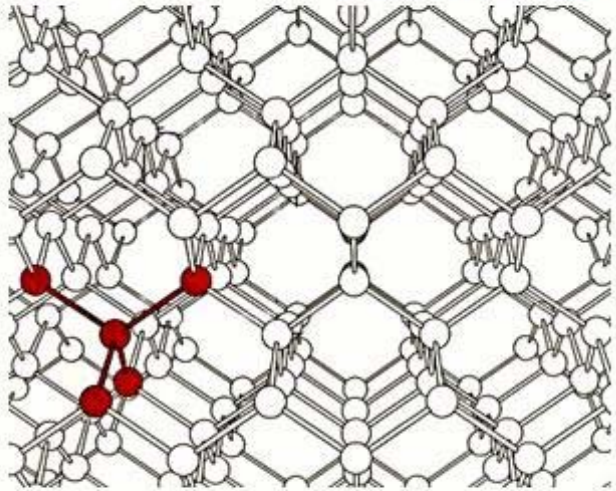
- The Chemistry of Carbon
  - A New Form of Carbon: Nanotubes
  - Activity: Building Nanotube Models
- Nanotubes in Biology and Medicine
  - Biosensors
  - Filtration of Biocontaminants
- Carbon Nanotubes – Stronger than steel
  - Tensile strength of Carbon Nanotubes
  - Composite Materials
  - Applications

Chemistry of Carbon

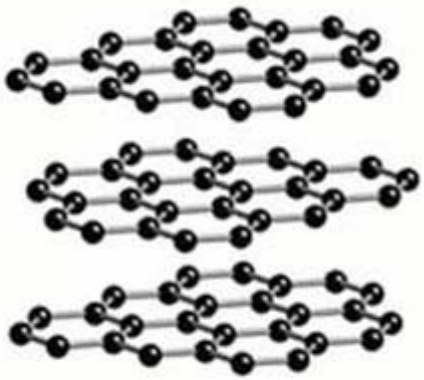
Carbon Atoms



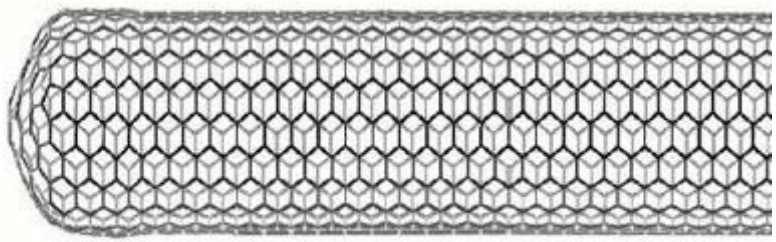
Diamond



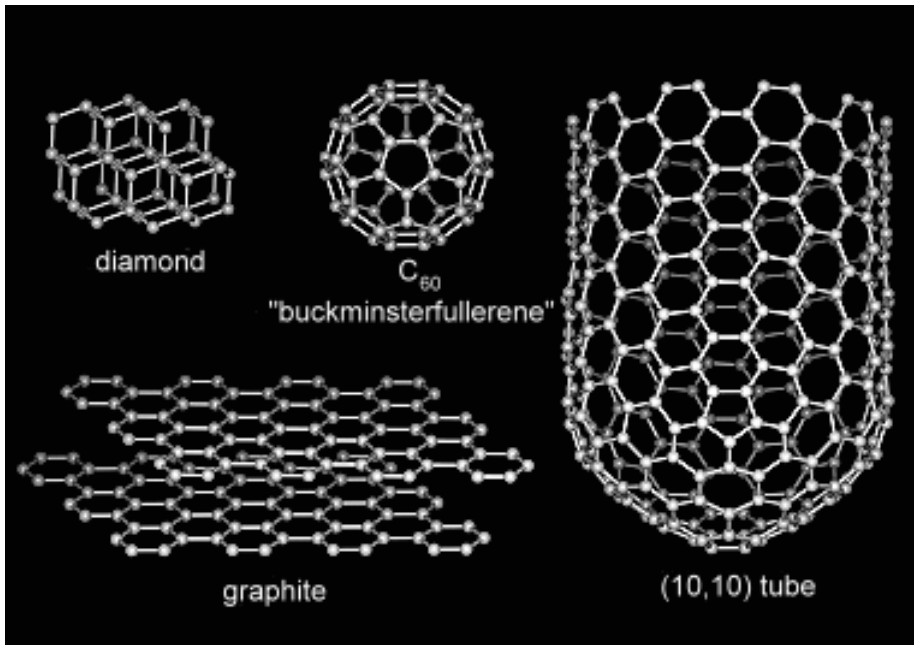
Graphite



Nanotube

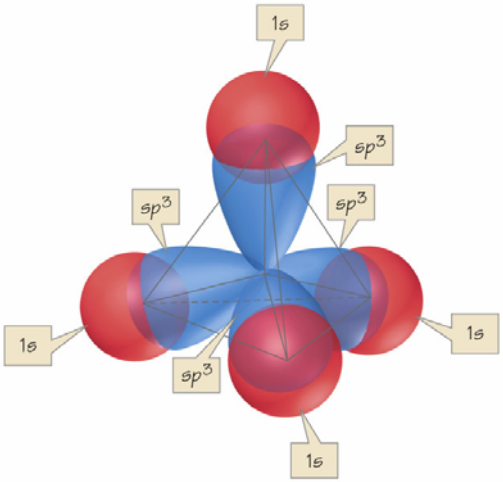


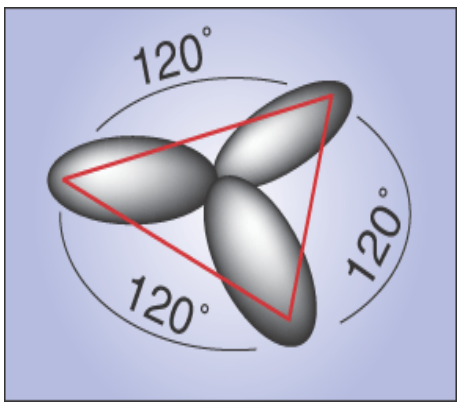
Forms of Carbon



- 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.

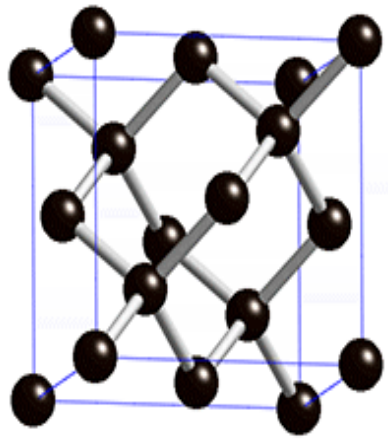
Graphite





- 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 sp^2 orbital hybridization. The pi orbital electrons delocalized across the hexagonal atomic sheets of carbon contribute the graphite's conductivity.

