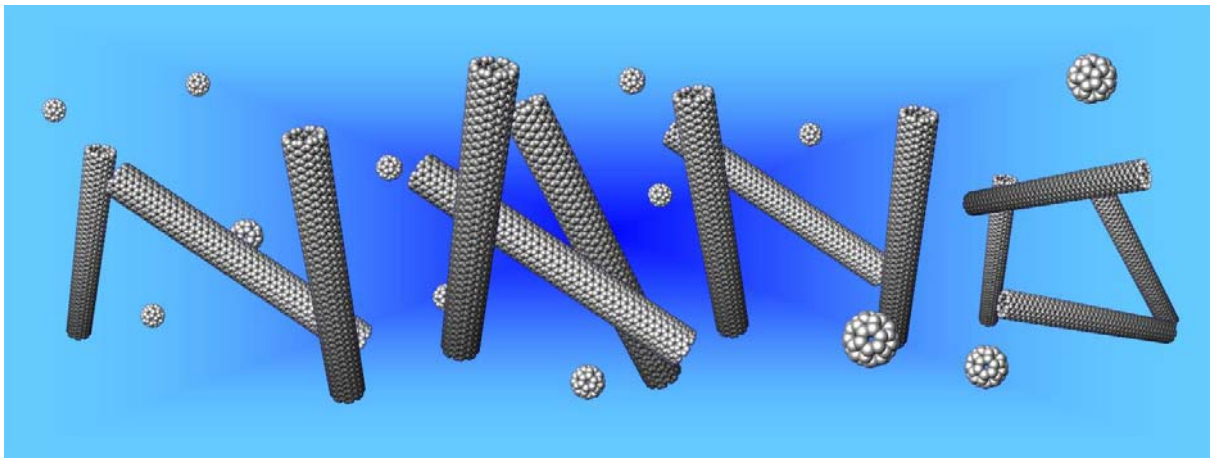


Materials

Definitions of nanotechnology

The term “nanotechnology” was invented by Professor Norio Taniguchi at the University of Tokyo in 1971.

The original definition, translated into English

“’Nano-technology' is the production technology to get the extra high accuracy and ultra fine dimensions, i.e. the preciseness and fineness on the order of 1 nm (nanometer), 10^{-9} meter in length.”

Definitions of nanotechnology

NASA's definition

"Nanotechnology is the creation of functional materials, devices and systems through control of matter on the nanometer length scale (1-100 nanometers), and exploitation of novel phenomena and properties (physical, chemical, biological, mechanical, electrical...) at that length scale."

Nanotechnology; early days

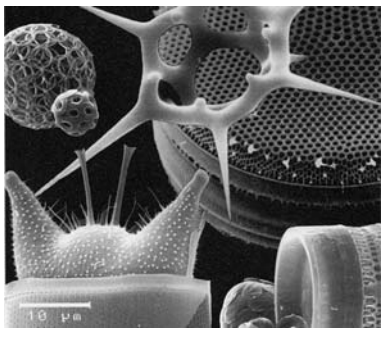
- **Ca. 400 A.D.: Glass coloured by Ag and Au nanoparticles (Lycurgus cup, British Museum)**
- **Paintings: Au particles**
- **19'th century: Photography; Ag-nanoparticles.**
- **1857: Michael Faraday: How metal particles affects the colour of church windows**
- **1908: Gustav Mie: Explanation of dependence of colour of glasses on metal size and kind**
- **1950-1960: Small metal particles**
- **1960s: Ferrofluids**

