What are nanomaterials and nanoparticles ?
Could we see them?
How can we obtain them?

Pr. Charles Kappenstein

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Ouline

What are nanomaterials and nanoparticles?

- Importance of scale
- Some examples
- Properties, surface is a key parameter

How can we obtain them?

Could we see them?

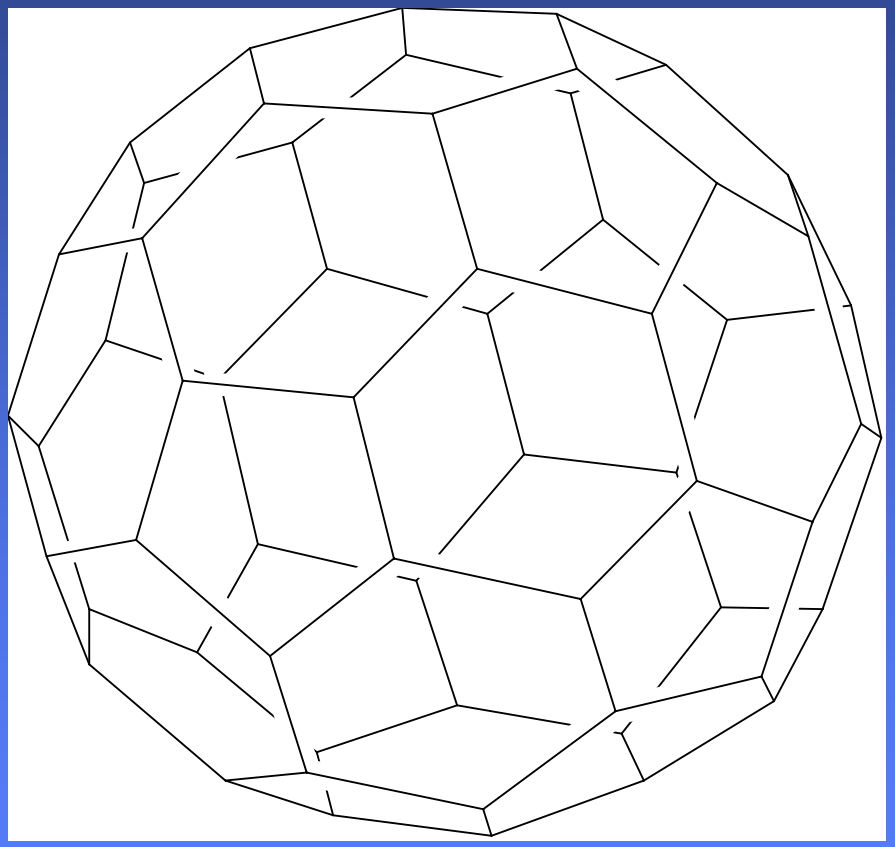
- Optical and electronic microscopy
- Atomic force microscopy

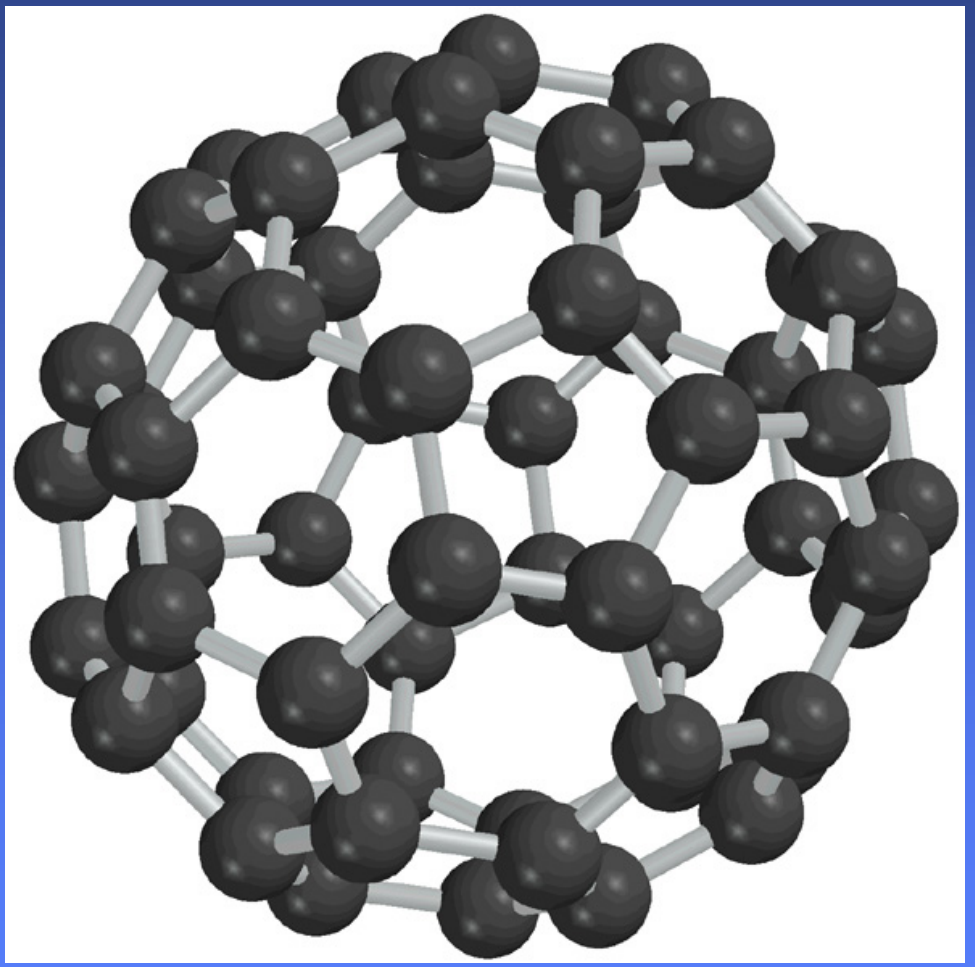
Applications

Conclusion : toxicity and ethical concerns

What are nanomaterials and nanoparticles?

Importance of scale: 1 nm = 10^{-9} m
➔fullerene molecule C_{60}





What are nanomaterials and nanoparticles?

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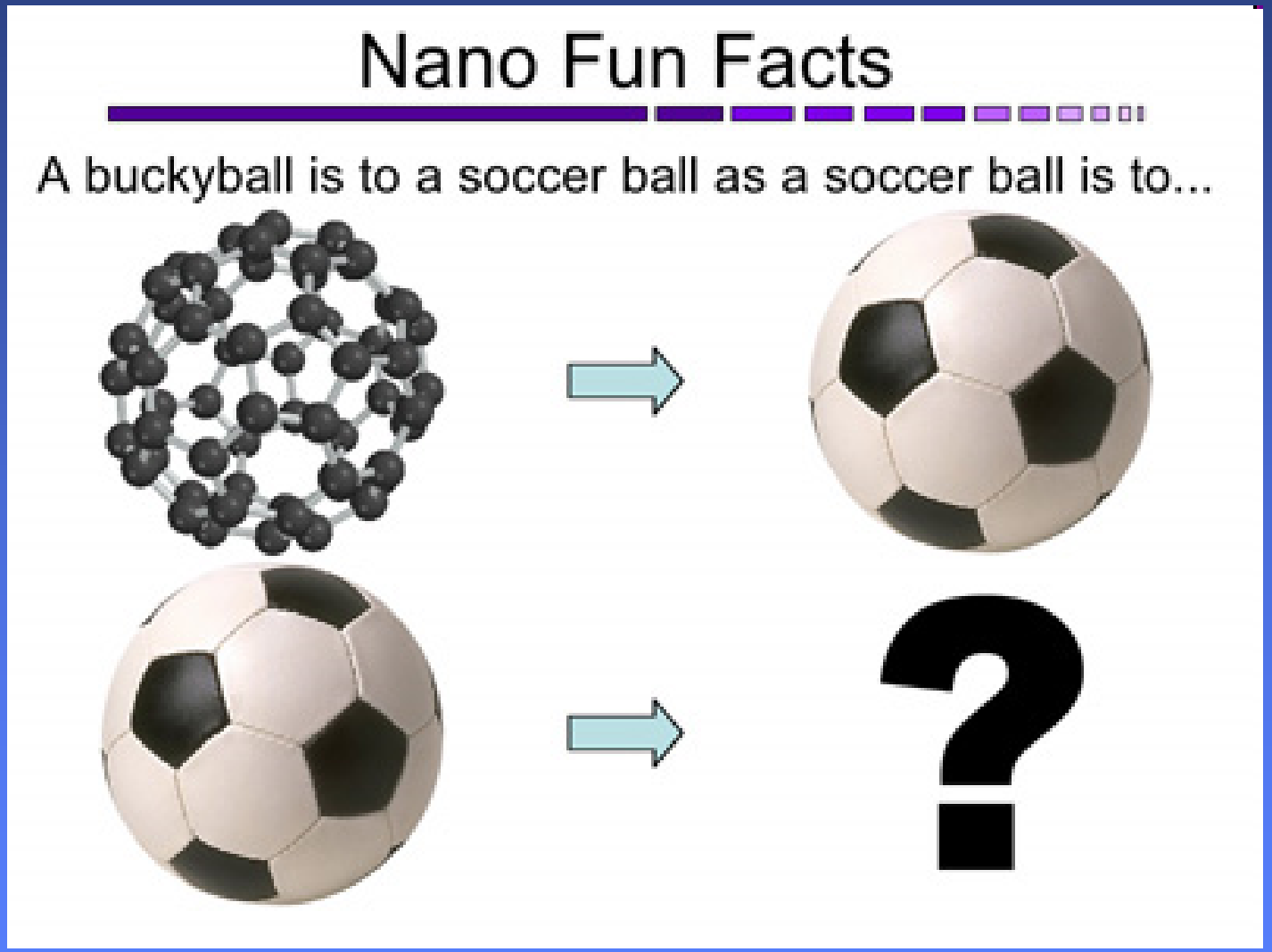

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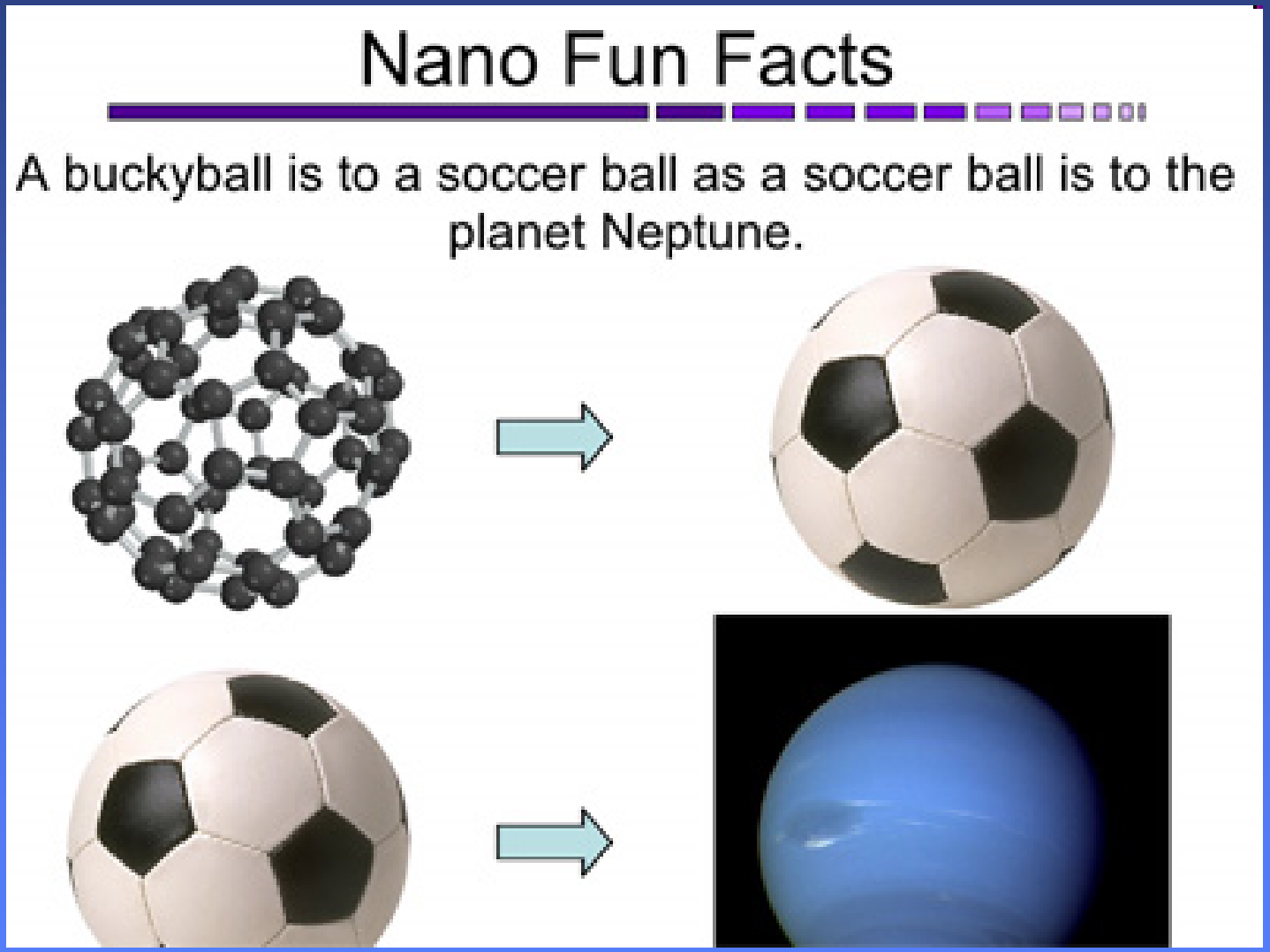


What are nanomaterials and nanoparticles?