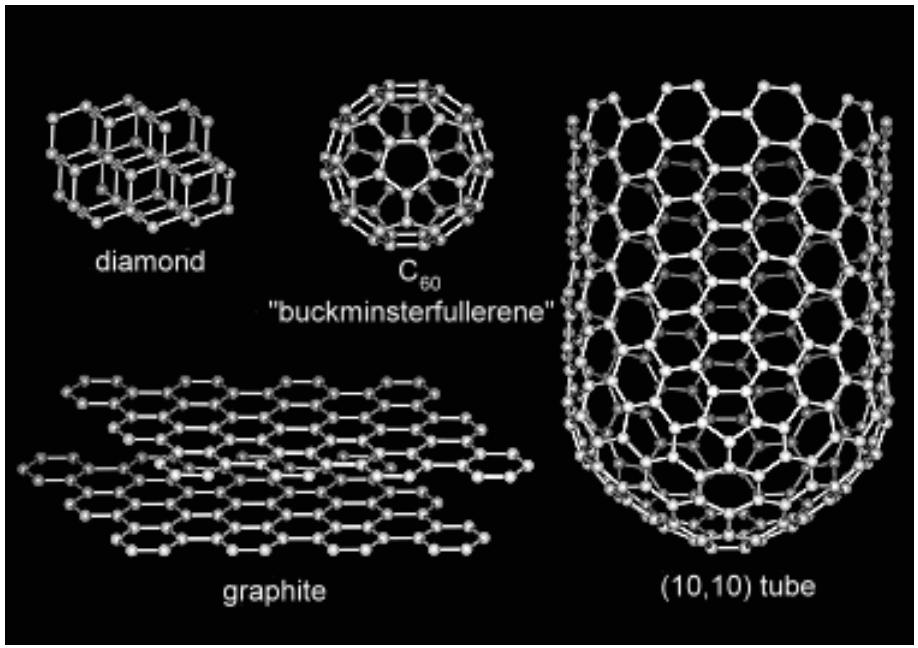
Diamonds



• 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.

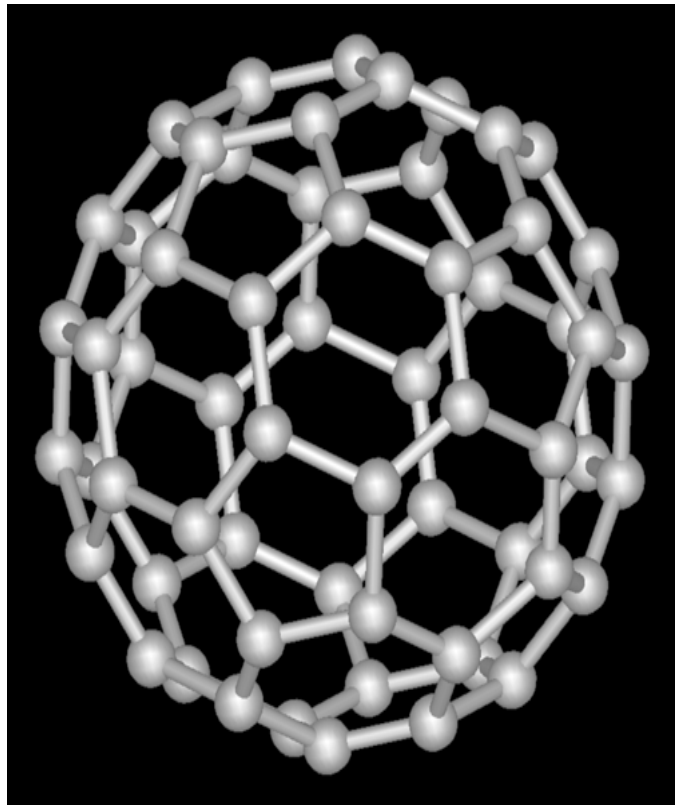
History of Carbon Nanotubes



- 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.

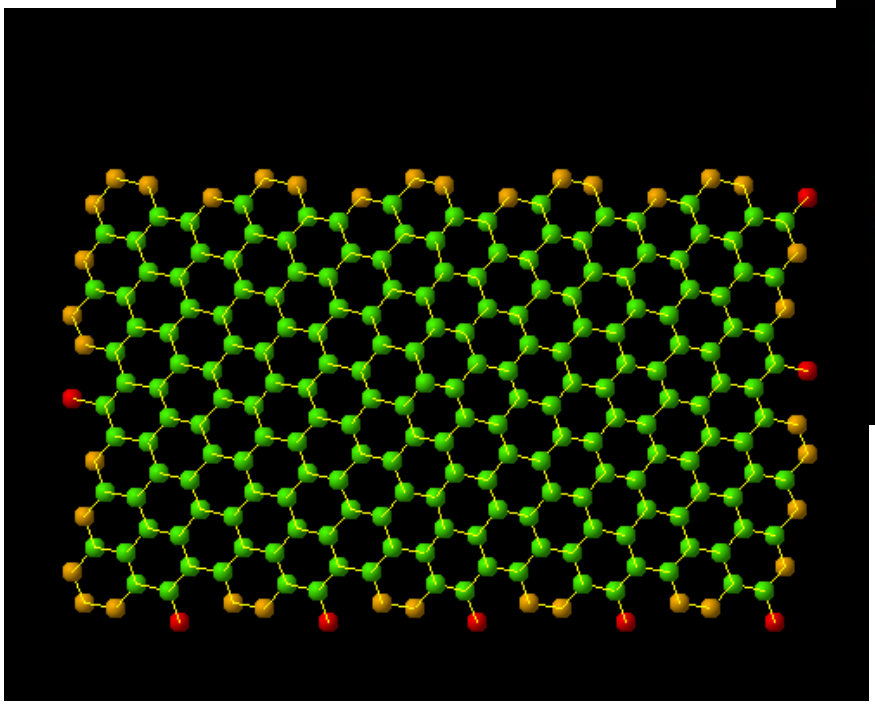
Fullerenes

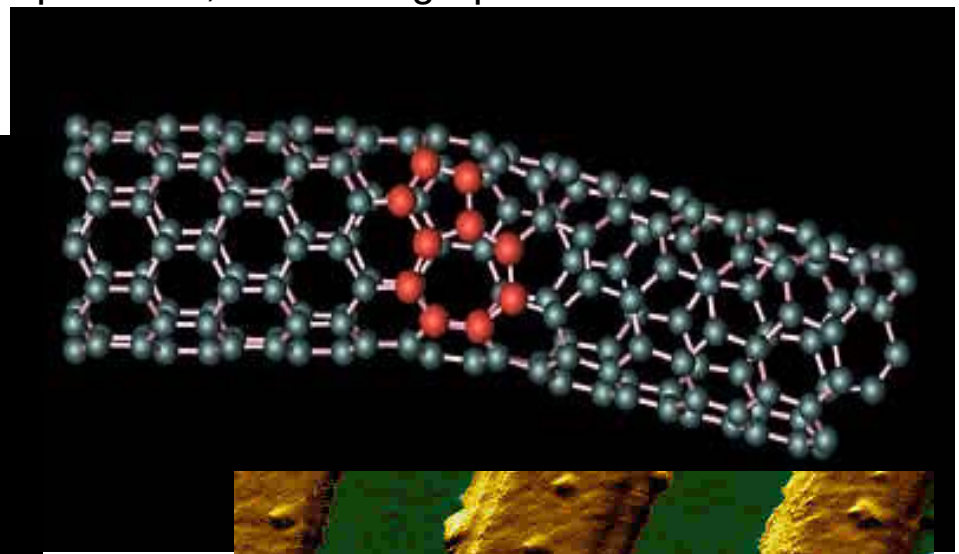
- The Fullerenes are a recently discovered allotrope of carbon.
- Fullerenes are not very reactive due to the stability of the graphite-like bonds