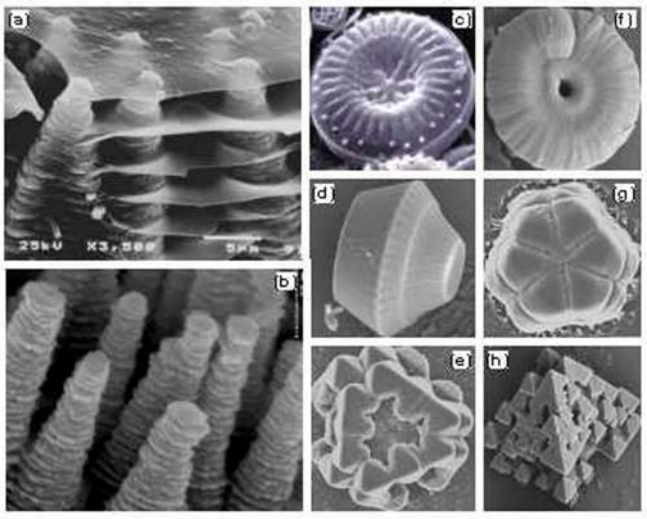
Lycurgus cup, British Museum

Nanotechnology; even earlier days

Nano-structures in nature

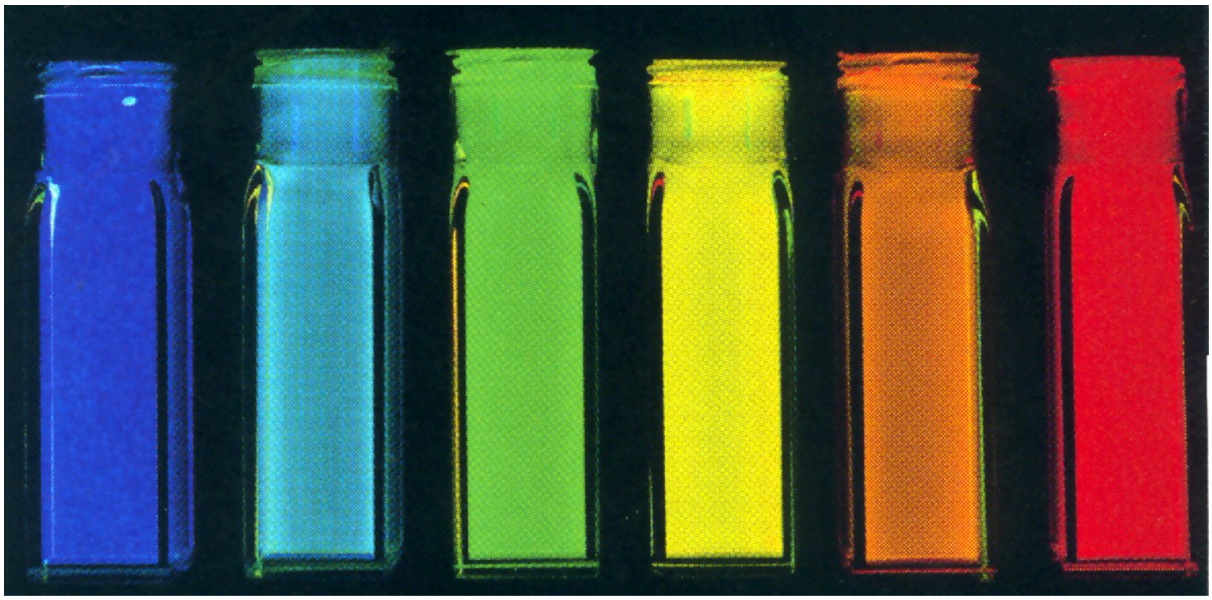
- **Shell: nanobricks and nanoglue**
- **Nanomotors**
- **Nanostructure**





Complex nanostructed crystals have been prepared showing striking similarities with those observed in biominerals. (a) is nacre in red-abalone. (b) is synthetic ZnO crystals. (c) is a diatom. (d) to (h) are different types of synthetic silica crystals. The morphology depends on the growth conditions and can be controlled.

Particle size dependent luminescence of CdSe



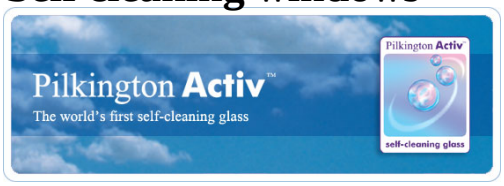
Applications of nanotechnology

Medicine; diagnostics, therapy
Genomics; sequencing?

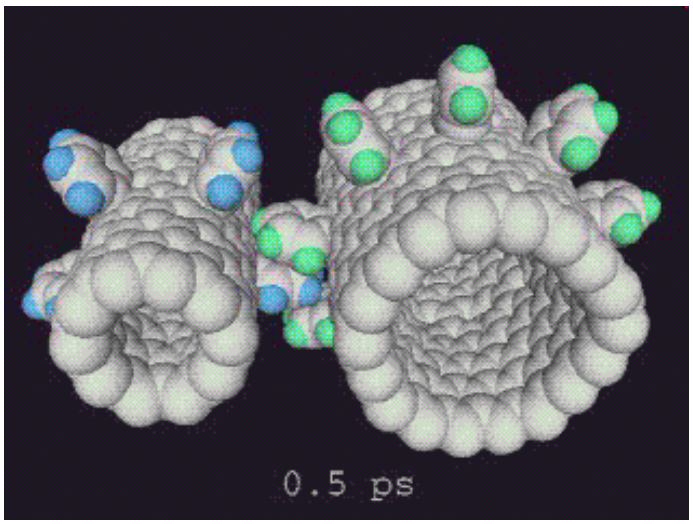
Nano-electronics
Actuators
Nanorobots
catalysis
…