Importance of scale: 1 nm = 10^{-9} m

Nano Fun Facts

If the atoms in your body were the size of golf balls, how tall would you be?

Nano Fun Facts

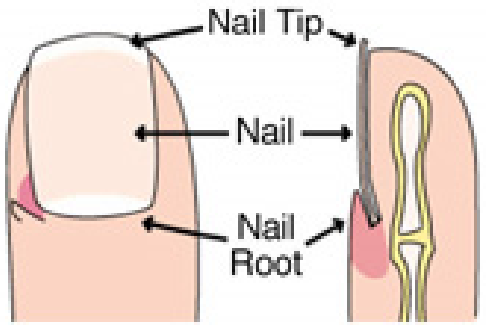
If the atoms in your body were the size of golf balls, you could touch the moon (earth-moon distance = 385000 km).

What are nanomaterials and nanoparticles?

Importance of scale: 1 nm = 10^{-9} m

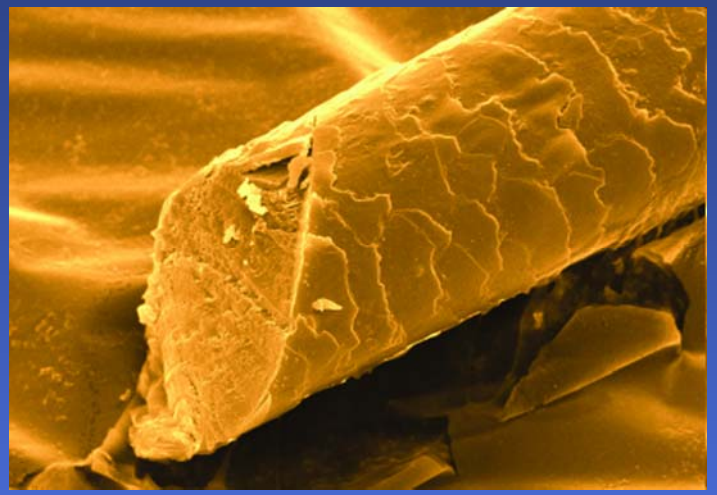
Nano Fun Facts

In the time it takes to read this sentence, your fingernails will have grown 1 nm.

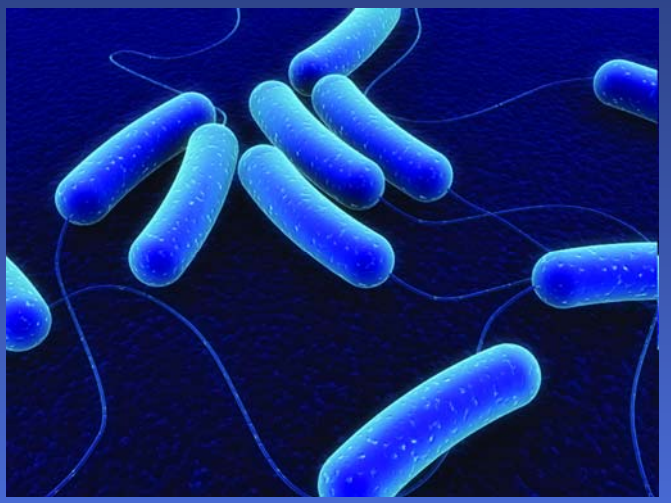


What are nanomaterials and nanoparticles?

Some examples: at the micrometer scale level



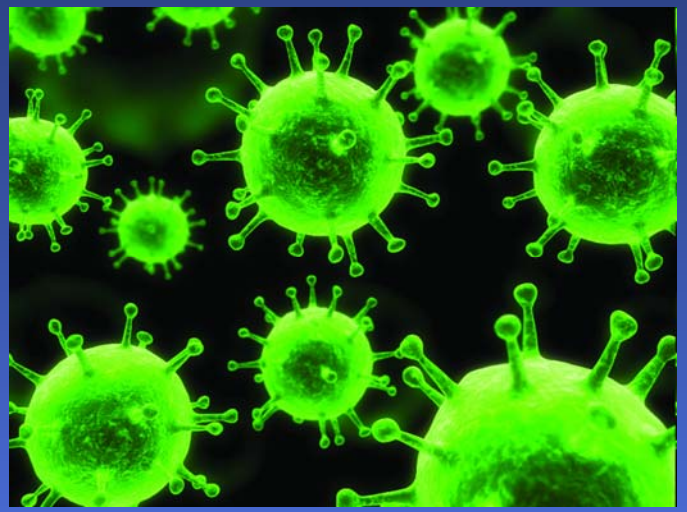
Hair diameter: 40-50 µm



Bacteria 5 to 20 µm

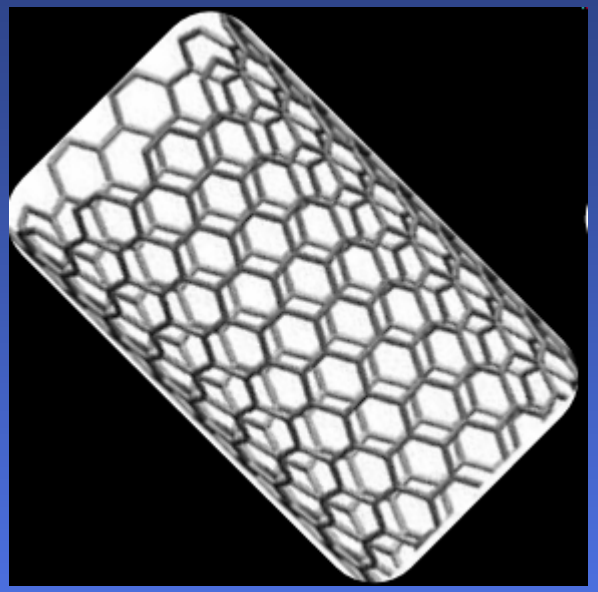
What are nanomaterials and nanoparticles?

Some examples: at the nanometer scale level



Virus (30-50 nm)

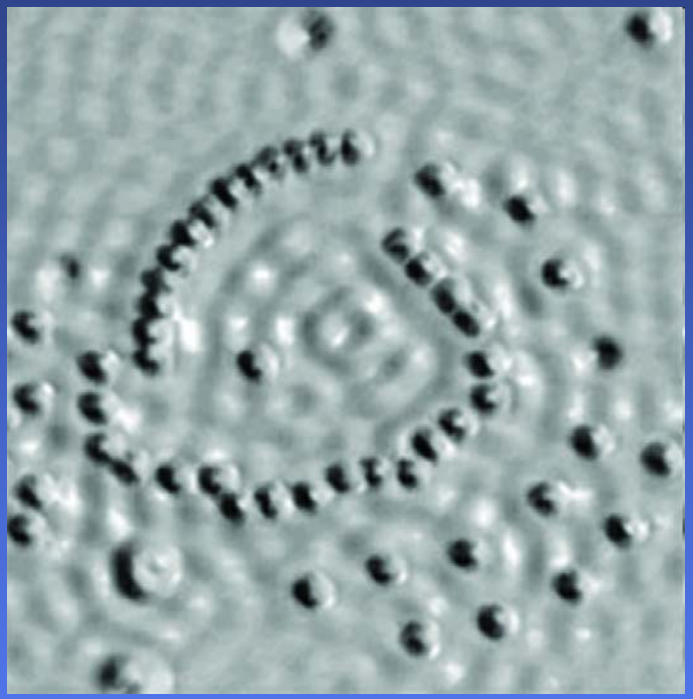
ADN (2.5 nm)



CNT (~1 nm in diameter)

What are nanomaterials and nanoparticles?

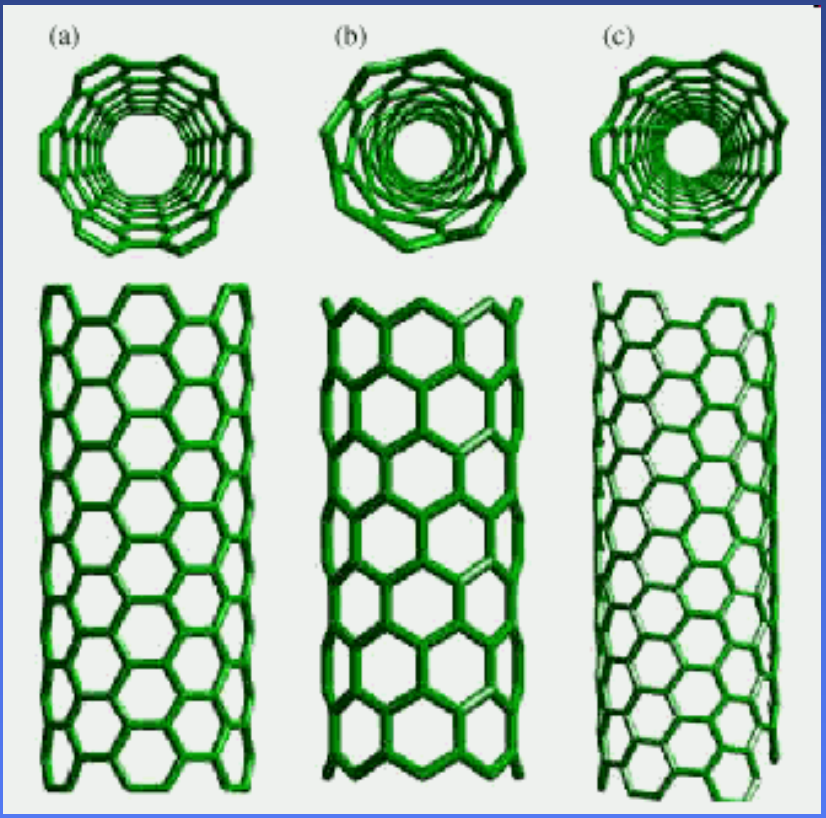
Some examples: size of atoms

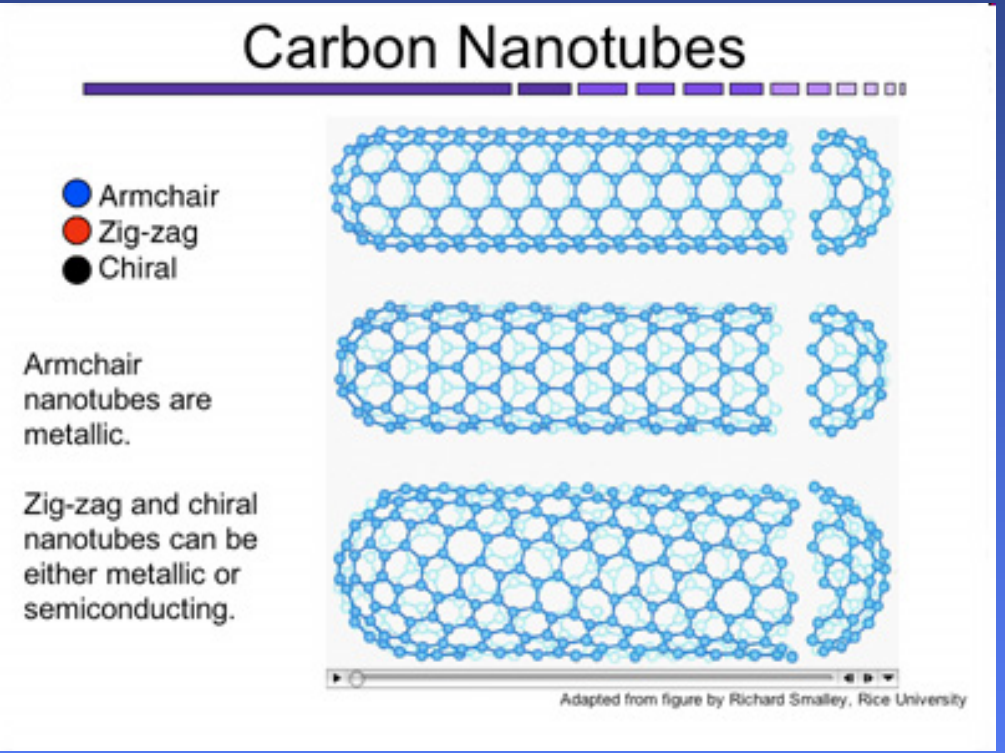


Atoms are smaller than a nanometer. One atom measures ~0.1-0.3 nm, depending on the element.

What are nanomaterials and nanoparticles?