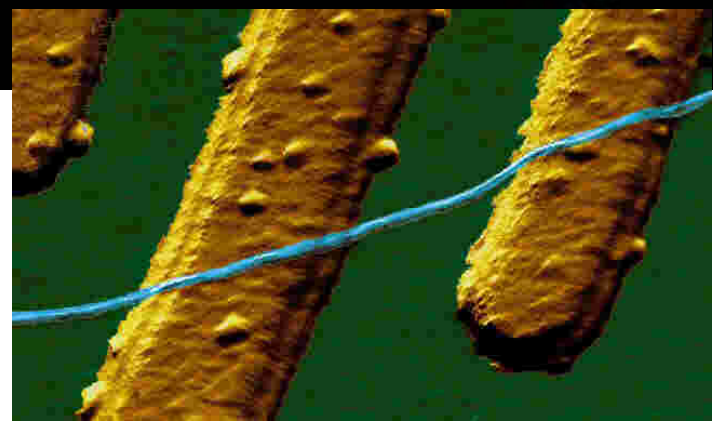


Carbon Nanotubes

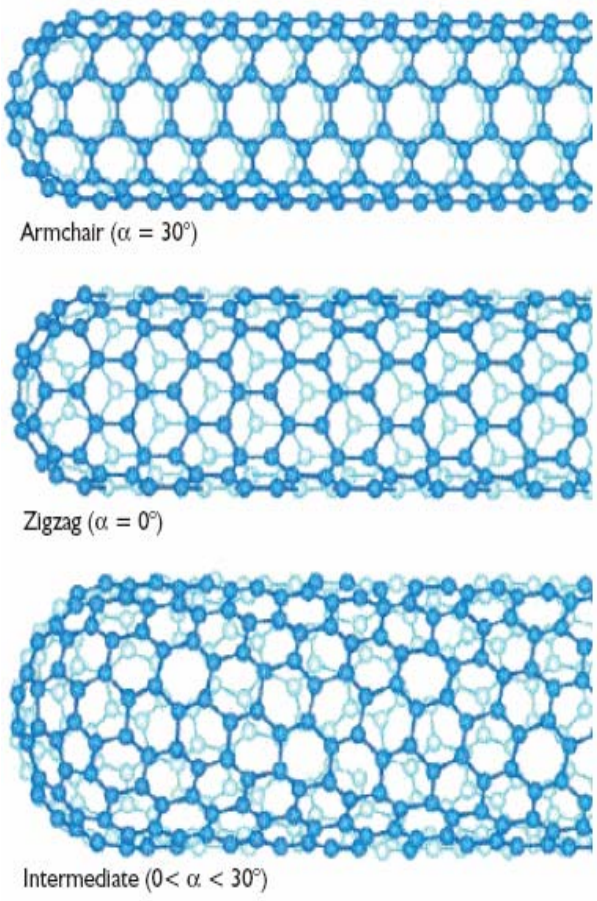
- Carbon nanotubes are cylindrical carbon molecules with novel properties that make them potentially useful in a wide variety of applications.
- Nanotubes are composed entirely of sp^2 bonds, similar to graphite.

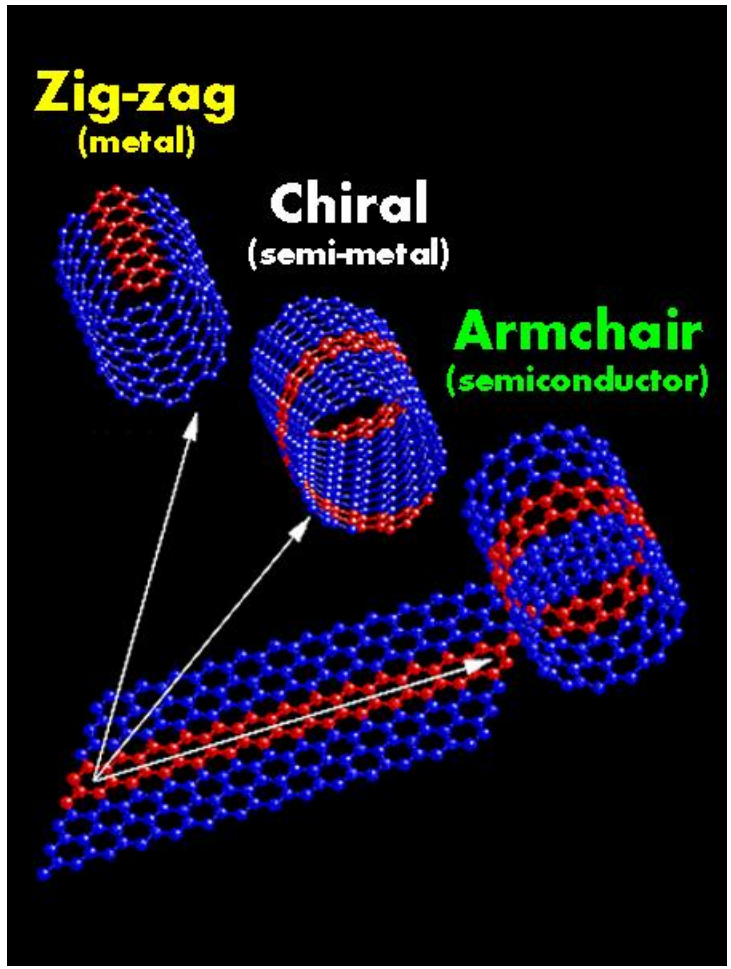




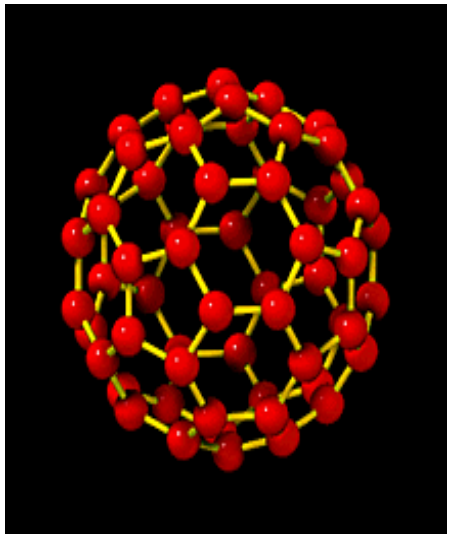


What makes nanotubes different from one another?