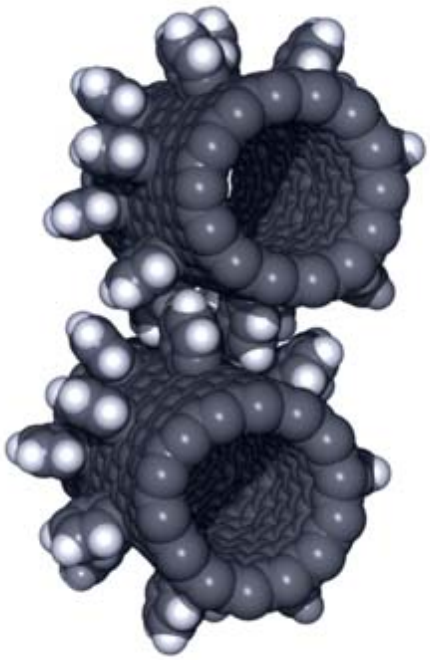
Ferrofluids

Self cleaning windows

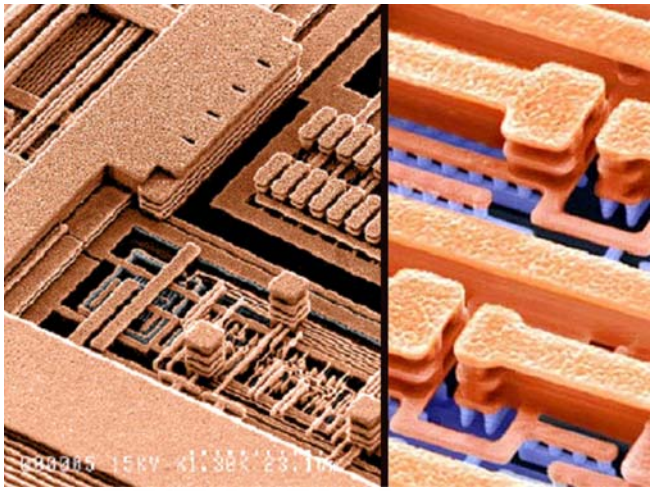


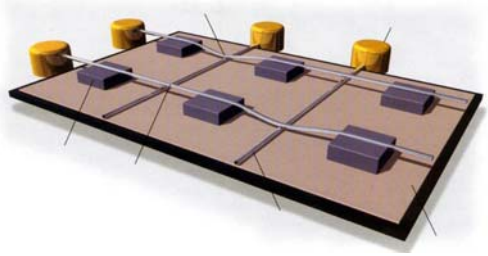
Nano-gear

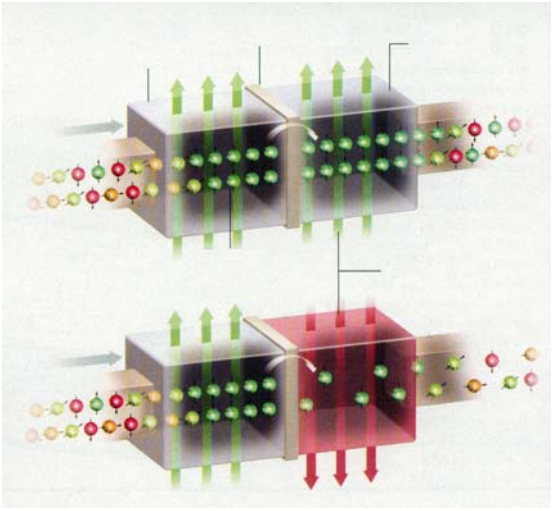




Electronics-Spintronics







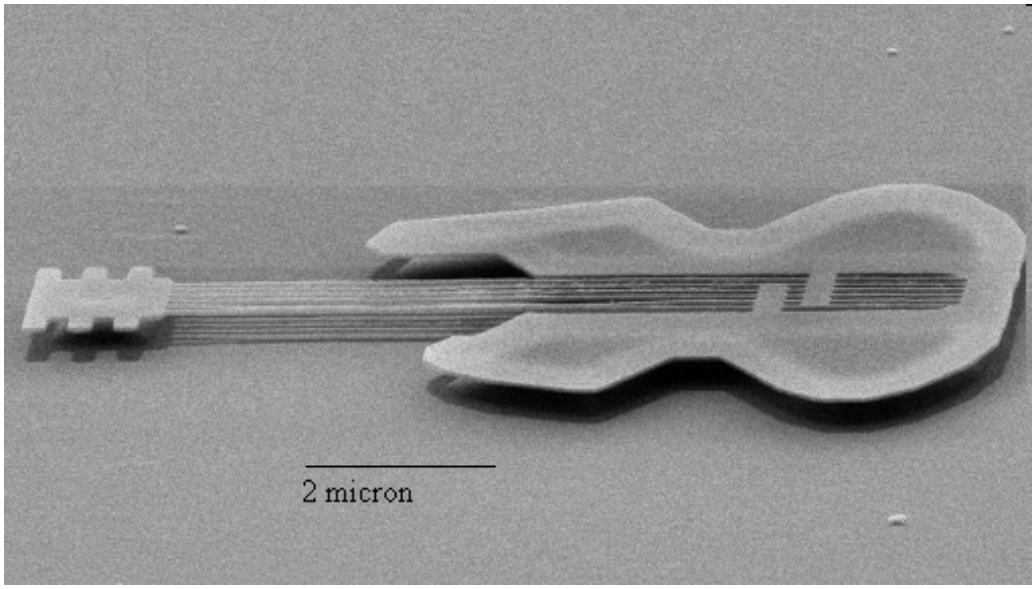
Nanostructuring
Top down or bottom up approach

Physical methods:
•Electron beam lithography
•Physical thin film deposition

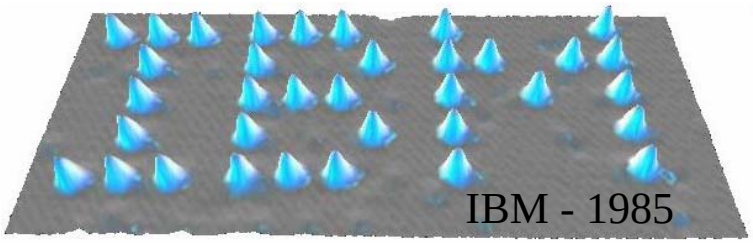
•Scanning tunneling microscopy

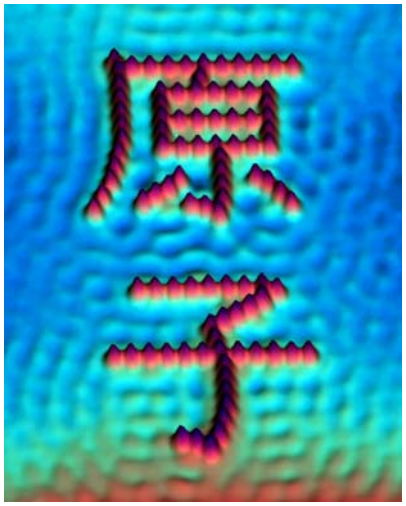
Chemical methods:
•Self-organization/self assembly
•Nanoparticles
•Chemical thin film deposition

