Introduction to Nanotechnology

- Textbook：
  Nanophysics and Nanotechnology
  by:
  Edward L. Wolf

Instructor: ***H. Hosseinkhani***
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Classroom: A209
Time: Thursday; 13:20-16:10 PM
Office hour: Thur., 10:00-11:30 AM or by appointment

Sep 15	Introduction	Hossein
Sep 22	Systematic of Making Things Smaller	Hossein
Sep 29	What are limits to smallness	Hossein
Oct 6	Quantum Nature of the Nanoworld	CW Chen
Oct 13	Quantum Consequence for the Macroworld	CW Chen
Oct 20		
Oct 27	Self-Assmbled Nano-Strauctur e in Nature and Industry	Hossein
Nov 3		
Nov 10	**Midterm**	
Nov 17	Physics-based Experimental Approaches to Nanofabrication and Nanotechnology	Hossein
Nov 24		
Dec 1	Quantum Technologies based on Magnetism, Electron and Nuclear Spin, and Superconductivity	KH Chen
Dec 8		
Dec 15	Silicon Nanoeletronic and Beyond	Hossein
Dec 22		
Dec 29	Looking into the Future	LC Chen
Jan 5		
Jan 12	**Final Exam**	

Objective of the course

The course, Introduction to Nanotechnology (IN), will focus on understanding of the basic molecular structure principals of Nano-materials. It will address the molecular structures of various materials. The long term goal of this course is to teach molecular design of materials for a broad range of applications. A brief history of biological materials and its future perspective as well as its impact to the society will be also discussed.

Evaluation; Score: 100%:

Mid-term Exam: 30%
Final Exam: 30%
Scientific Activity: 40 % (Home work, Innovation Design)

Contents

- Introduction (*Prof. Hossein*)
- Systematic of Making Things Smaller (*Prof. Hossein*)
- What are limits to smallness (*Prof. Hossein*)
- Quantum Nature of the Nano-world (*Prof. CW Chen*)
- Quantum Consequence for the Macro-world (*Prof. CW Chen*)
- Self-Assembled Nano-Structure in Nature and Industry (*Prof. Hossein*)
- Physical-based Experimental Approaches to Nanofabrication and Nanotechnology (*Prof. Hossein*)

- Mid-term Exam

Contents

- Quantum Technologies based on Magnetism, Electron and Nuclear Spin, and Superconductivity (*Prof. KH Chen*)
- Silicon Nanoeletronic and Beyond (*Prof. Hossein*)
- Looking into the Future (*Prof. LC Chen*)