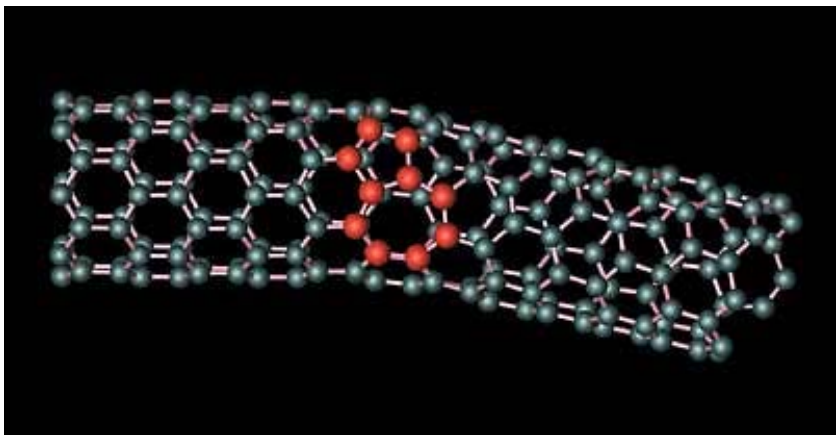




Inquiry Activity



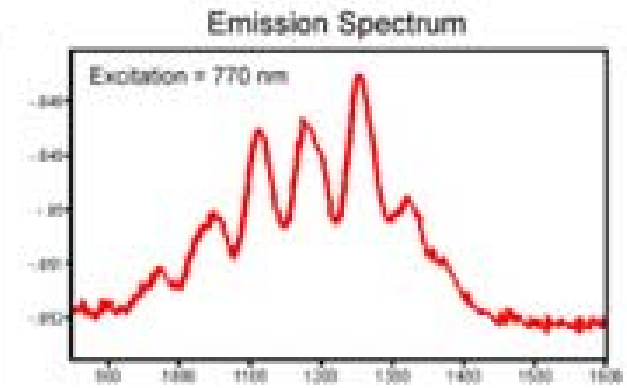
Buckyballs



Nanotubes

Ideal sensor molecule

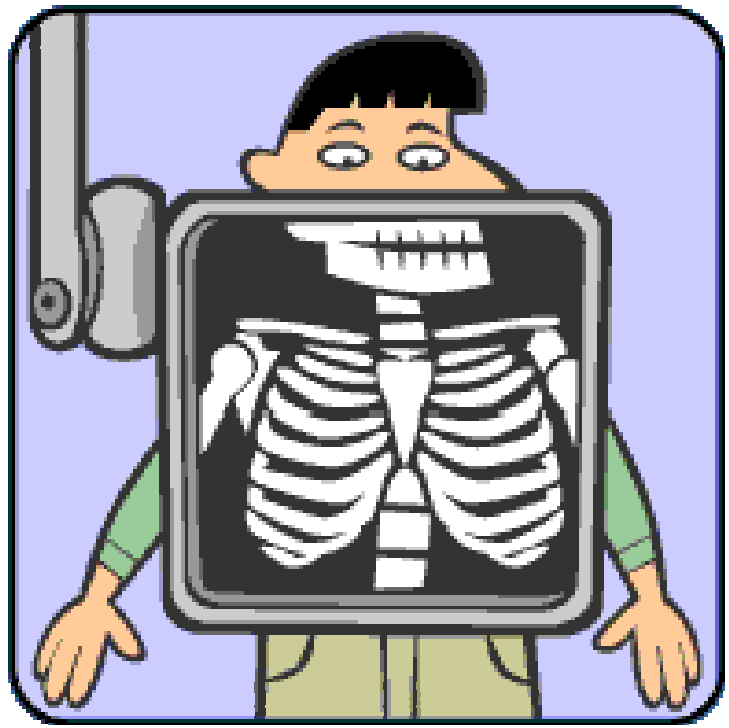
- Remarkable Properties of CNTs
  - Carbon Nanotubes “glow”
  - Excited in the near-IR range of the EM spectrum
  - Different than almost all other dyes
  - Continuous fluorescence- no photobleaching
- Ideal for sensor applications in the body



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

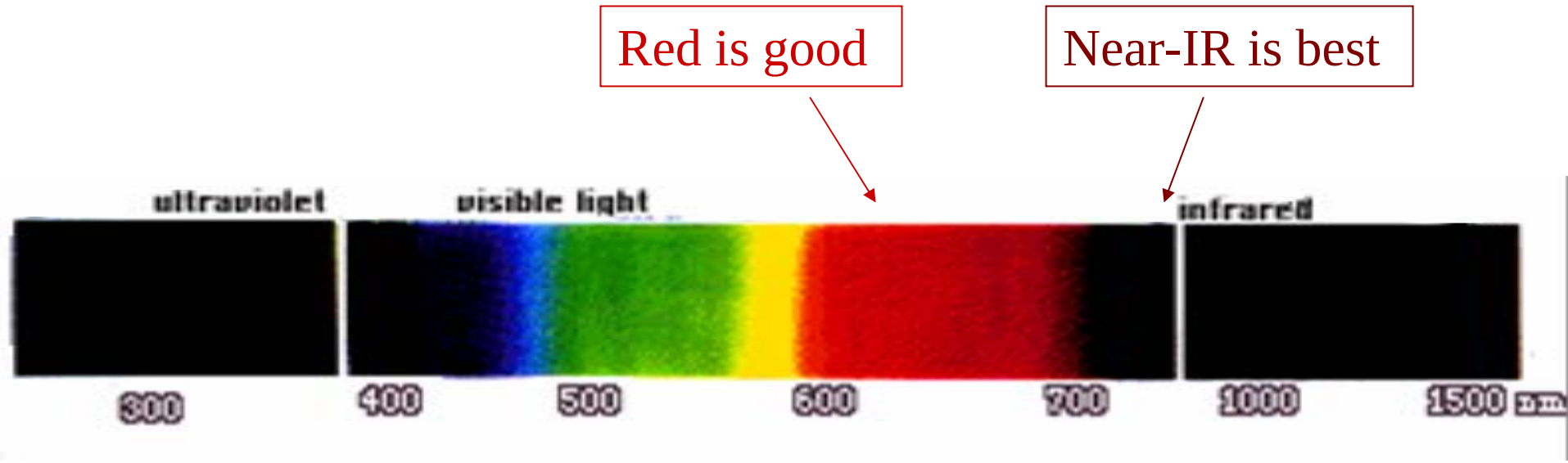


http://pbskids.org/lions/words/xray.html

Window into tissue

"There is a window in which light can penetrate into tissue: the near-IR wavelengths, from approximately 700 to 900 nm."

