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
Nanotechnology; even earlier days

Nano-structures in nature

• Shell: nanobricks and nanoglue
• Nanomotors
• Nanostructure
Complex nanostructured 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
- Nano-gear
- Self-cleaning windows
- Ferrofluids

Nano-pants

Pilkington Activ
The world's first self-cleaning glass

0.5 ps
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

Robert F. Curl Jr. Richard E. Smalley

Sir Harold W. Kroto

(a) $C_{60}$
(b) $C_{70}$
(c) La@C$_{52}$
(d) SWNT
(e) MWNT

• STRIP OF A GRAPHENE SHEET ROLLED INTO A TUBE

($n,0$) / ZIG ZAG

(m,n) / ARM CHAIR

CHIRAL (m,n)
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
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

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

Melting point - 1064°C

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