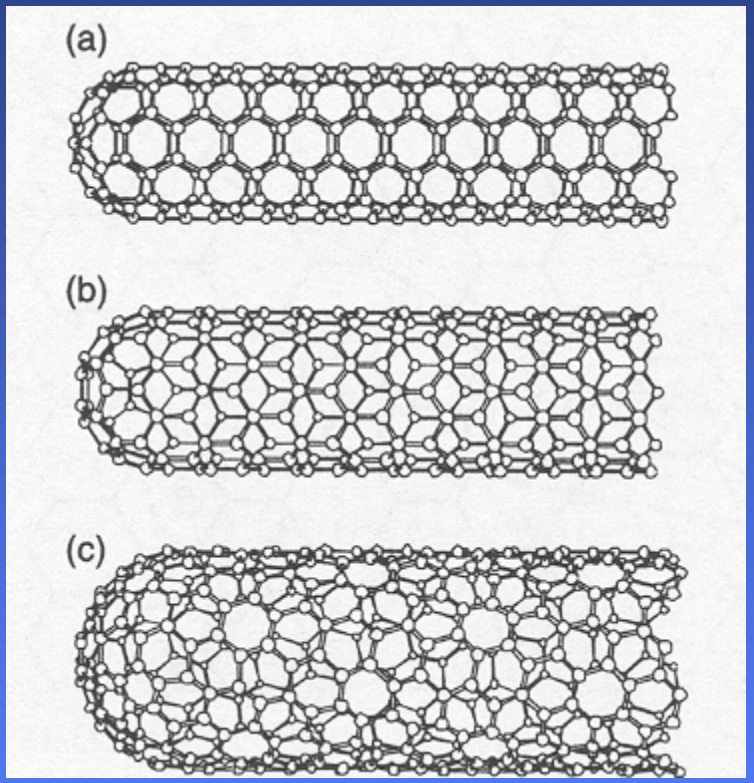
Carbon nanotubes (CNT)



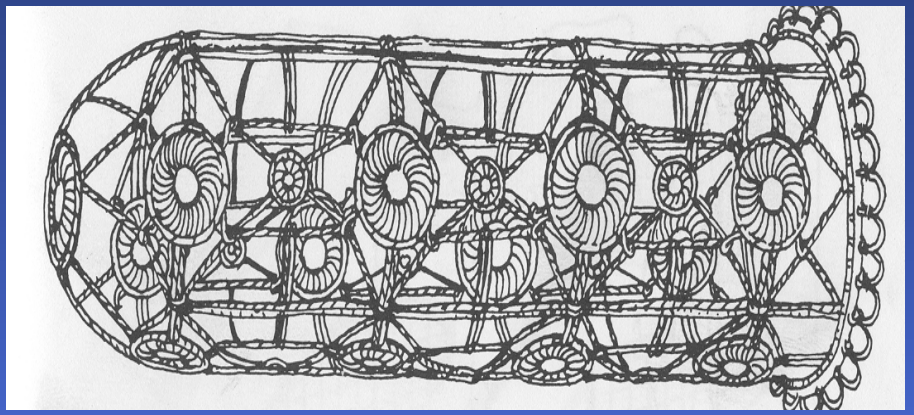


What are nanomaterials and nanoparticles?

Nanotubes de carbone



Current CNT models



First model published by Carelman in 1969 in his book « Catalogue d'Objets Introuvables » but with a different caption: lace condom

F12 — Préservatif en dentelle. Se fait à la demande en point d'Alençon, de Bruges, de Bruxelles, etc. Élégant et raffiné.

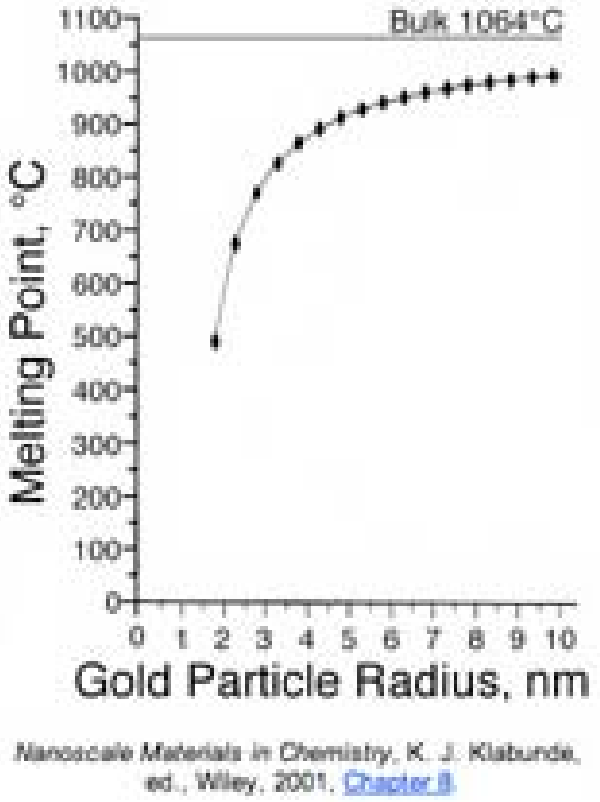
What are nanomaterials and nanoparticles?

Properties

Macroscale vs. Nanoscale Gold

Which properties are the same?

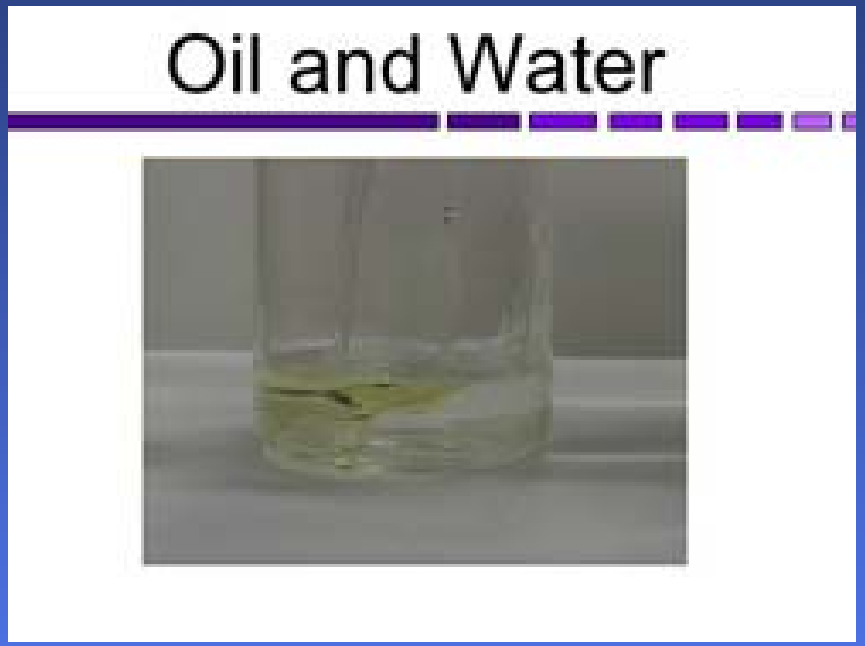
- Color?
- Melting Point?

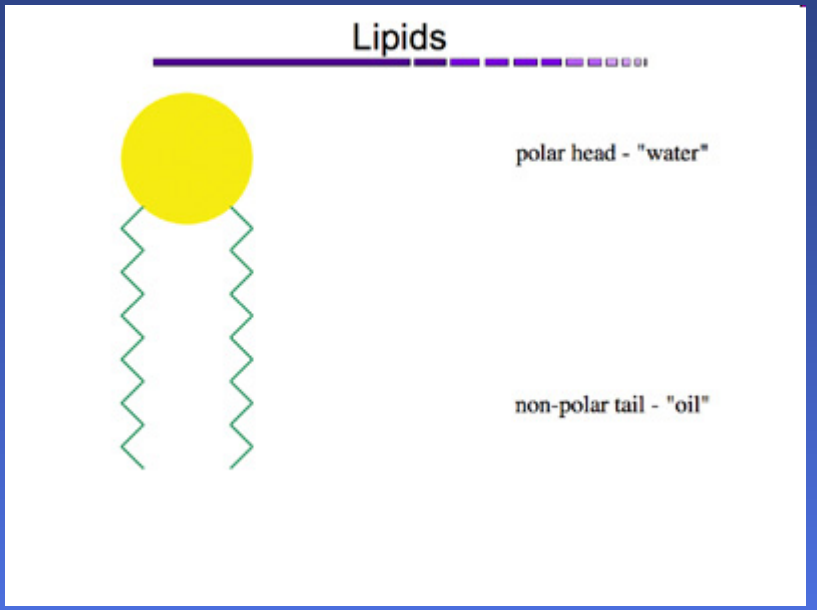


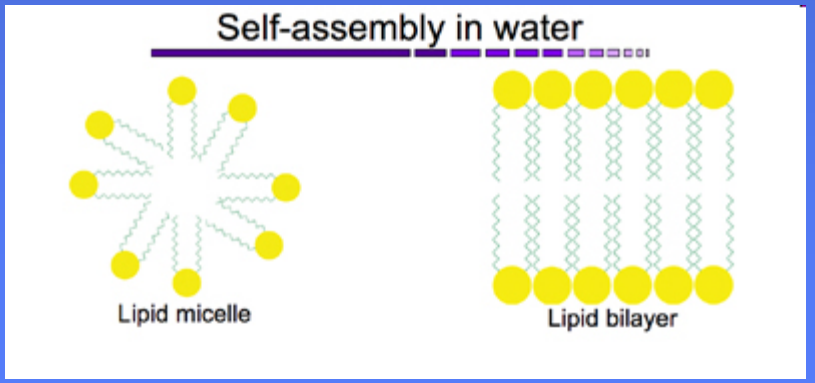
Nanoscale Materials in Chemistry, K. J. Klabunde, ed., Wiley, 2001, Chapter 8

What are nanomaterials and nanoparticles?

Surfaces and interfaces are key parameters



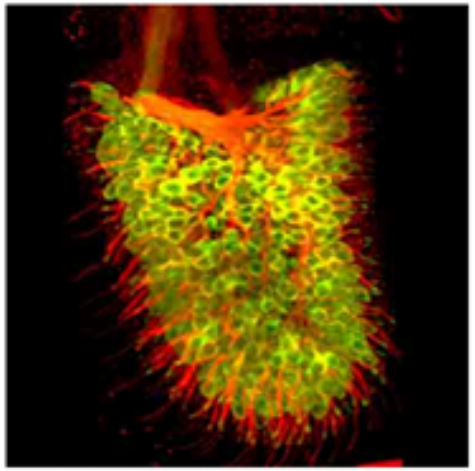




What are nanomaterials and nanoparticles?

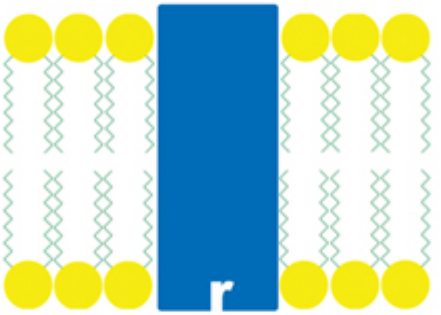
Surfaces and interfaces are key parameters

Olfactory Receptor Neurons



http://www.life.uiuc.edu/hing/research/flyfig1.html

Odor Receptor Protein



This olfactory receptor neuron will only respond to molecules shaped like the letter "r".

Sense of smell

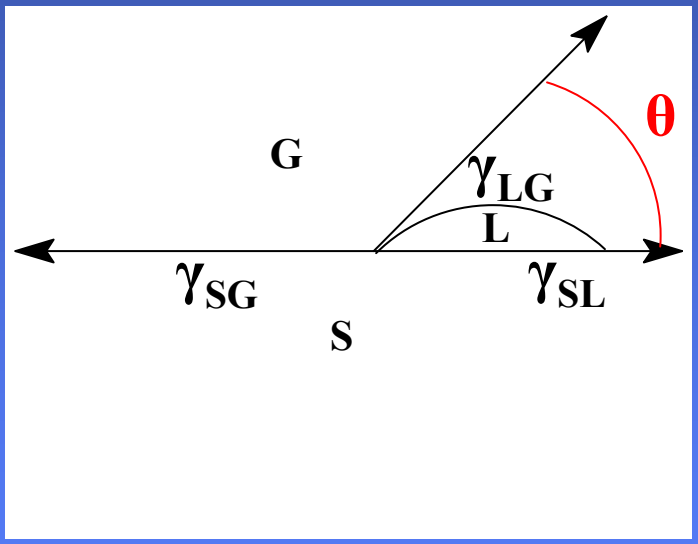
Some odors contain many different molecules. A different odor receptor protein senses each.

What are nanomaterials and nanoparticles?

Surfaces and interfaces are key parameters: surface energy and surface thermodynamics

➔ Surface tension γ (in $mN.m^{-1}$)

➔ Wetting angle θ ➔ Young's equation: $\gamma_{SL} + \gamma_{LG} \cos\theta = \gamma_{SG}$



$\Theta < 90^\circ$ hydrophilic surface
= good wettability

$\Theta > 90^\circ$ hydrophobic surface
= bad wettability

$\Theta > 140^\circ$ superhydrophobic surface

Video ➔ magic sand

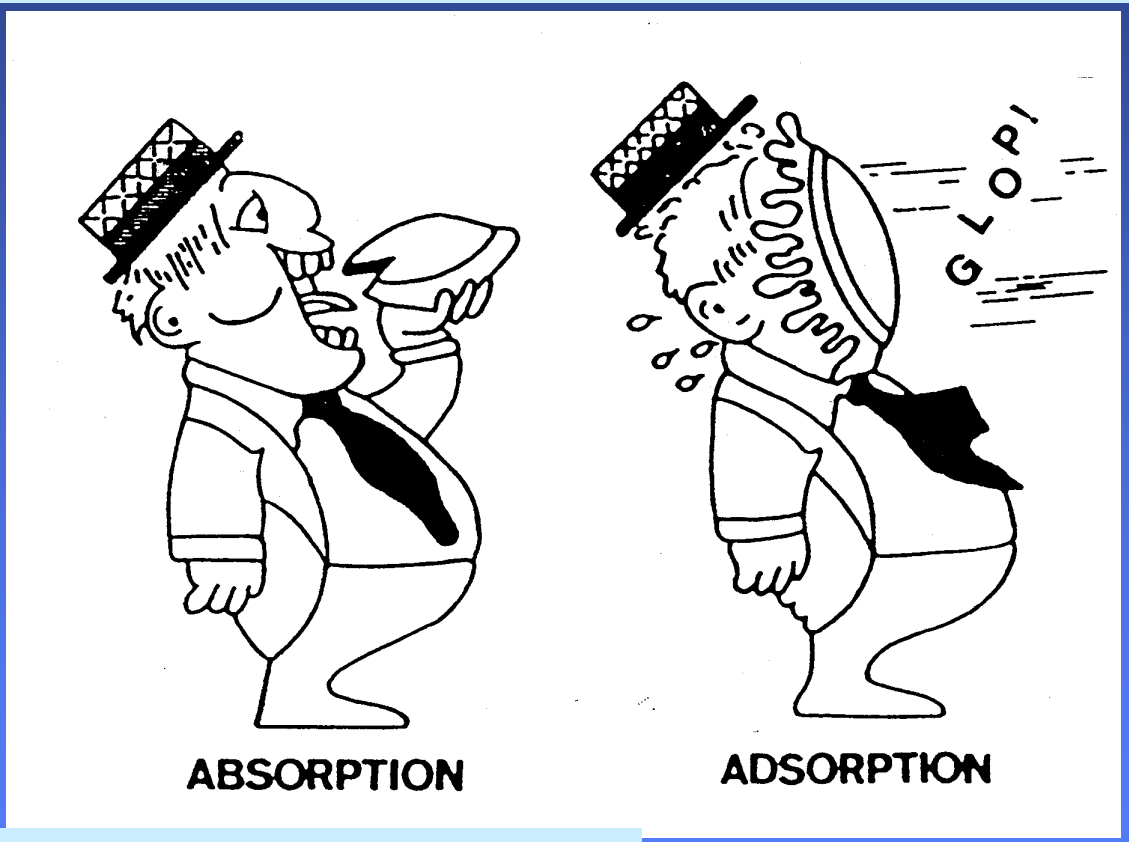
What are nanomaterials and nanoparticles?