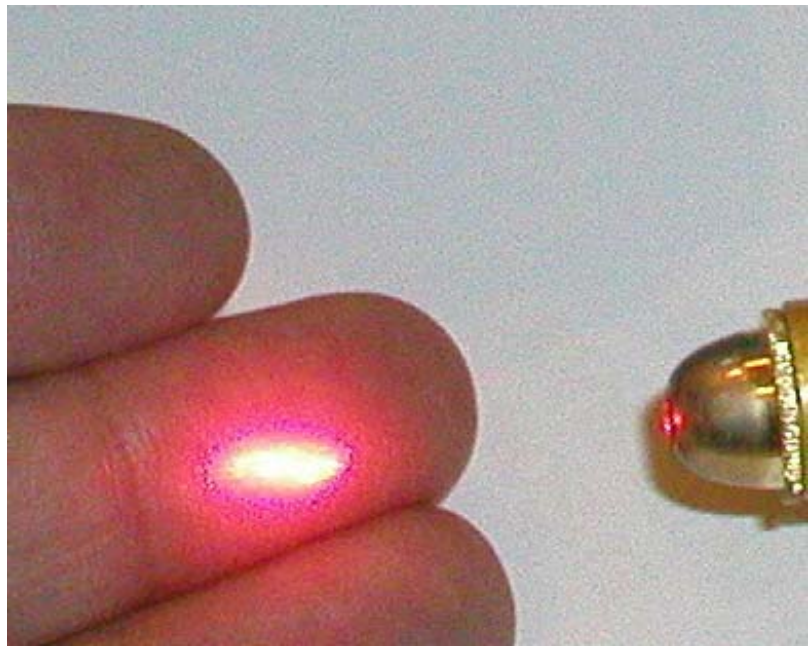
(http://www.spie.org/web/oer/may/may00/cover2.html)



Lesson engagement

- How would you choose to test your blood?

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

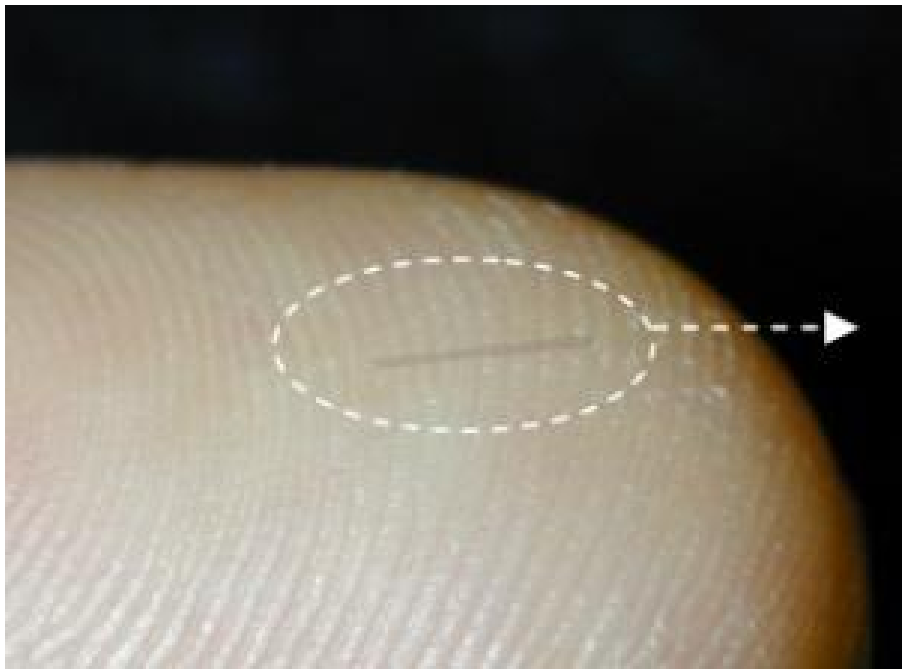


http://sci-toys.com/scitoys/scitoys/light/cliplead_transmitter.jpg

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)
- 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 → More fluorescence

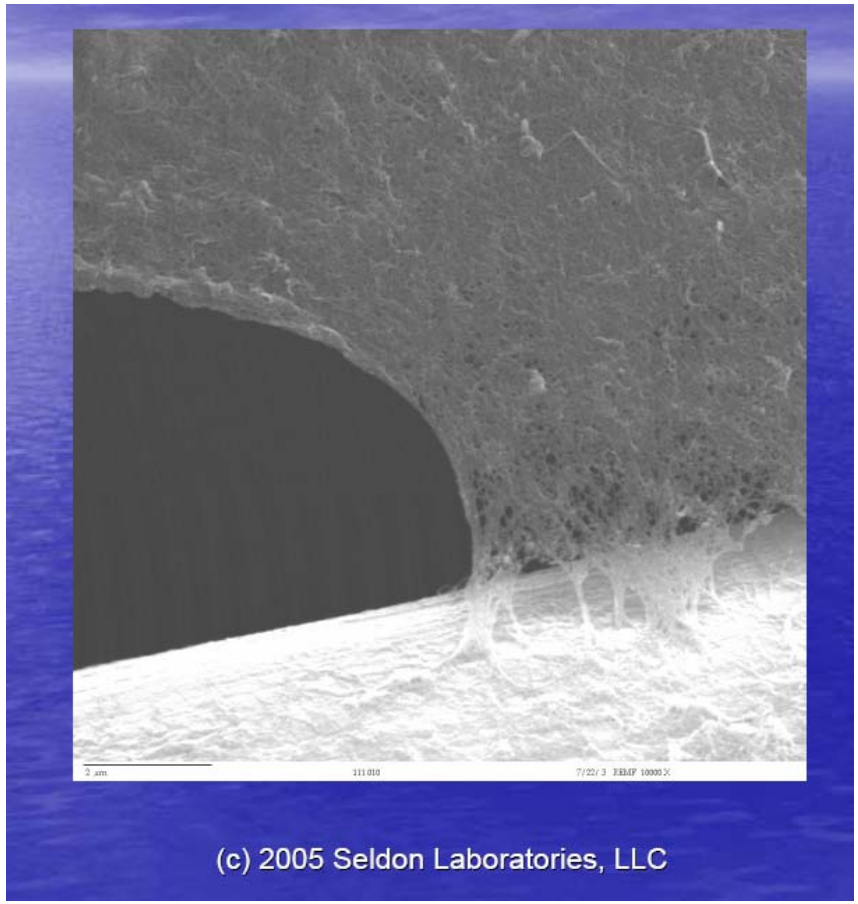
Another Exciting Property of CNTs

- 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

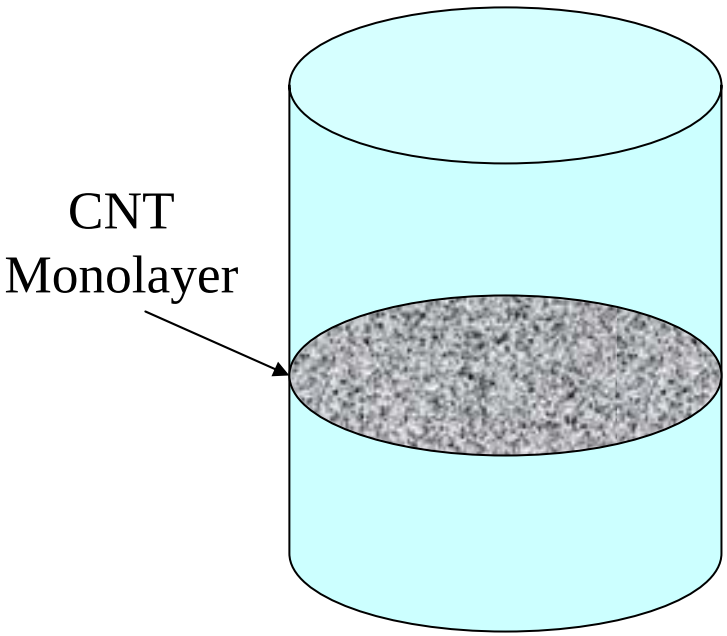
  http://www.seldontech.com/
- Removes chemicals
- Kills and removes bio-contaminants