e-beam and deep UV lithography



Scanning Tunneling Microscopy
Single atom manipulation



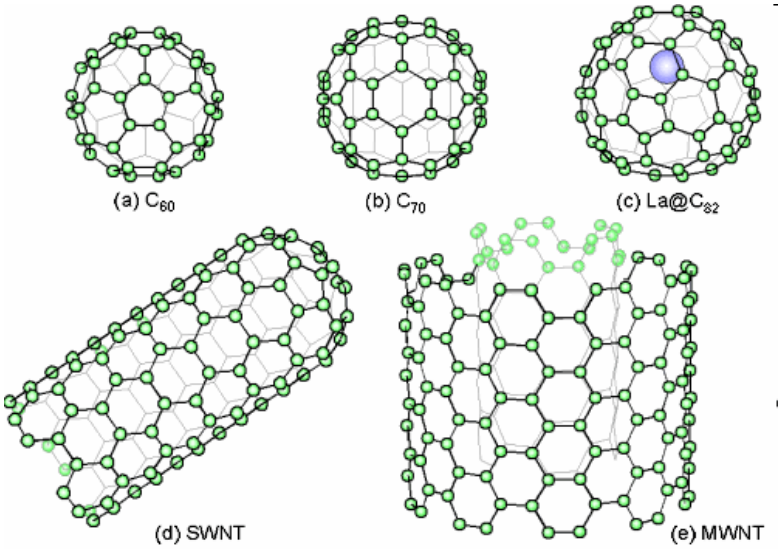


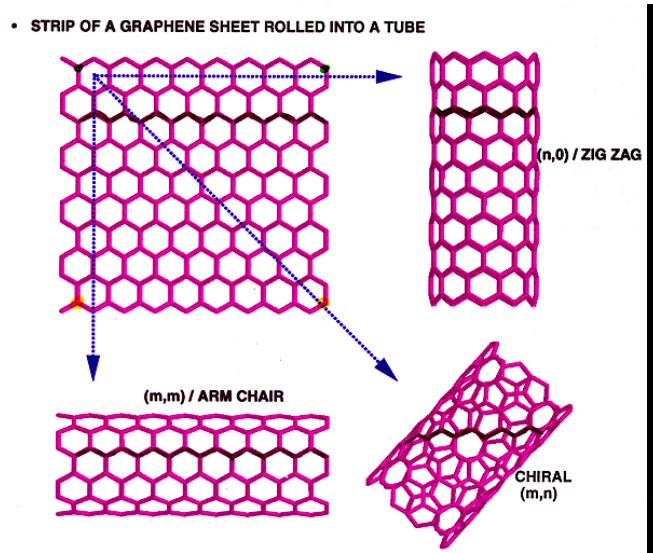
Fullerenes – 1985 (1996)

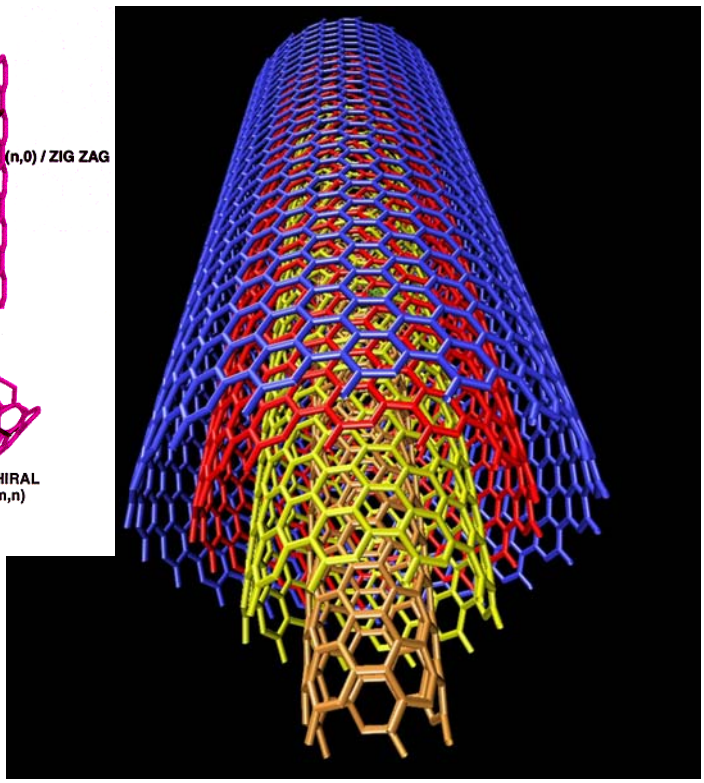
Robert F. Curl Jr.