Surfaces and interfaces are key parameters: surface energy and surface thermodynamics

➔**An experiment with ballons: pressure versus curvature radius**

What are nanomaterials and nanoparticles?

Surfaces and interfaces are key parameters: do not mix up adsorption and absorption!
Adsorption is a surface process



Video ➔ superadsorbant

Outline

What are nanomaterials and nanoparticles?

How can we obtain them?

Could we see them?

- Optical and electronic microscopy
- Atomic force microscopy

Applications

Conclusion : toxicity and ethical concerns

How can we obtain them?

Formation of nanomaterials:

- Milling: 1 cube with 1 mm edge length leads to 10^9 cubes with 1 µm edge length and to 10^{18} cubes with 1 nm edge length !!
- Incomplete combustion ie: soot containing fullerenes
- Catalytic decomposition: CNT
- Torch decomposition: alumina, silica, titanium oxide
- Chemical synthesis: molecular engines ➔ video

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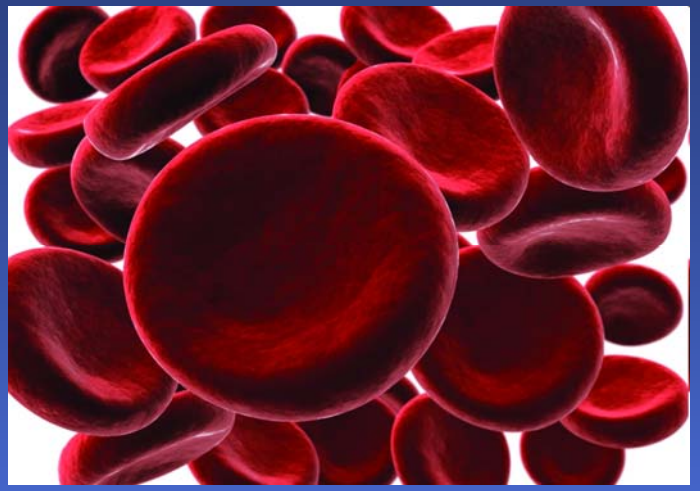
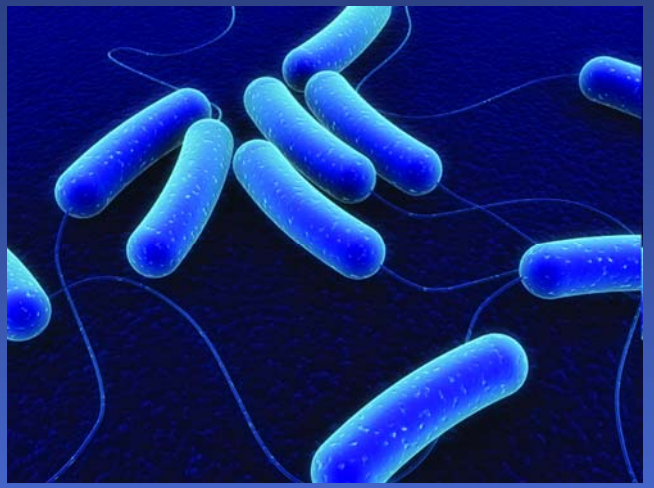
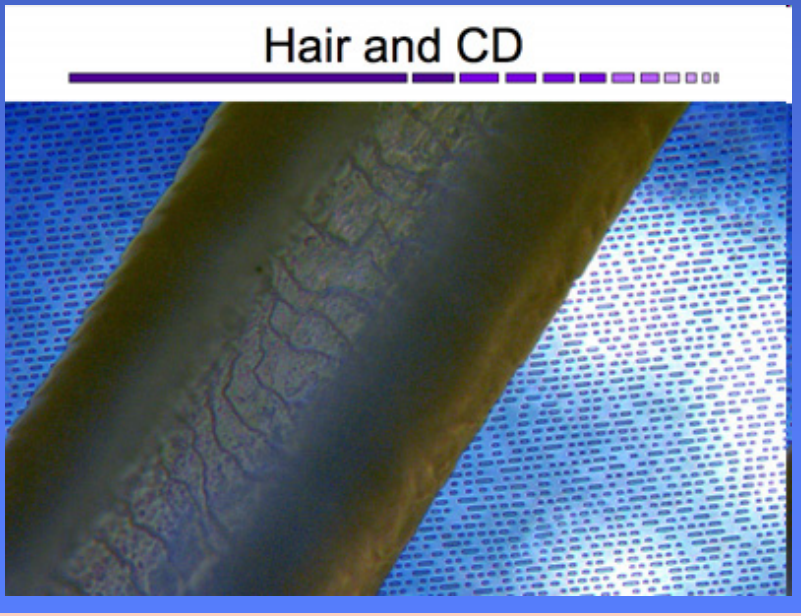
Could we see them?

Optical microscopy: up to micrometer



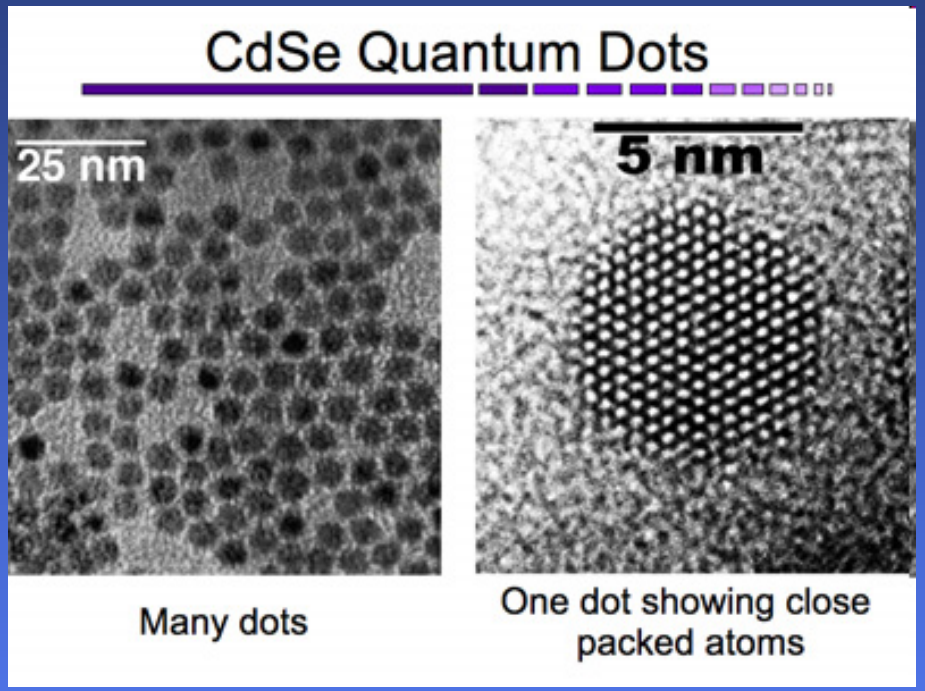


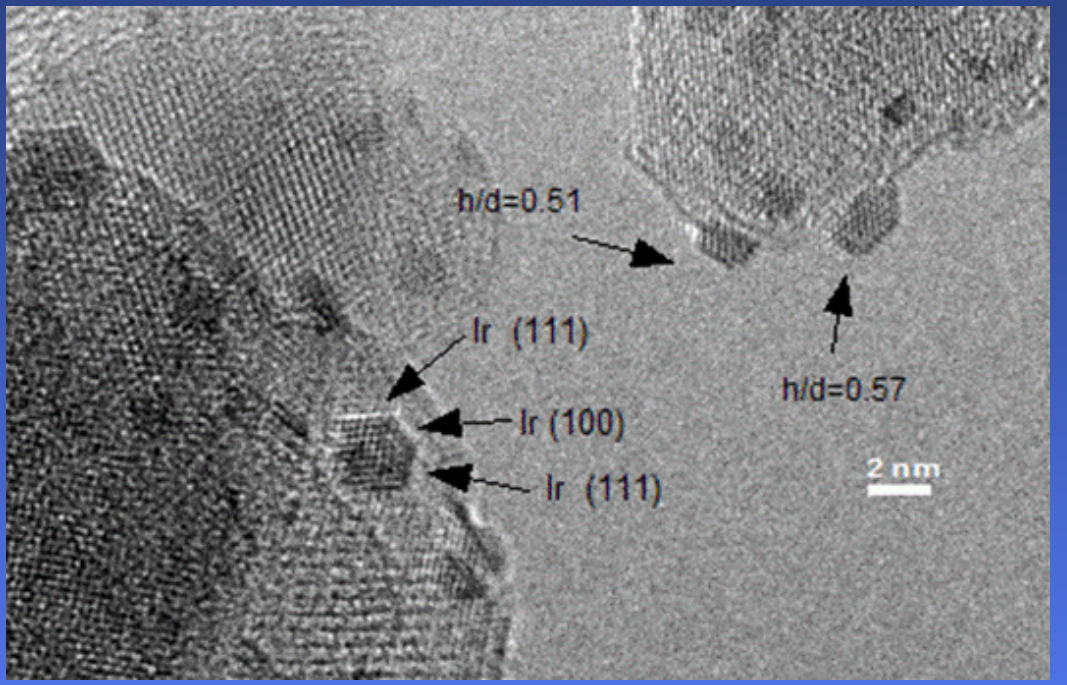
Red cells (6-10 μm) – Bacteria (5-20 μm)



Could we see them?

Electron microscopy





Cadmium selenide nanoparticles

Iridium nanoparticles on alumina substrate

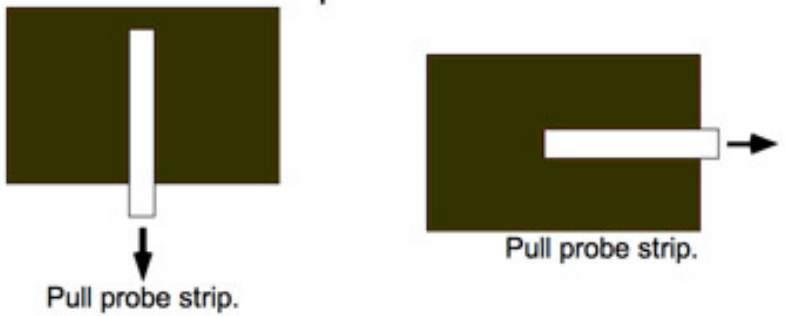
Could we see them?

STM (Scanning Tunneling Microscopy) ➔ an experiment

Refrigerator Magnet

Imaging

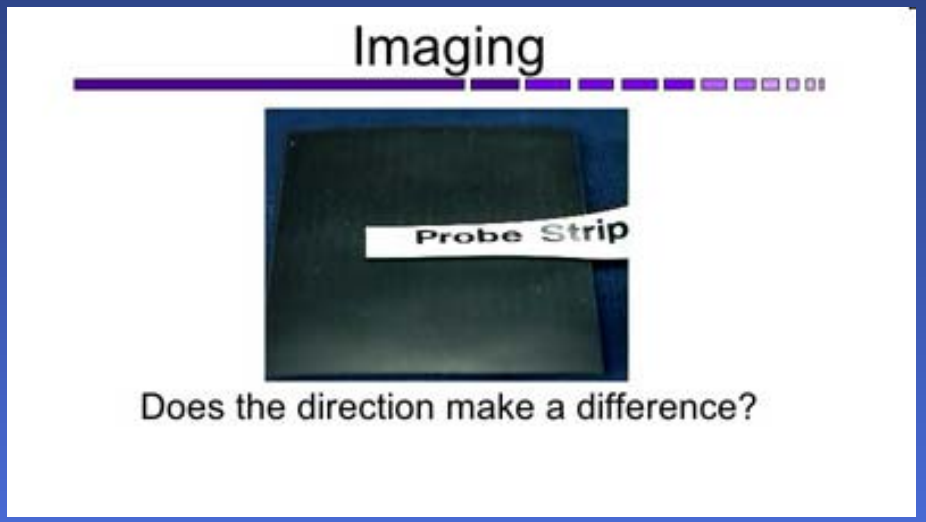
Remove strip from a refrigerator magnet to make a probe.