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

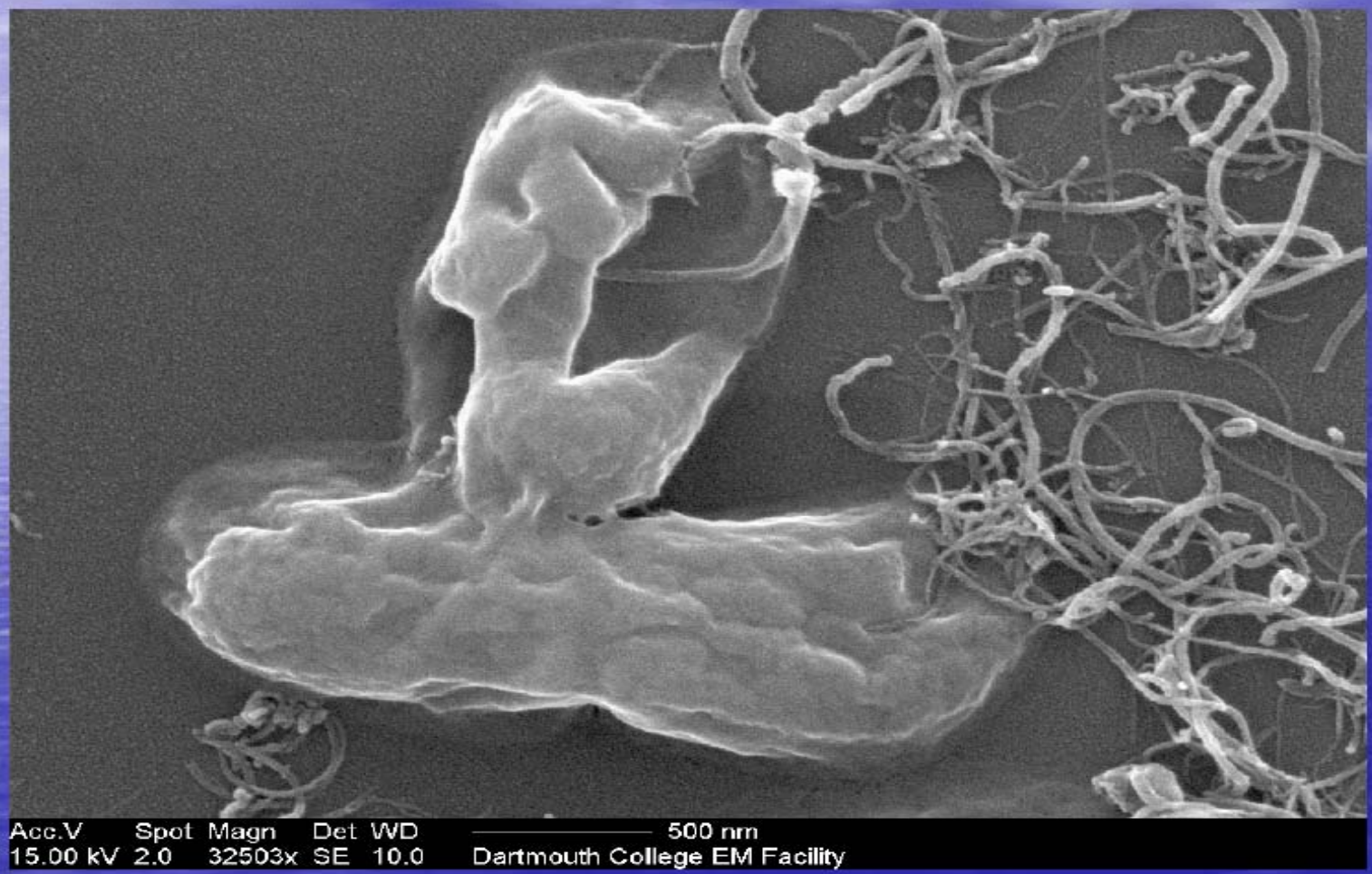


Nanotubes	Bacteria	Ratio
60 nm	2 μm	0.03
Sticks	Marbles	Ratio
1 mm	1.25 cm	0.08

TUMBLE game ($9.99)

http://www.pressmantoy.com/

Antibacterial Properties



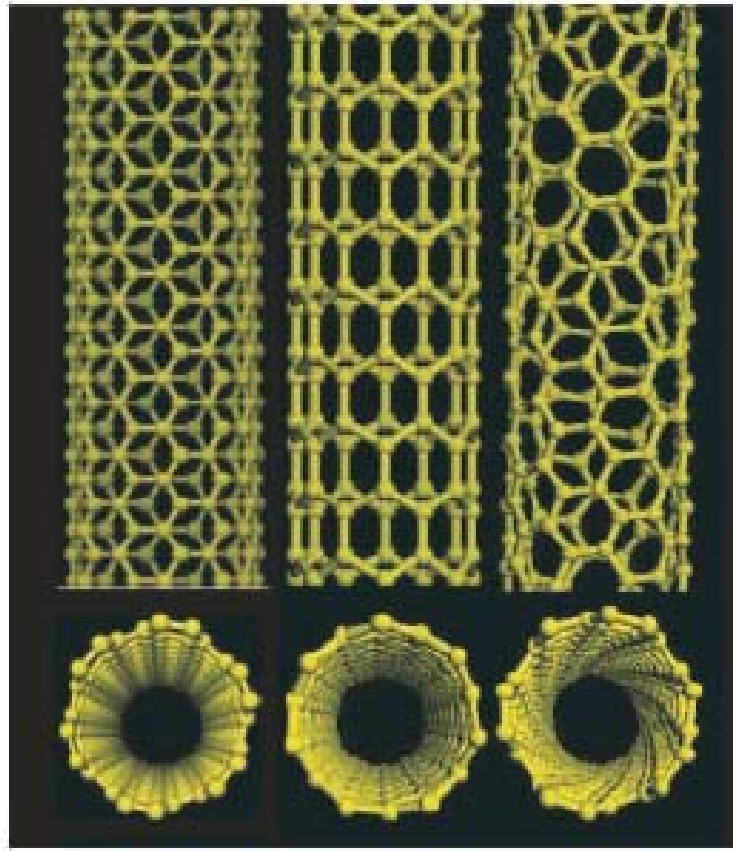
Applications for the Military

- Prototype built as a “backpack”
- United States Air Force currently testing the device
- Can filter large volumes of water from dirty sources (EVEN URINE!)