- Final Exam


The Nanoscience
The beginning of the end

Nano-Products

Nanobots

Nanomedic

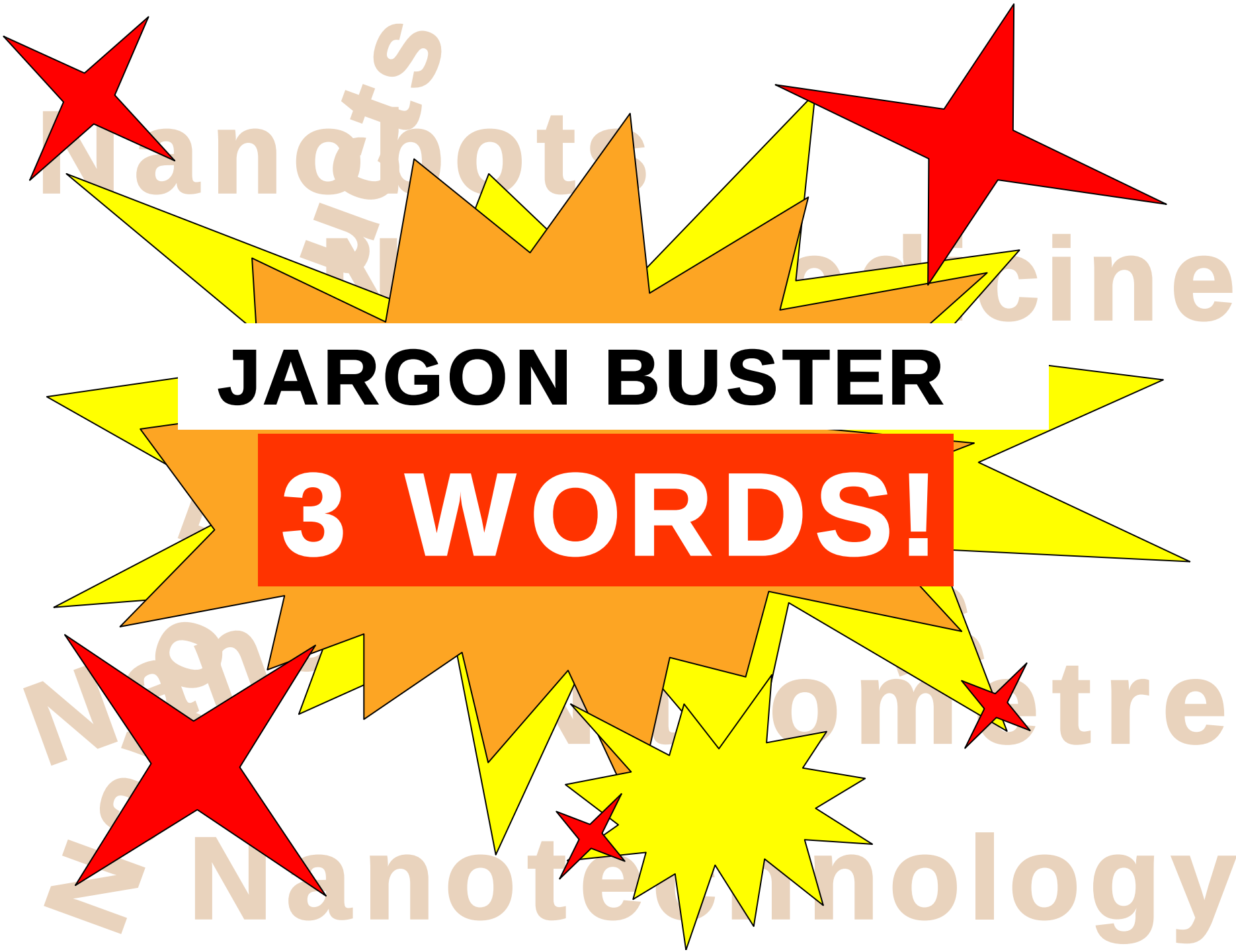
stuff

Nanosci

stuff

Nanometre

Nanotechnology


JARGON BUSTER
3 WORDS!

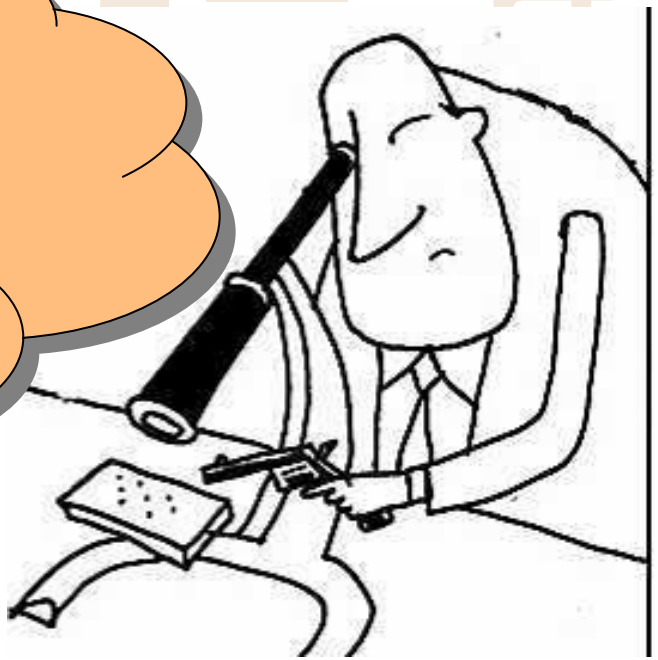
Nano:

A prefix that means very, very, small.

The word nano is from the Greek.

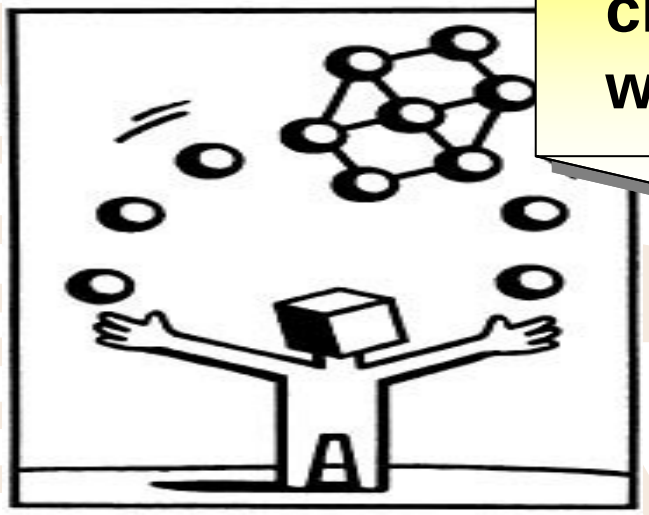
word ‘Nanos’ meaning Dwarf.