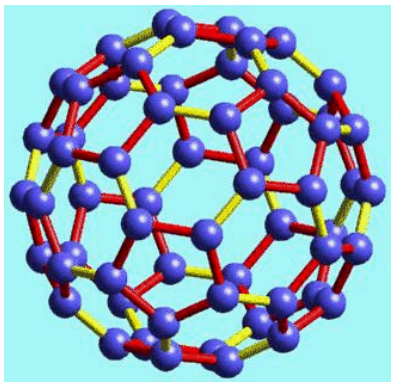
Richard E. Smalley

Sir Harold W. Kroto



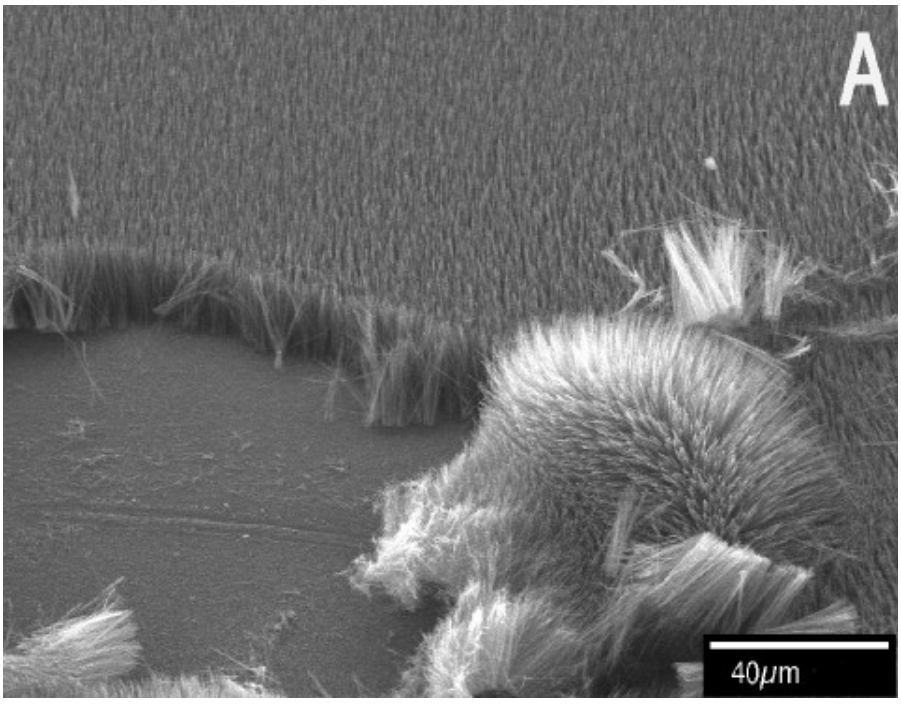






Properties of carbon nanotubes

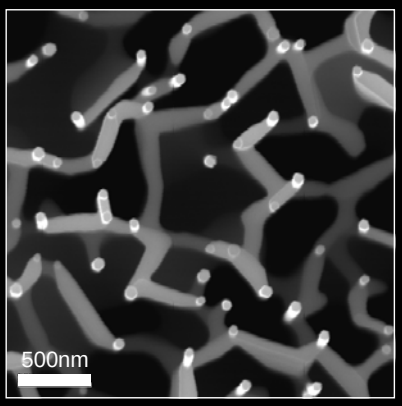
- Single walled/multiwalled (SWNT/MWNT)
- Made by: Laser evaporation, carbon arc, Chemical Vapour Deposition
- Metallic/semiconducting depending on ”chirality”
- High thermal conductivity (2 x diamond)
- Magnetoresistivity (low temperature)
- Mechanical properties; SWNT
  - Young’s modulus 10 times that of steel,
  - 20 times stronger than steel

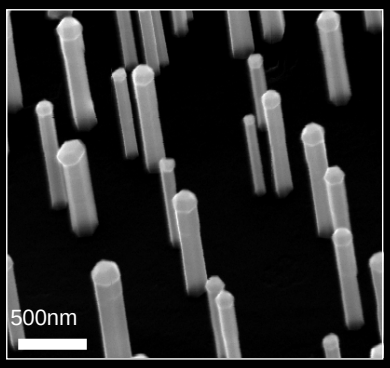


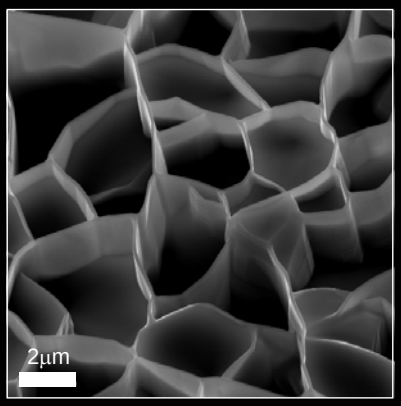
SEM image of large arrays of well-aligned carbon nanotubes

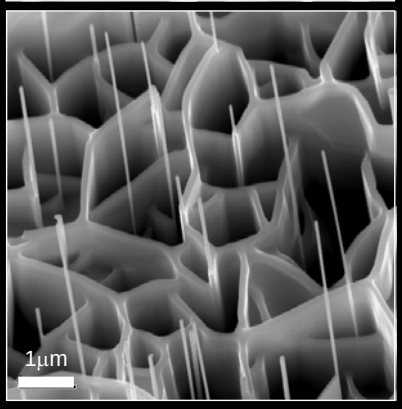
AMES RESEARCH CENTER
CENTER FOR NANOTECHNOLOGY

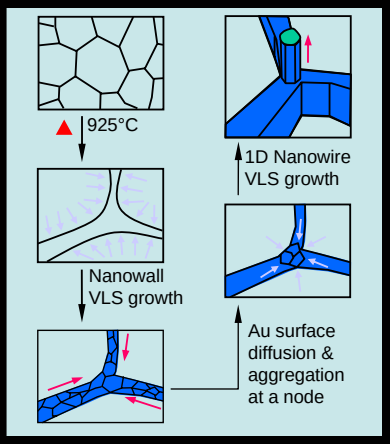
Directional Metal Oxide Nanowires & Nanowalls Growth (Cont')