Safe Water Available Anywhere

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



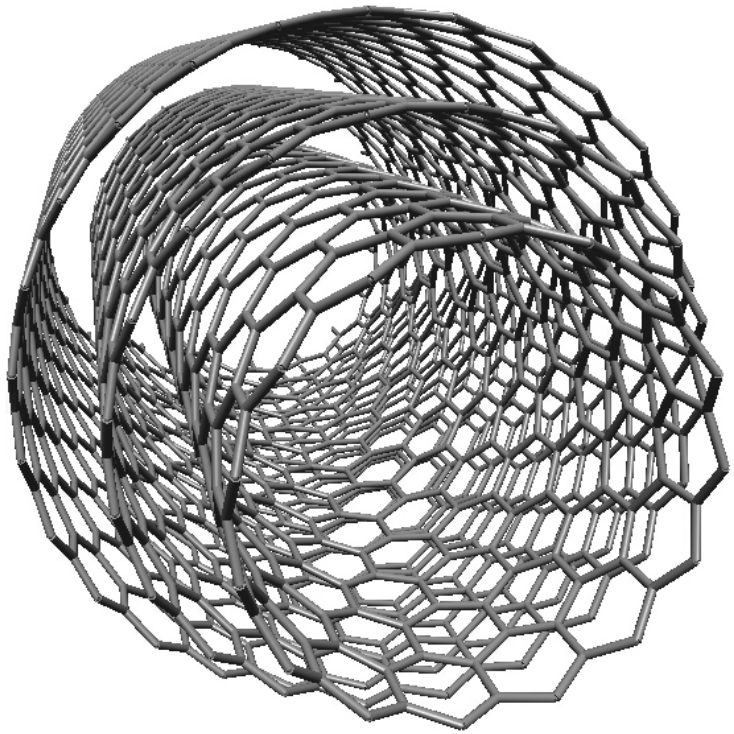
Source: Baughman, R. H., Zakhidov, A. A., Heer, W. A. Carbon Nanotubes-the Route Toward Applications. *Science's Compass Review. Science*, **297**, 787-792 (2002).

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

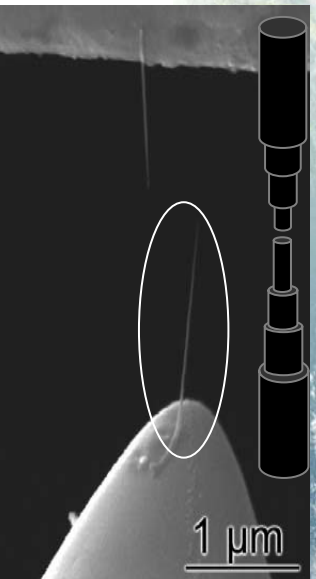
Carbon Nanotubes in Composite Materials

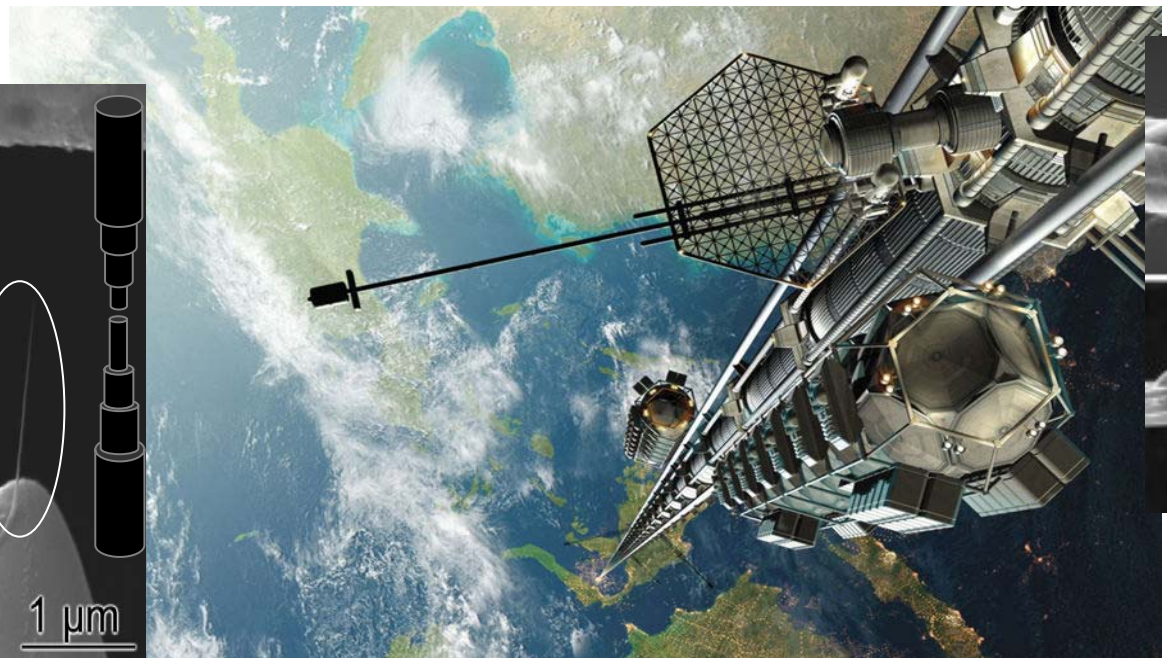
- CNT can act as a strong fiber to improve the strength, elasticity, and conductivity of a material.
- Challenges
  - Dispersing the nanotubes uniformly throughout the matrix
  - Reducing intratube sliding in MWNT
  - Creating adhesion between the carbon nanotube and the matrix that results in an effective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

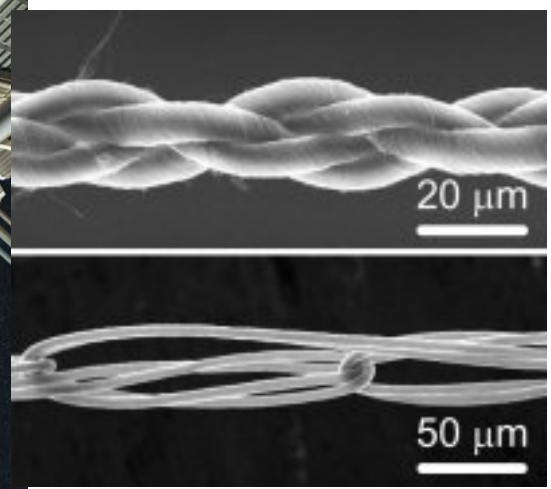


Mechanical Properties and applications of Carbon nanotubes (CNTs)