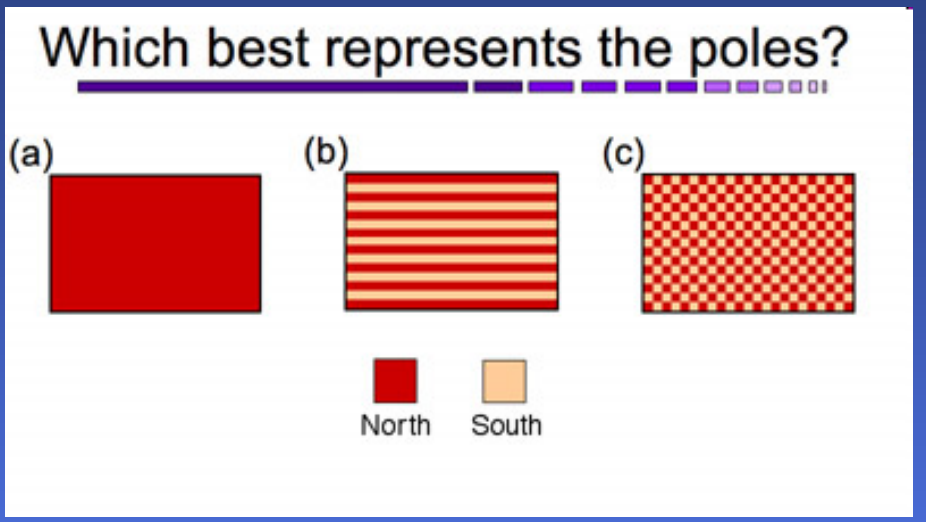


Does the direction make a difference?

Could we see them?

STM (Scanning Tunneling Microscopy) ➔ an experiment





Could we see them?

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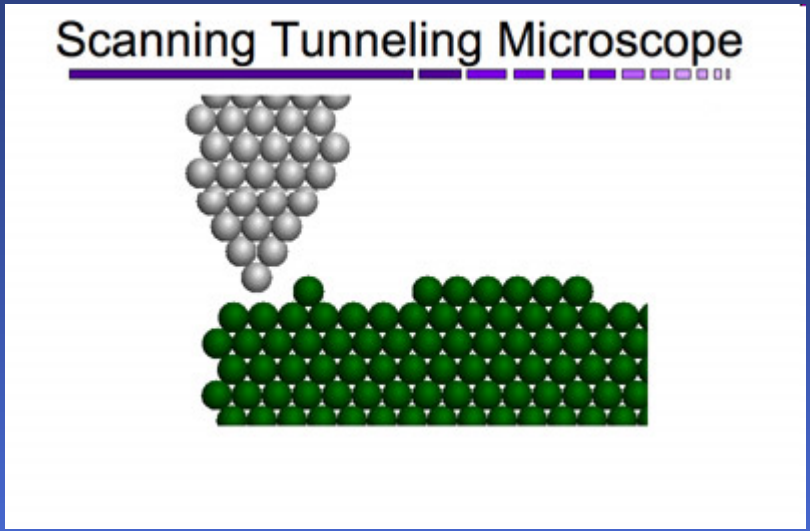
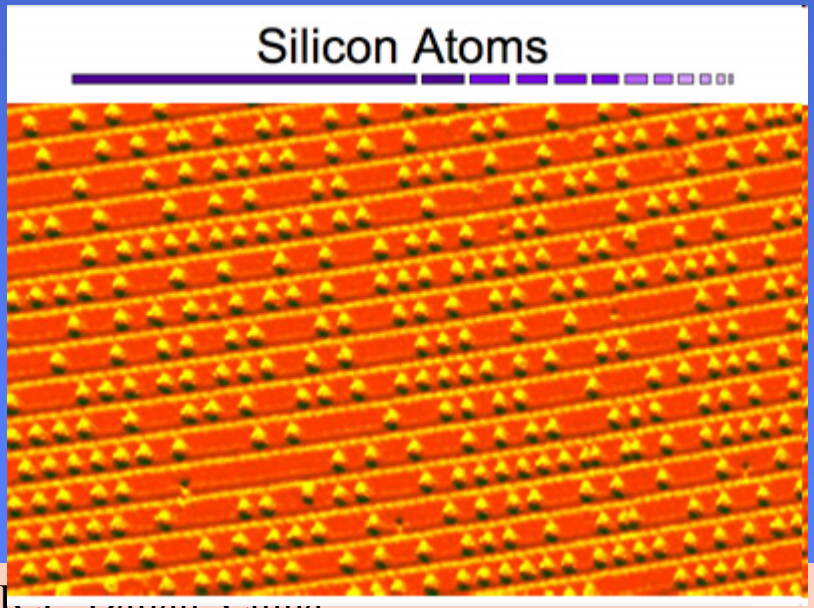
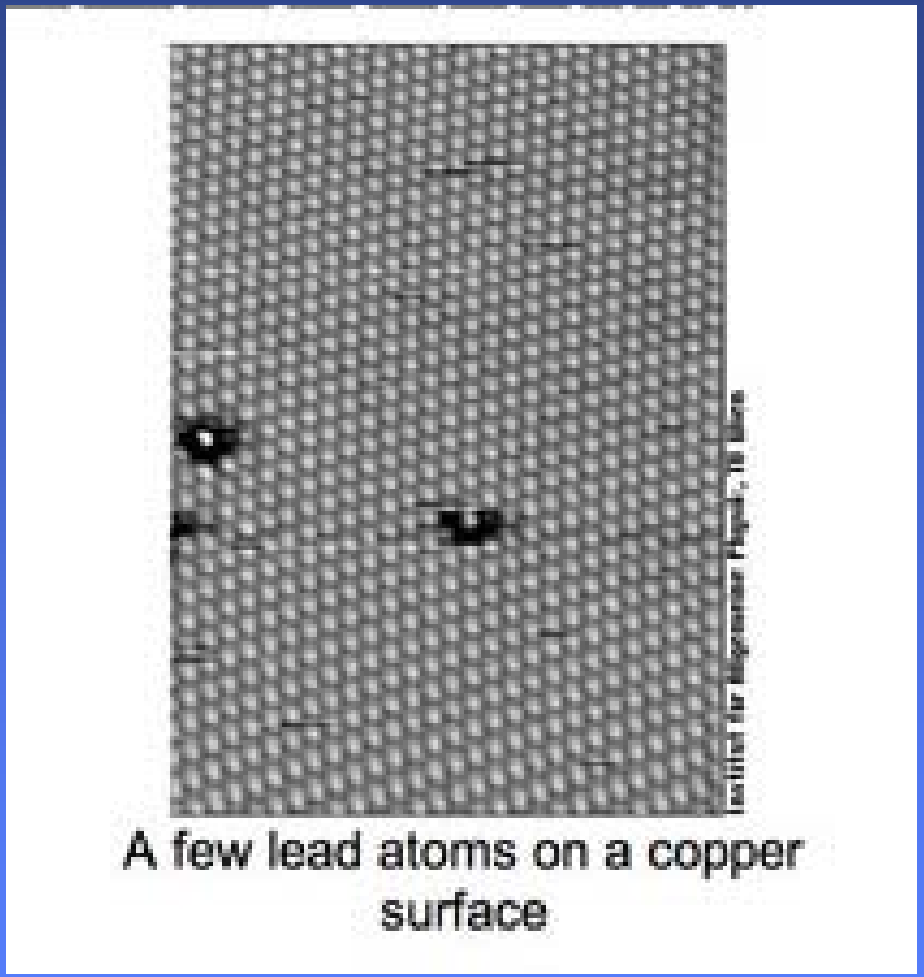
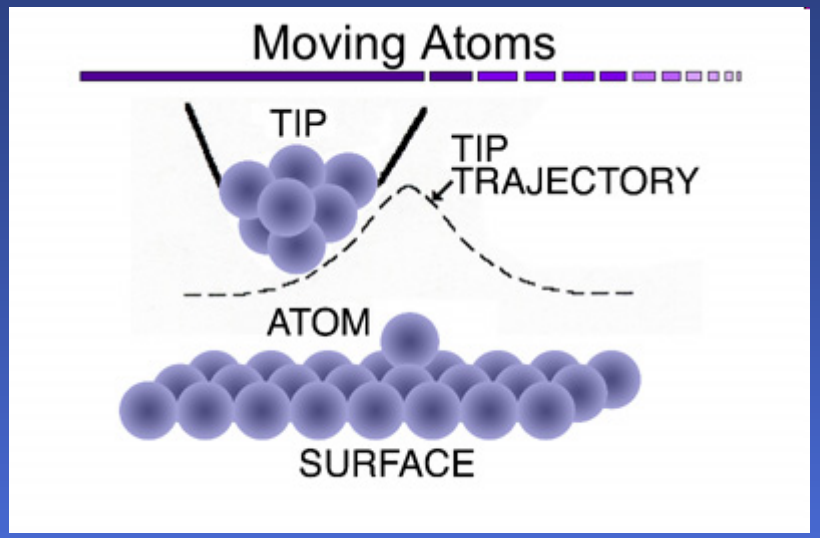


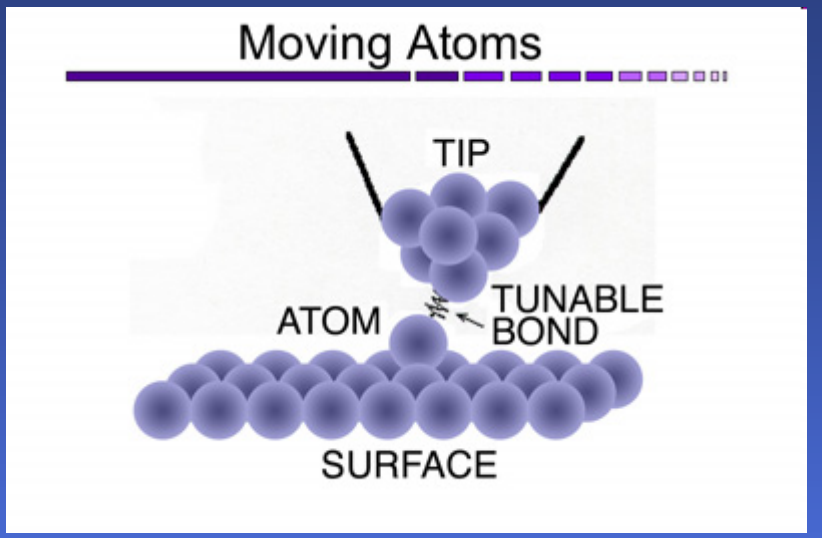


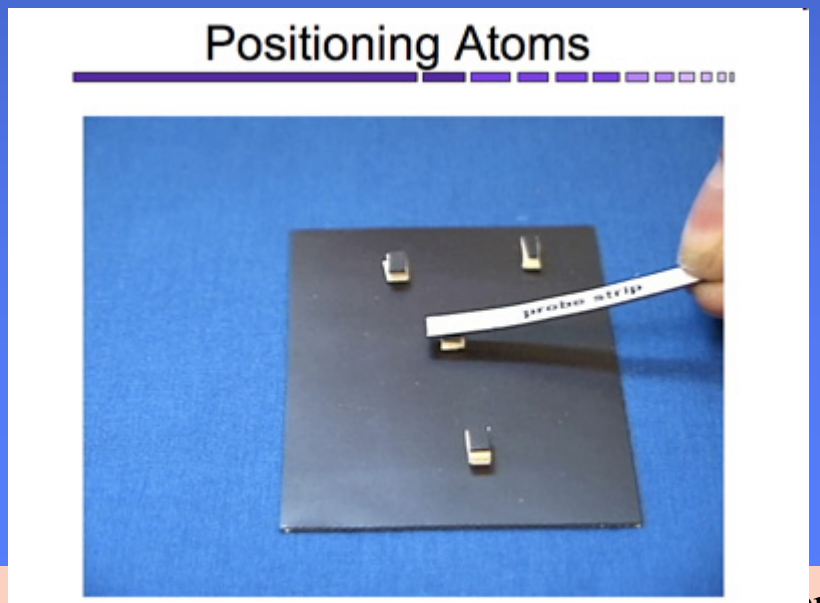

A few lead atoms on a copper surface

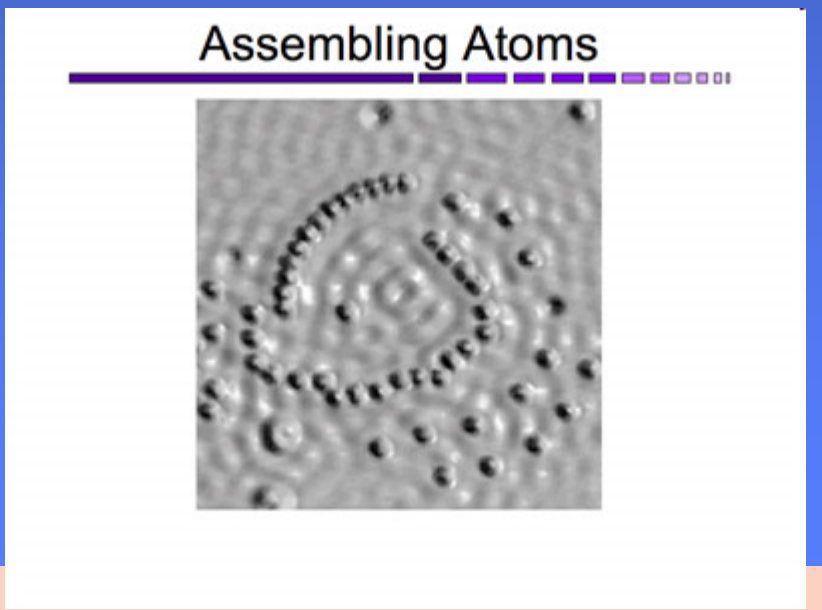
Could we see them and move them?