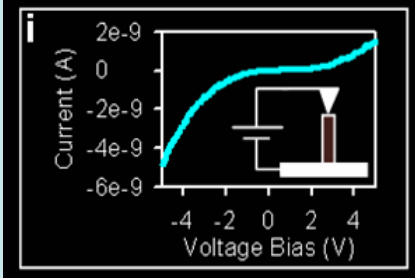






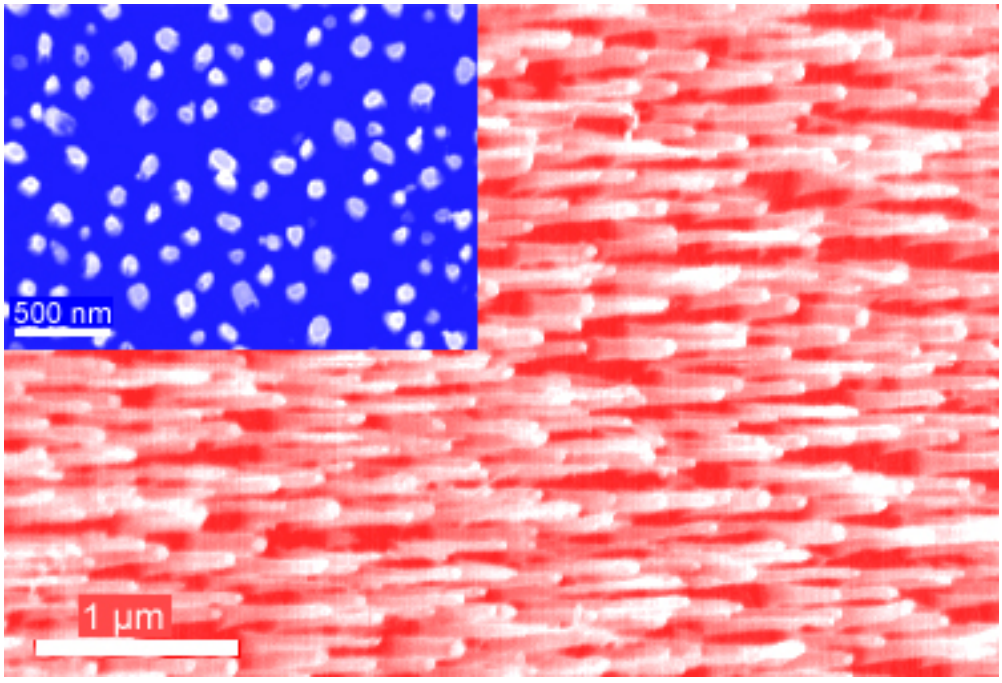


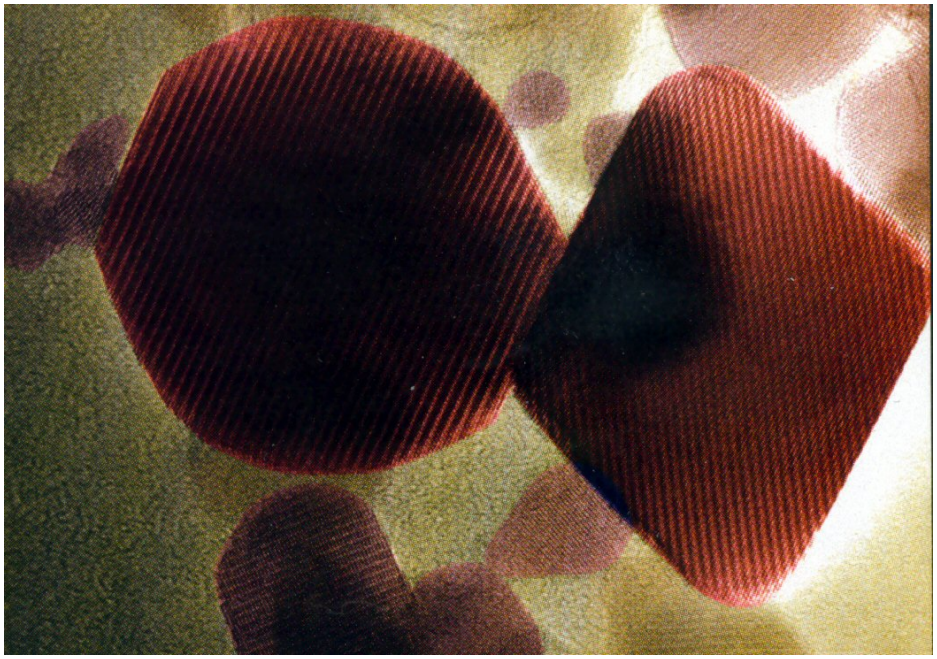




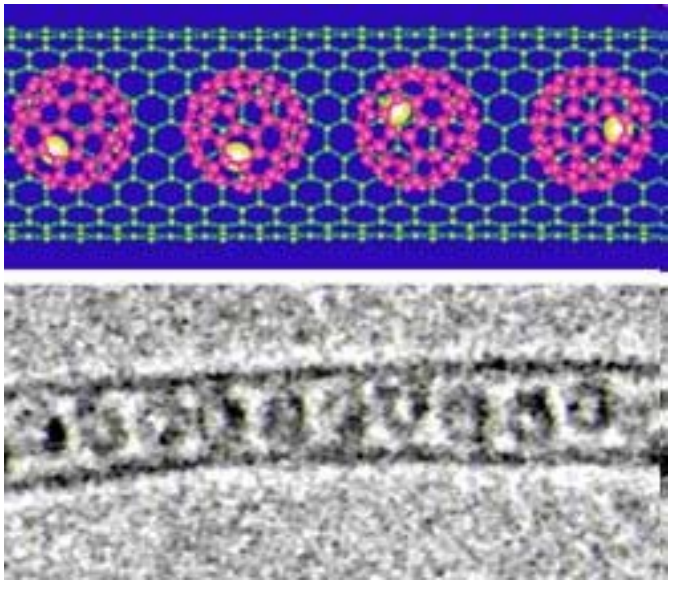
Ng et al *Science* 300, 1249 (2003)