- 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







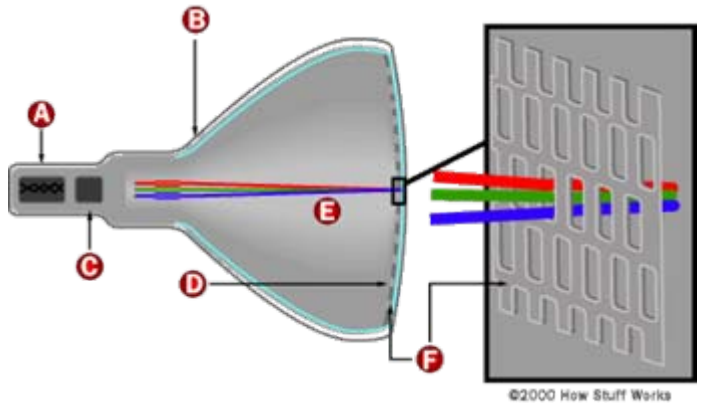
CNT in Action

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

CRT Televisions

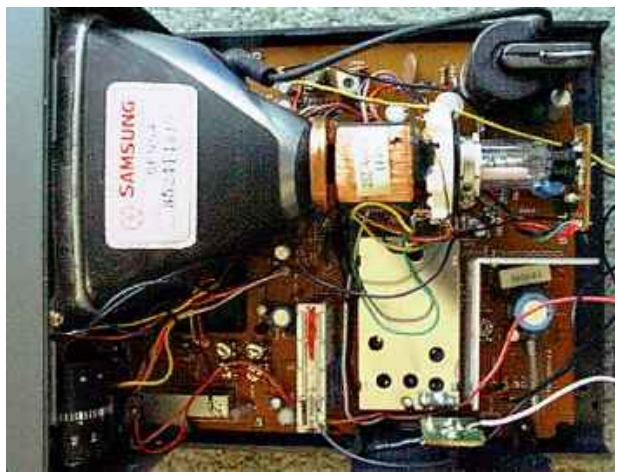
In an older TV (CRT) a cathode emits electrons towards an anode and onto a phosphor screen.



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

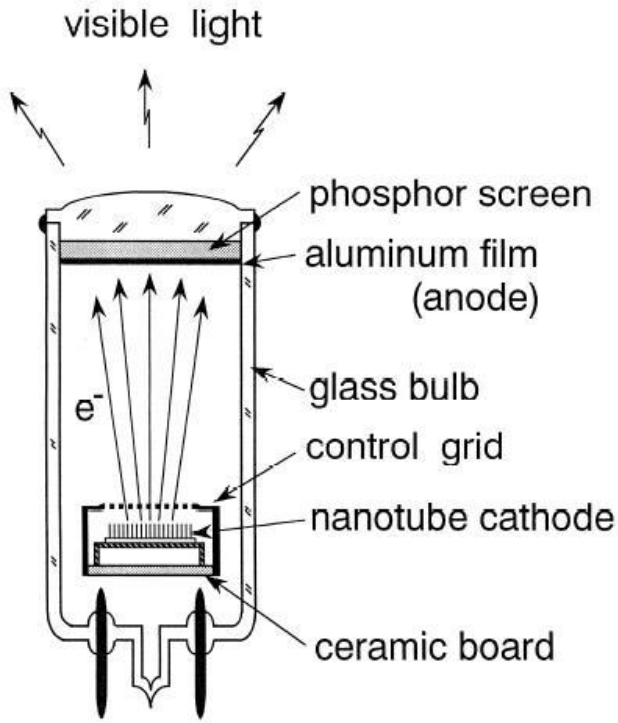
How does a Field Emission Display differ from a CRT?

An FED has electron emitters behind every pixel.



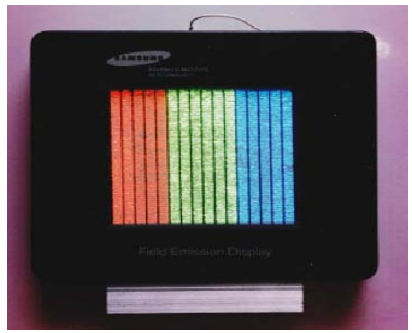
Source (both images): howstuffworks. www.howstuffworks.com

Field Emission Displays



How is an FED different from an LCD?

Lower power consumption, higher brightness, wider viewing angle.



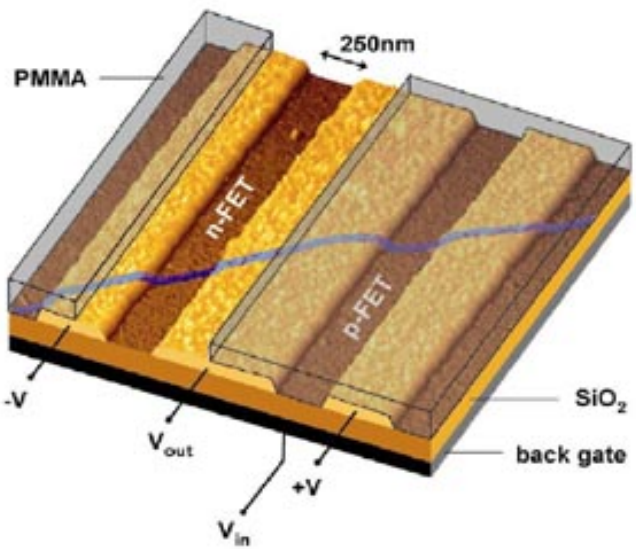
Why are carbon nanotubes a good choice in an FED?

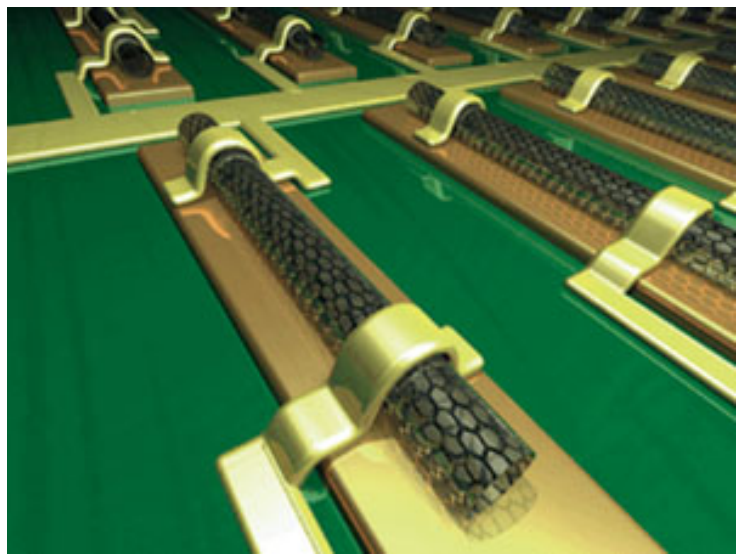
Nanotubes are able to generate a high electric field due to their small tip They are stable emitters with a long lifetime.

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





Acknowledgments

- Boston University GK-12 program STAMP: Science, Technology and Math Partnerships
- Seldon Technologies for use of their photographs and slides
- Boston University Center for Nanoscience and Nanobiotechnology

CENTER FOR NANOSCIENCE AND NANOBIOTECHNOLOGY

The Space Elevator