AFM (Atomic Force Microscopy)





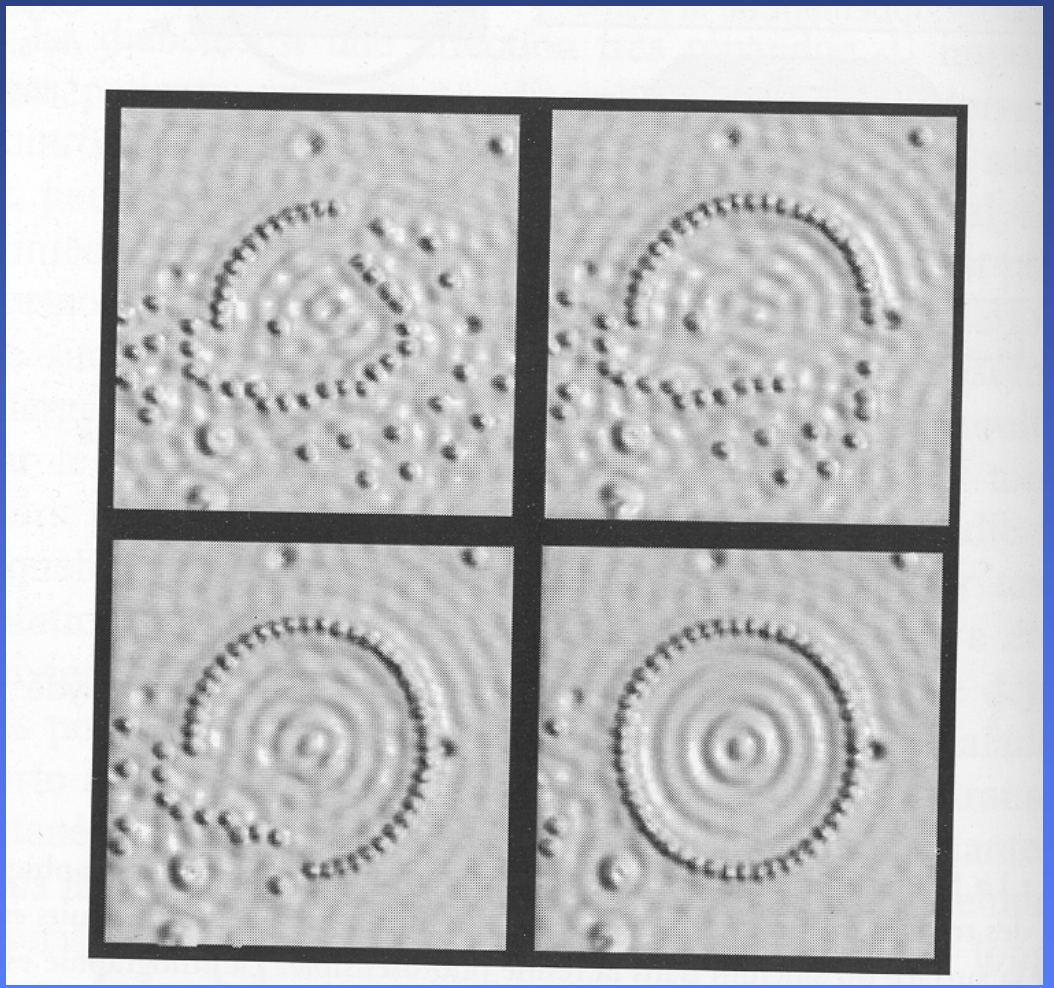




Could we see them and move them?

AFM (Atomic Force Microscopy)

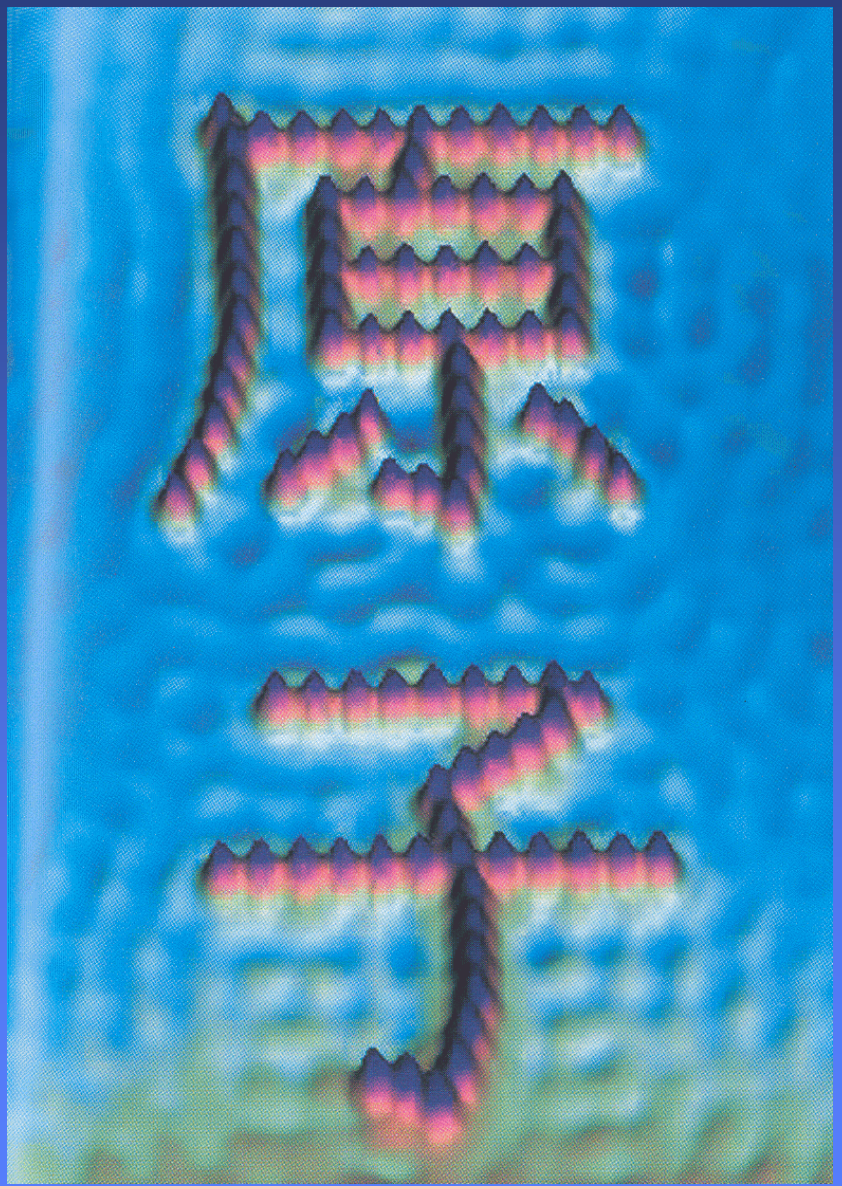
How to draw a circle with iron atoms randomly deposited on copper. The Fe atoms are displaced one by one by the tip of a AFM



Could we see them and move them?

AFM (Atomic Force Microscopy)

Japanese character (kanji) meaning atoms
Iron atoms on copper



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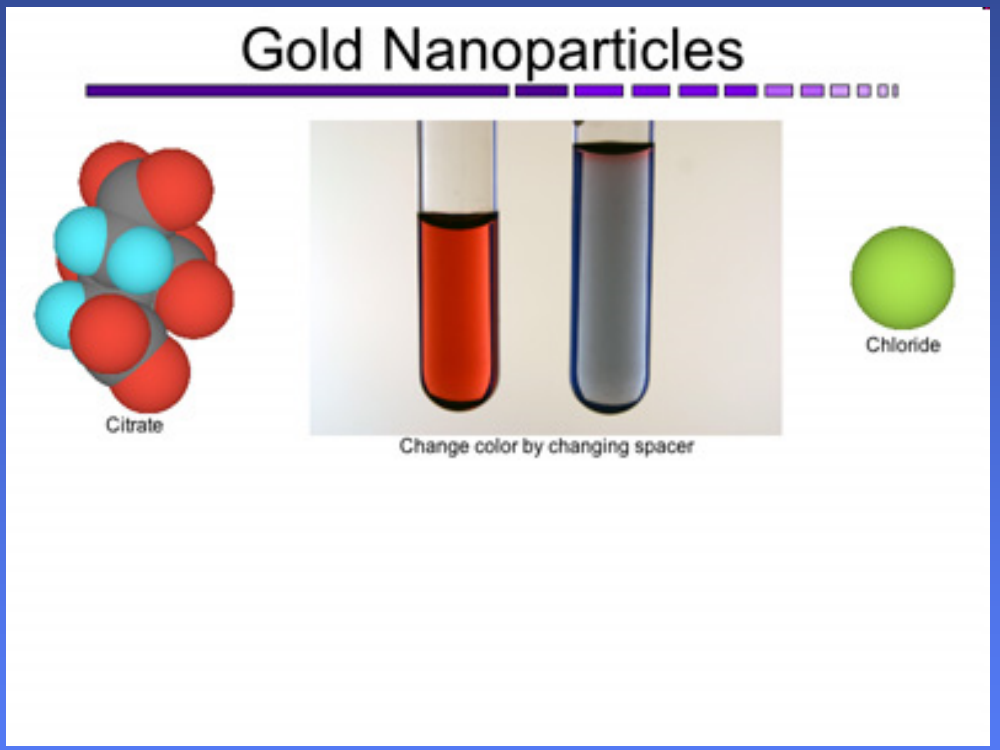
Conclusion : toxicity and ethical concerns