Used in NASA presentations





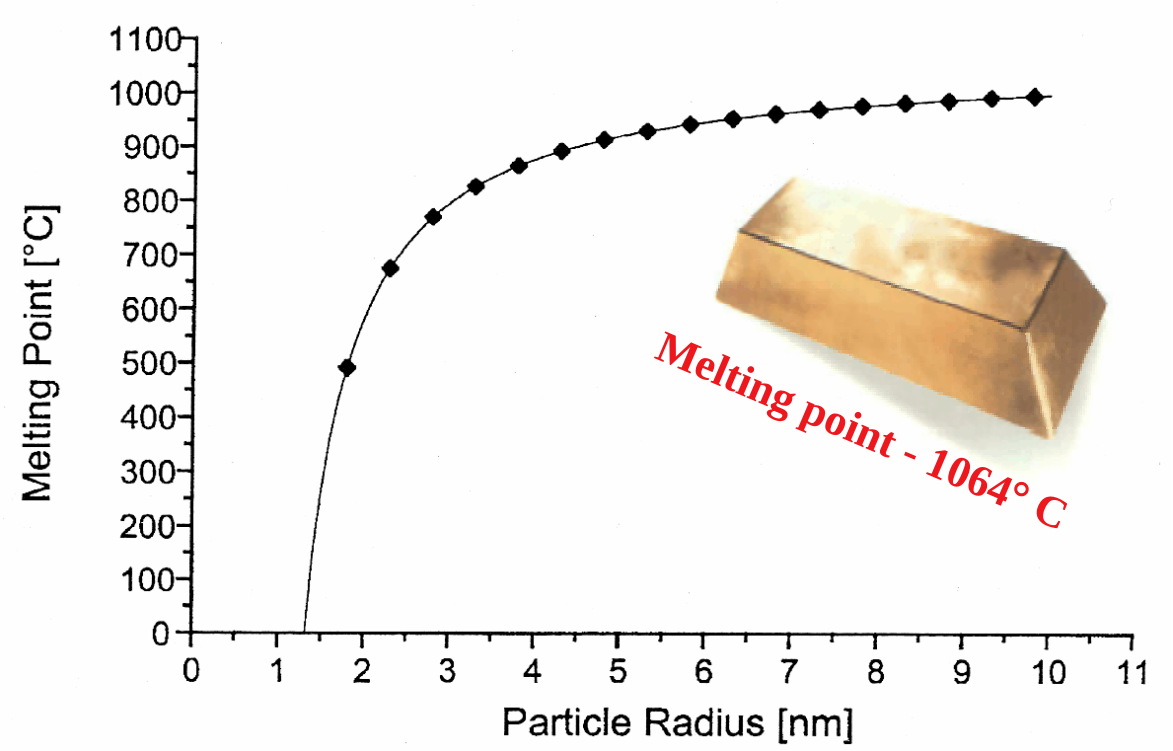
Gadolinium atoms in fullerenes in carbon nanotubes



Cubic crystal, diamond lattice type, n unit cells on one side

n	Size (nm) GaAs	N_{atoms} (total)	N_{atoms} (Surface)	Percentage of surface atoms
2	1.13	94	48	51
3	1.70	279	108	39
4	2.26	620	192	31
5	2.83	1165	300	26
6	3.39	1962	432	22
10	5.65	8630	1200	14
15	8.48	$2.8 \cdot 10^4$	2700	10
25	14.1	$1.3 \cdot 10^5$	7500	6
50	28.3	$1.0 \cdot 10^6$	$3.0 \cdot 10^4$	3
100	56.6	$8.1 \cdot 10^6$	$1.2 \cdot 10^5$	2
1000	570	$8 \cdot 10^9$	$1.2 \cdot 10^7$	0.15
10^6	0.6mm	$8 \cdot 10^{18}$	$1.2 \cdot 10^{13}$	0.0000015

Size dependent properties



Understanding Size

- 1 meter

source: CERN http://microcosm.web.cern.ch/microcosm

Understanding Size

- 10 centimeters

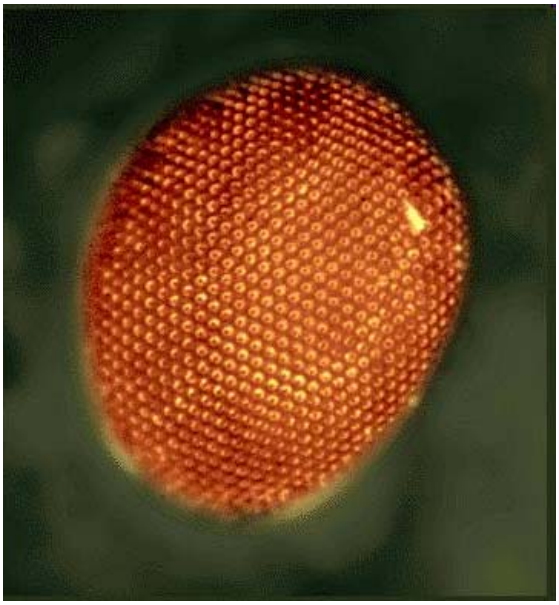
source: CERN http://microcosm.web.cern.ch/microcosm