Applications of nanomaterials

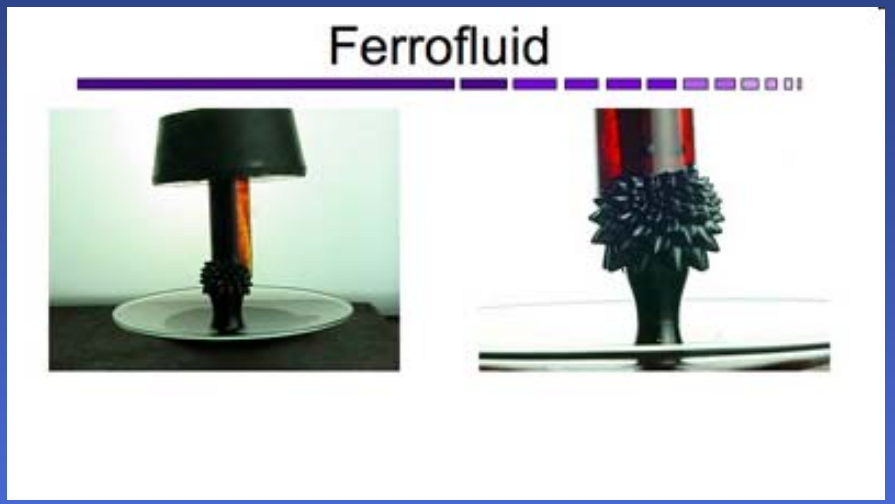
Gold nanoparticles

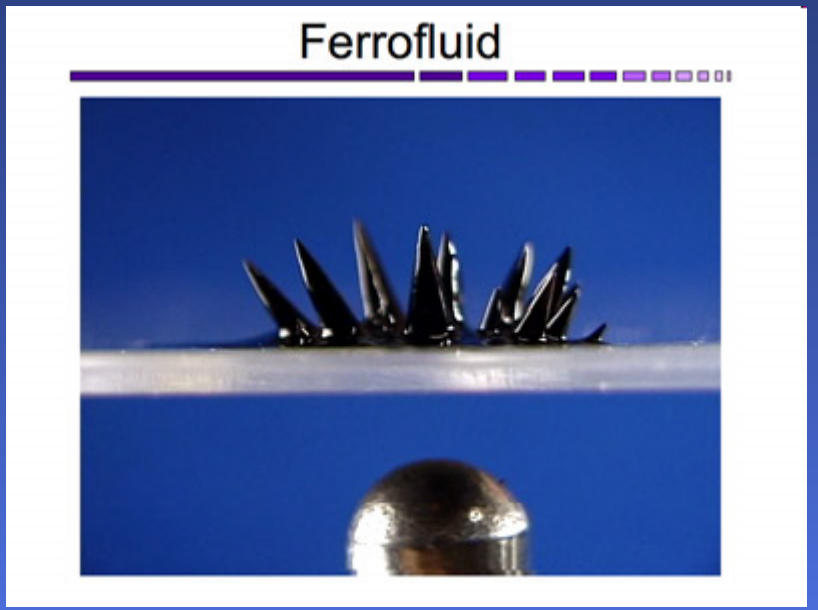
- catalysis
- medicine

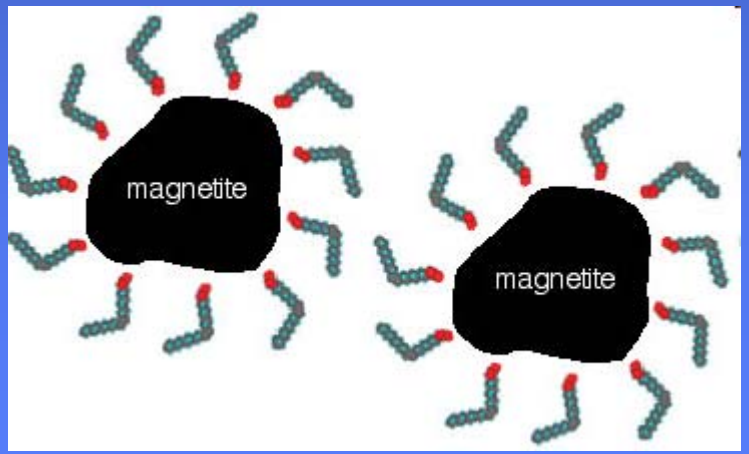


Applications of nanomaterials

Magnetism and ferrofluids ➔ video







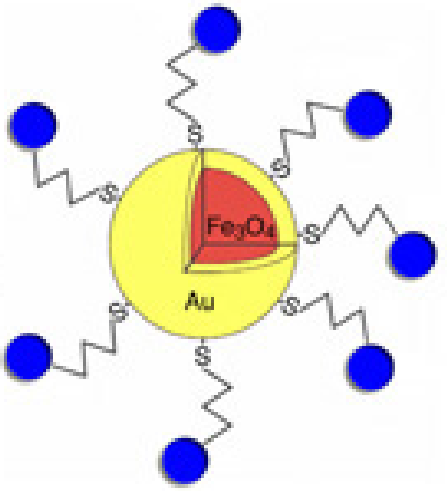
Applications of nanomaterials

Magnetism and ferrofluids

Medical Applications

Coat with drugs, antibodies, peptides, or oligonucleotides

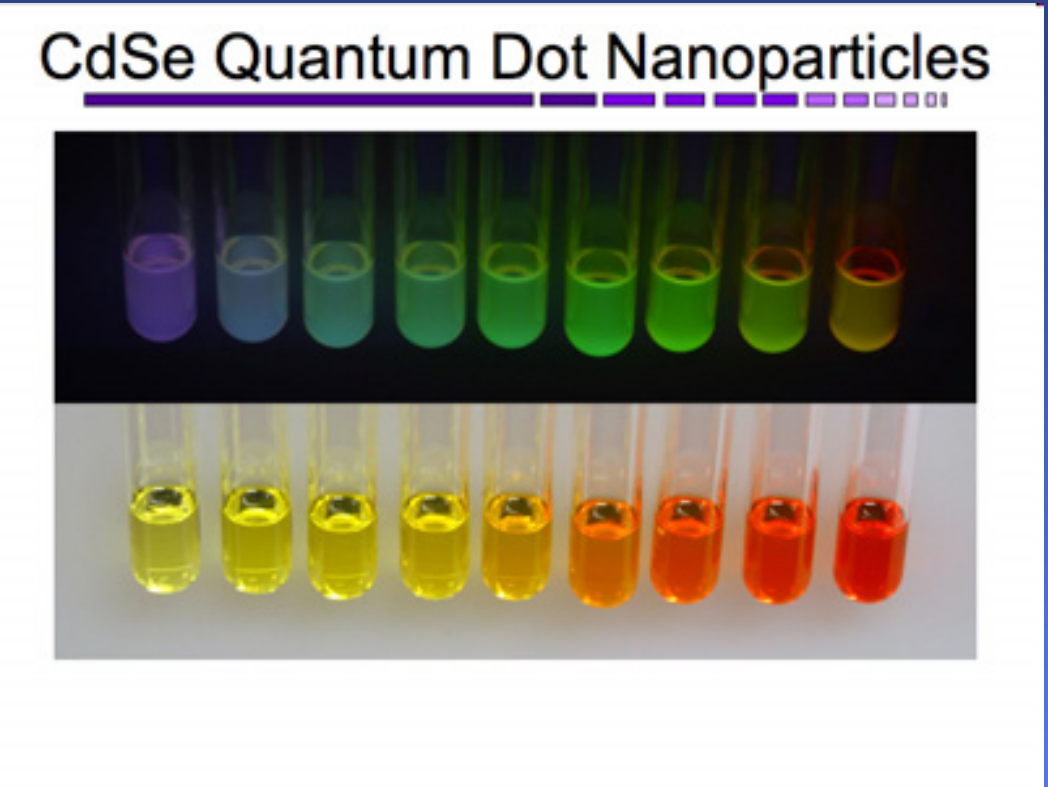
Use magnetic fields to position
- Deliver drugs to targets (especially for chemotherapy)
- "Tag and drag" removal (especially for toxins)

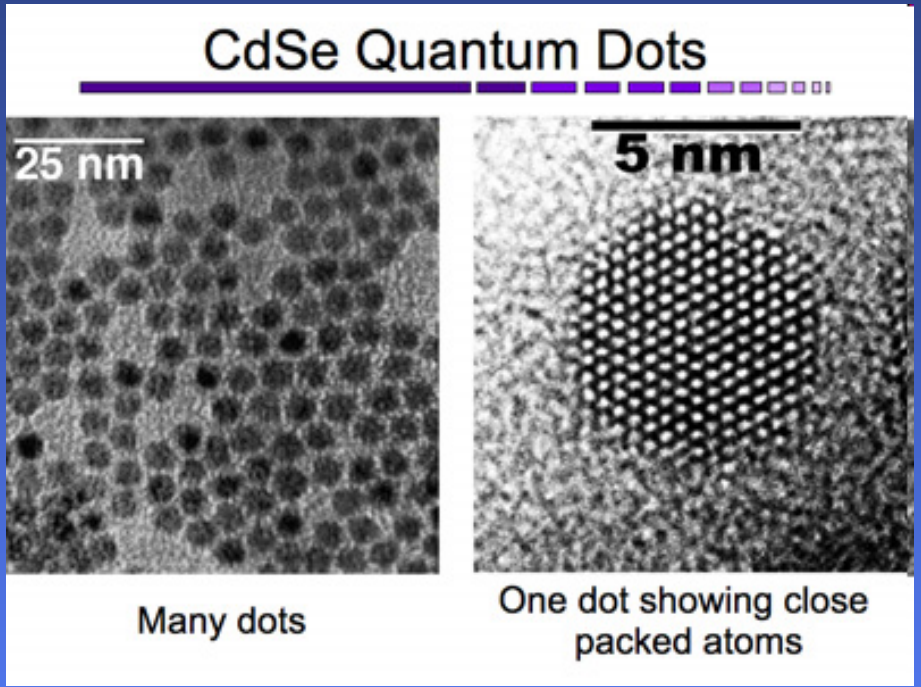


Paula Gould, "Nanoparticles Probe Biosystems," Materials Today, Feb 2004, pages 36-43.

Applications of nanomaterials

Semiconductors and quantum dots

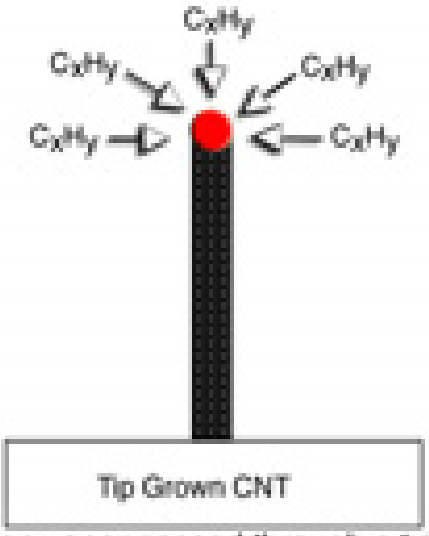




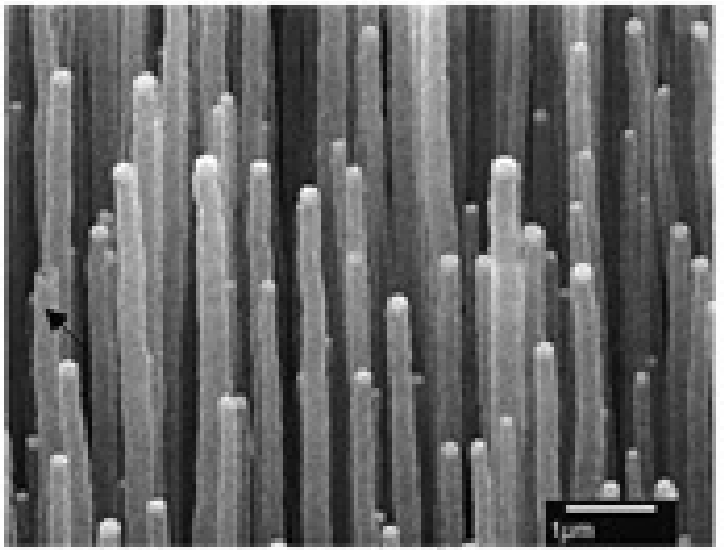
Applications of nanomaterials

Carbon nanotubes: synthesis

Carbon Nanotube Synthesis



Hydrocarbon vapor passed through a tube furnace in presence of a catalyst.



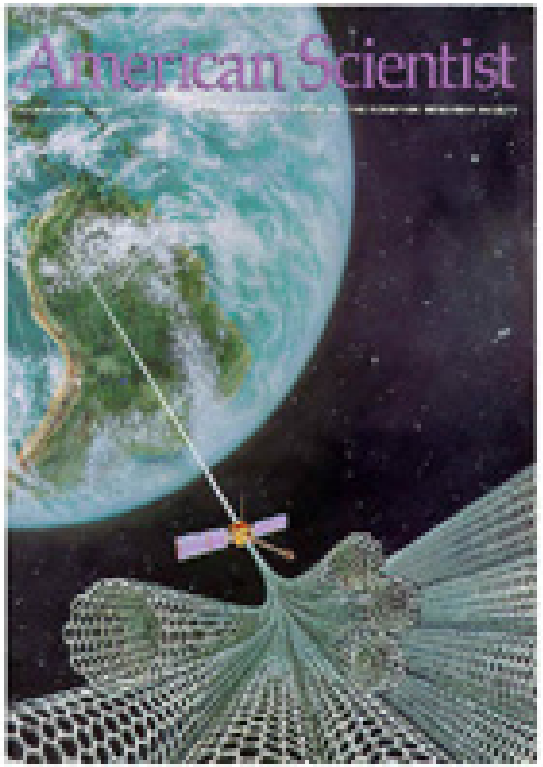
A nickel cap is on the tip of each nanotube (except arrow).

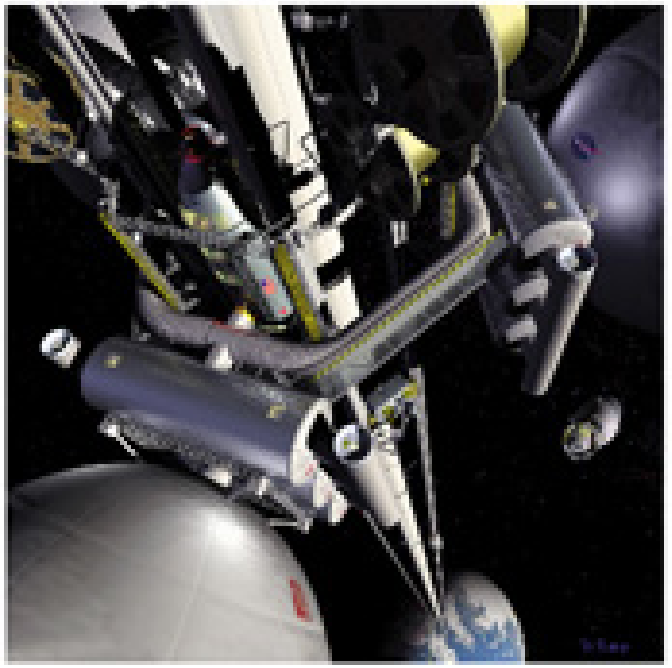
- Yoshinori Ando, Xinluo Zhao, Toshiki Sugai, and Mukul Kumar, "Growing Carbon Nanotubes," *Materials Today*, Oct 2004, pages 22-49.
- Z. F. Ren, Z. P. Huang, J. W. Xu, J. H. Wang, P. Bush, M. P. Siegal, P. N. Provencio, "Synthesis of Large Arrays of Well-Aligned Carbon Nanotubes on Glass," *Science*, 282, 1105-1107 (1998).