Understanding Size

- 1 centimeter

source: CERN http://microcosm.web.cern.ch/microcosm

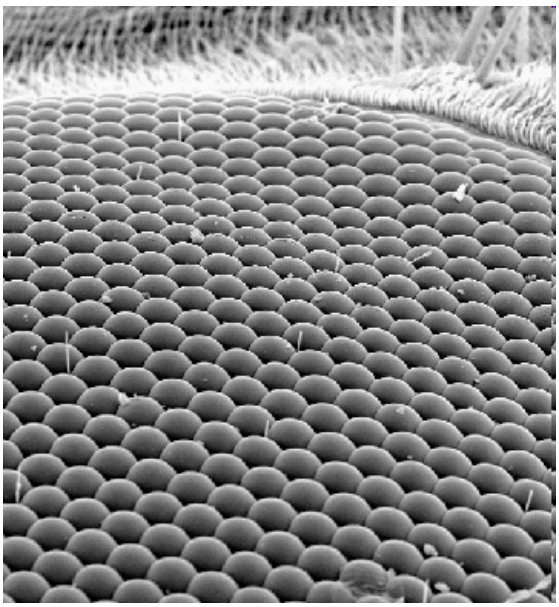
Understanding Size



- 100 micrometers

source: CERN http://microcosm.web.cern.ch/microcosm

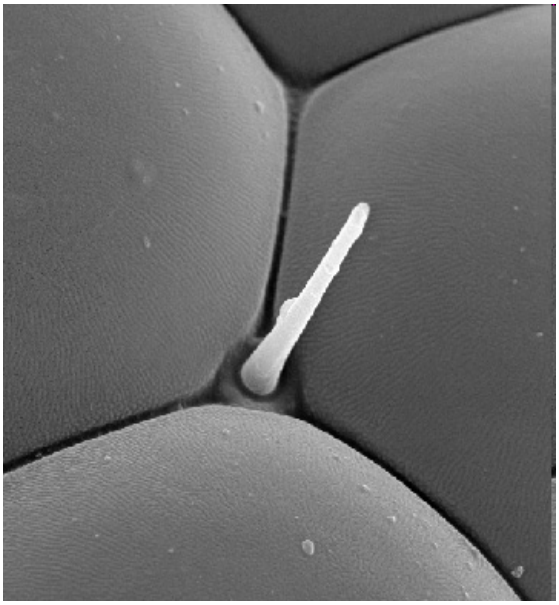
Understanding Size



- 10 micrometers

source: CERN http://microcosm.web.cern.ch/microcosm

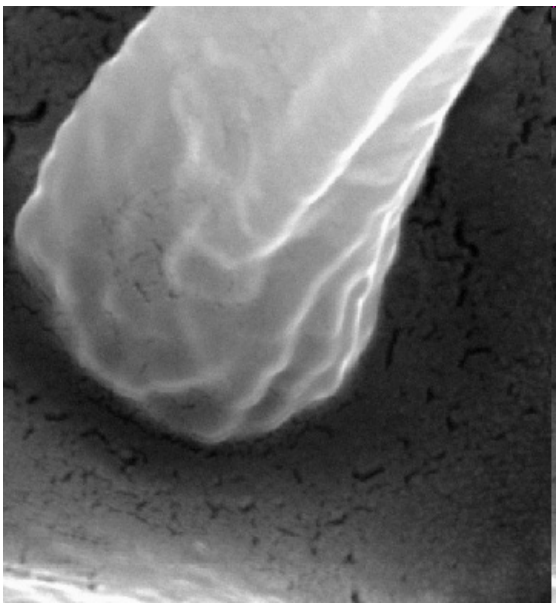
Understanding Size



- 1 micrometer

source: CERN http://microcosm.web.cern.ch/microcosm

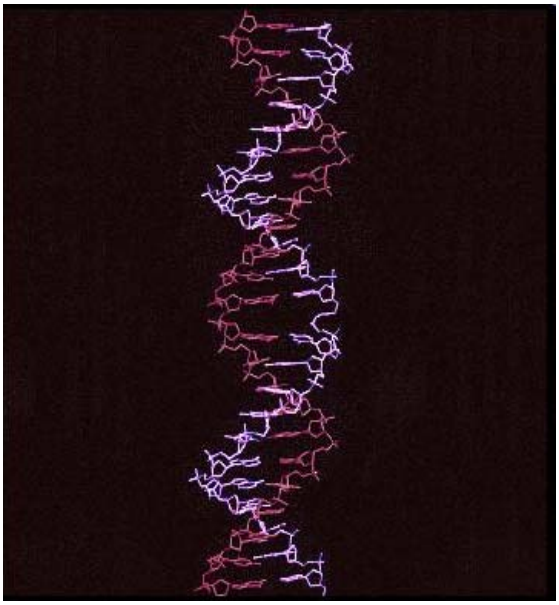
Understanding Size



- 100 nanometers

source: CERN http://microcosm.web.cern.ch/microcosm

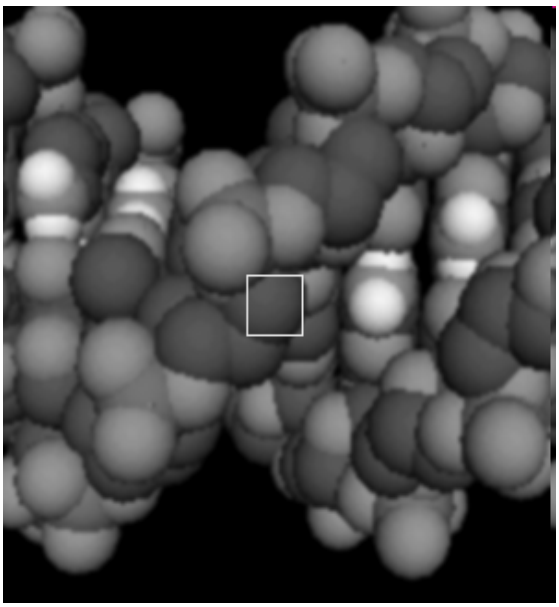
Understanding Size



- 10 nanometers

source: CERN http://microcosm.web.cern.ch/microcosm

Understanding Size



- 1 nanometer

source: CERN http://microcosm.web.cern.ch/microcosm