Applications of nanomaterials

Carbon nanotubes: a space elevator

Space Elevator



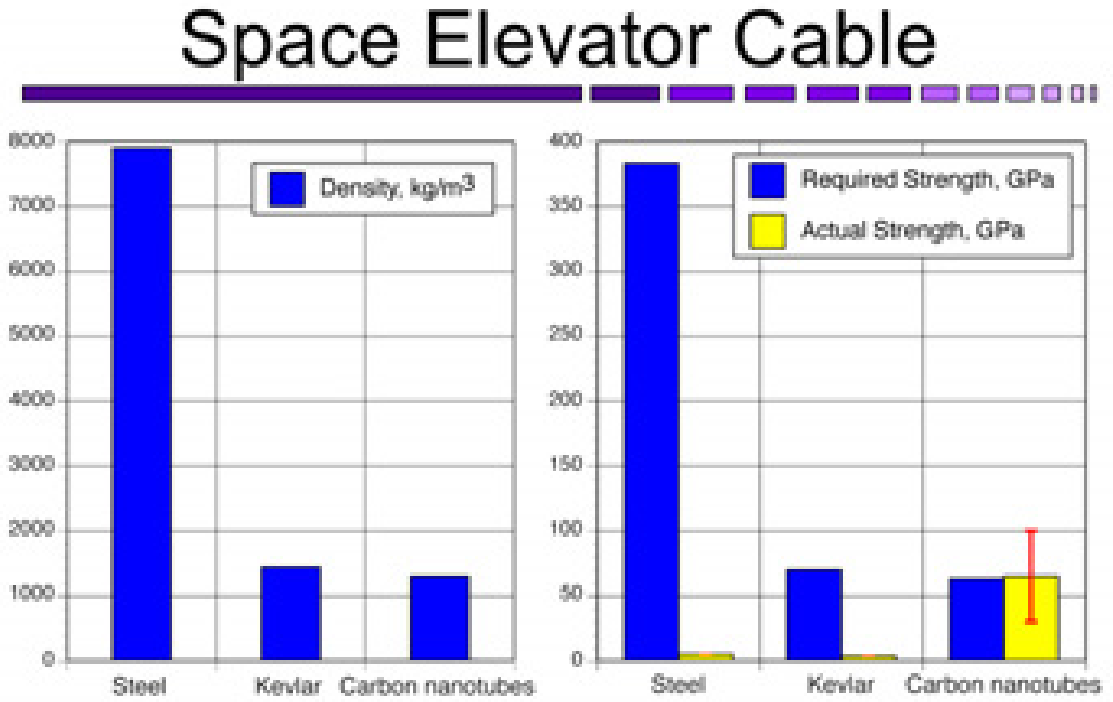


http://flightprojects.msfc.nasa.gov/fd02_elev.html

http://www.americanscientist.org/template/AssetDetail/assetid/26780

Applications of nanomaterials

Carbon nanotubes: a space elevator



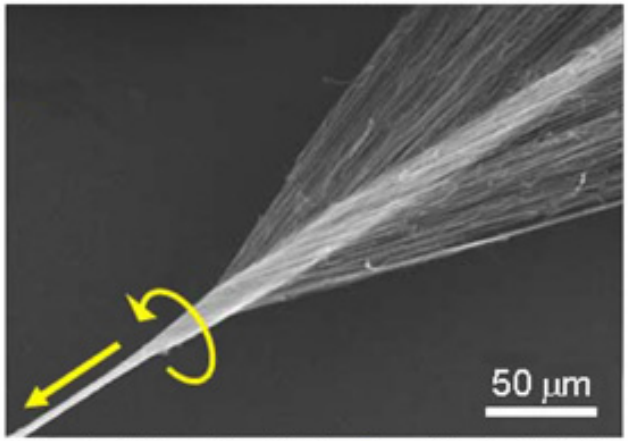
Space Elevator Cable

- Need high strength, low density
  - Longest carbon nanotube ~ 1 cm
  - Geosynchronous orbit at 36,000 km
- Defects reduce strength
  - Longer nanotubes have more defects
  - Oxygen atoms and micrometeorites produce defects

Applications of nanomaterials

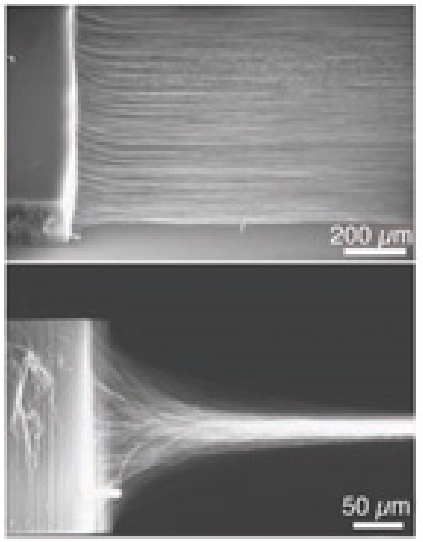
Carbon nanotubes: shape forming

Spinning Carbon Nanotubes



Mei Zhang, Ken R. Atkinson, and Ray H. Baughman, Science, 19 November 2004, 1358-1361.

Carbon Nanotube Sheets



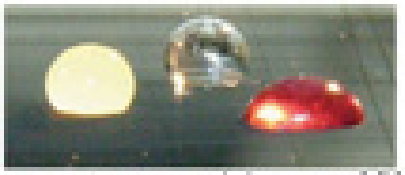
Pull 5 cm x 1 m-long sheet at 1 m/min.

Mei Zhang, Shaoli Fang, Anvar A. Zakhidov, Sergey B. Lee, Ali E. Aliev, Christopher D. Williams, Ken R. Atkinson, Ray H. Baughman, "Strong, Transparent, Multifunctional, Carbon Nanotube Sheets," *Science*, 19 August 2005, 1215-1219.

Applications of nanomaterials

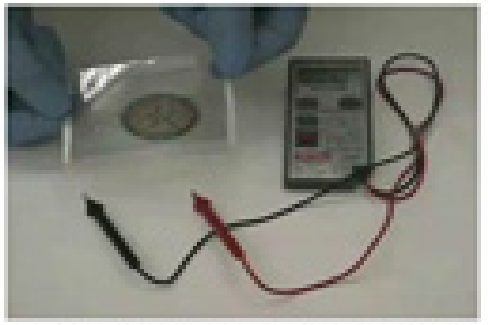
Carbon nanotubes: shape forming
(MWNT = Multi Walled Nano Tubes)

Carbon Nanotube Sheets



Orange juice, water, grape juice on a MWNT sheet.

MWNT sheets are strong, lightweight (0.0015 g/cm^3), transparent, and electrically conducting. They can support millimeter-sized liquid droplets that are 50,000 times their own weight.



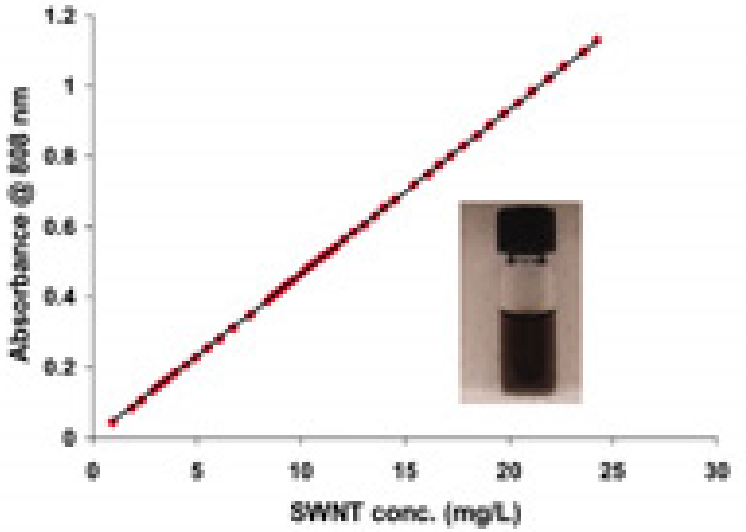
When sandwiched between plastic sheets, MWNT sheets can be bent with no change in electrical conductivity; this is important for flexible electronic circuits.

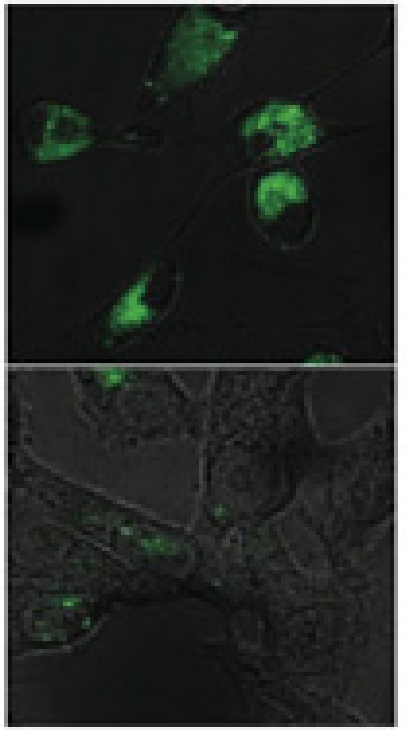
Mei Zhang, Shaoli Fang, Anvar A. Zakhidov, Sergey B. Lee, Ali E. Aliev, Christopher D. Williams, Ken R. Atkinson, Ray H. Baughman, "Strong, Transparent, Multifunctional, Carbon Nanotube Sheets," *Science*, 19 August 2005, 1215-1219.

Applications of nanomaterials

Carbon nanotubes: medical applications

Killing cancer with nanotubes





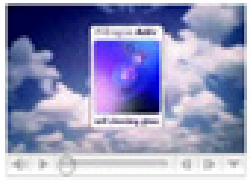
Functionalized carbon nanotubes (green) taken up by cancer cells with folate receptors (top) and normal cells (bottom). Magnification 20x.

N. W. S.Kam, M. O'Connell, J. A. Wisdom, and H. Dai, "Carbon nanotubes as multifunctional biological transporters and near-infrared agents for selective cancer cell destruction," PNAS, 102, 11600-11605, (2005) and Discover Magazine, Nov. 2005.

Applications of nanomaterials

Titanium dioxide and self-cleaning windows

Self-Cleaning Windows



Nanoparticles absorb UV to break down dirt.

Water spreads out on surface to rinse off.

http://www.popularmechanics.com/home_improvement/smart_consumer/1274896.html

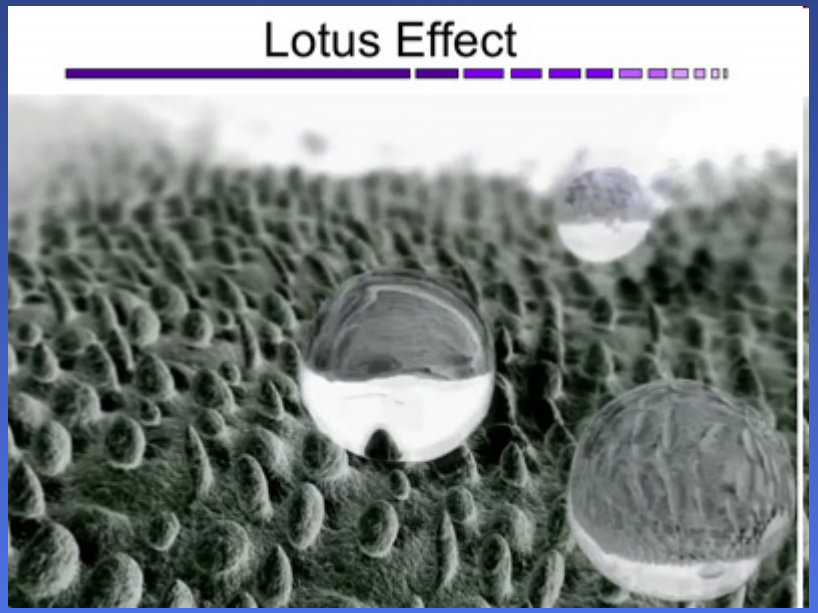
Paula Gould, "Smart, clean surfaces," *Materials Today*, Nov 2003, pages 44-48.
http://www.activglass.com/index_eng.htm
http://www.ppg.com/gls_residential/gls_sunclean/

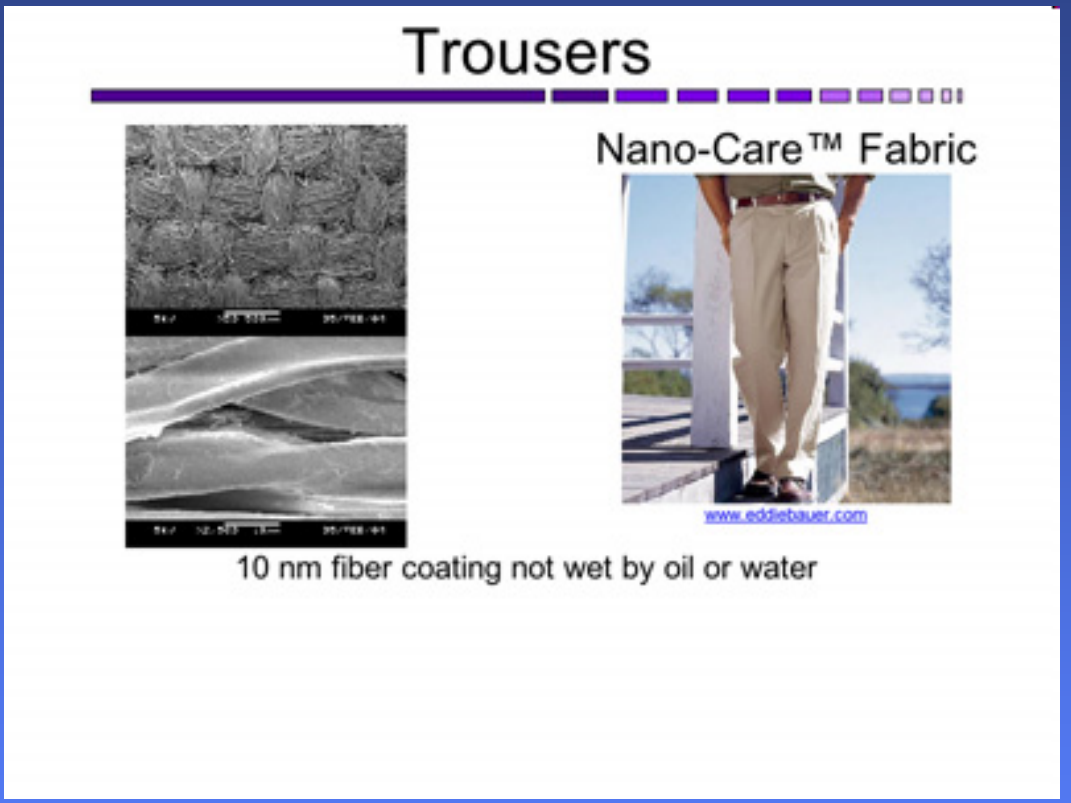
Self-Cleaning Surfaces

Water beads up on uneven surfaces.

Applications of nanomaterials

Superhydrophobic surfaces





Outline

What are nanomaterials and nanoparticles?

How can we obtain them?

Could we see them?

- Optical and electronic microscopy
- Atomic force microscopy

Applications

Conclusion : toxicity and ethical concerns

Conclusion : toxicity and ethical concerns

What is the toxicity of nanoparticles ?
Asbestos, a natural nanomaterial ➔ asbestos fibers and cancer
A discussion about ethics ➔ video

Minerals contenaing asbestos | Asbestos fibers | Electron microscopy view