It is a prefix used to describe "one billionth" of something, or 0.000000001.



Nanoscience

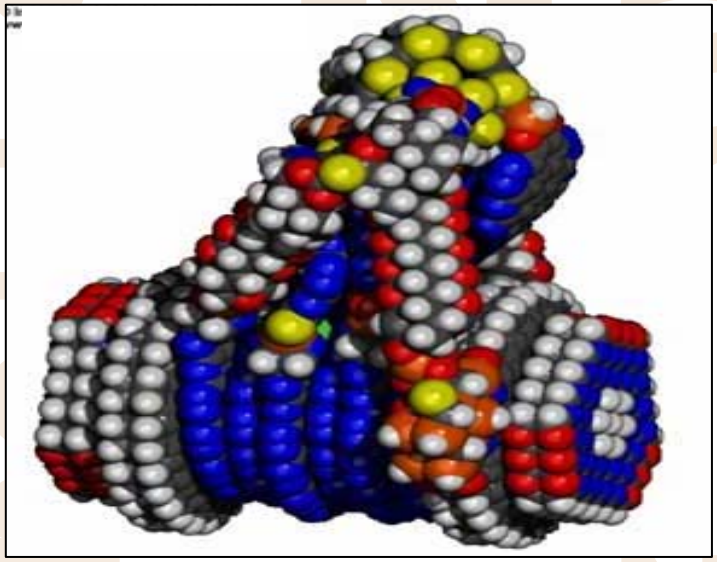
A part of science that studies small stuff.



It's not biology, physics or chemistry. It's all sciences that work with the very small.

Nanotechnology

The art and science of making useful stuff that does stuff on the nanometre length scale.



Includes advances in all industries, including the electronic, chemical, and pharmaceutical.

Understanding Size

- 1 metre

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

Understanding Size

- 10 centimetres

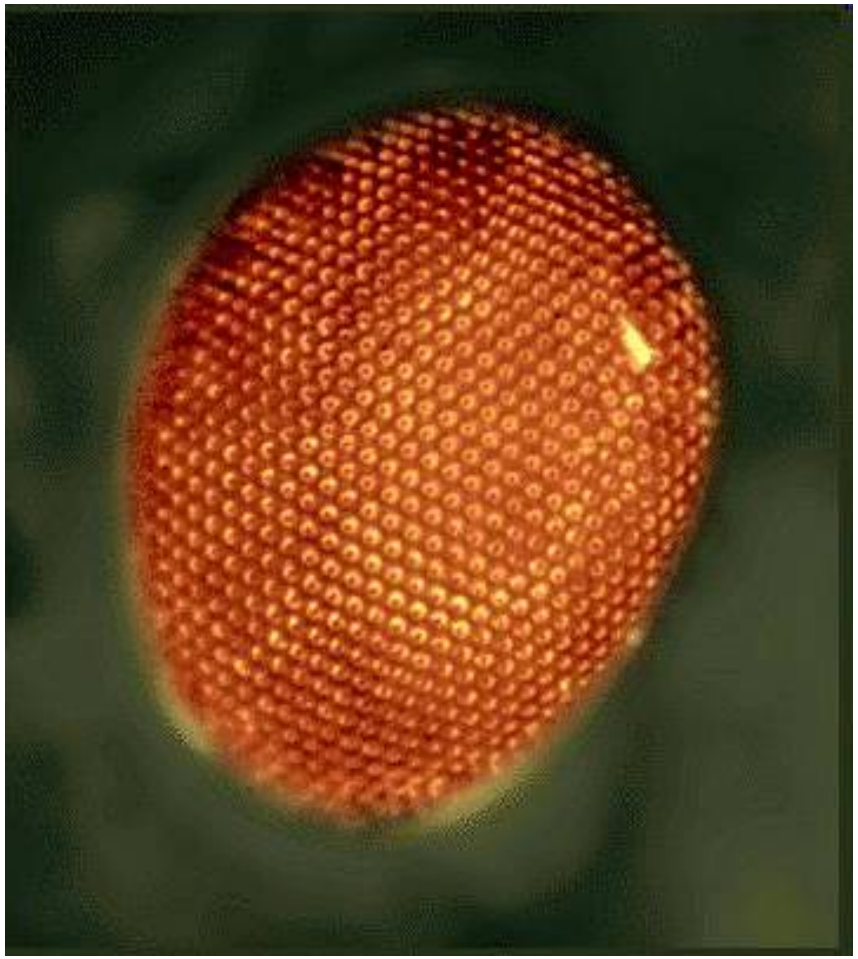
source: CERN http://microcosm.web.cern.ch/microcosm

Understanding Size

- 1 centimetre

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

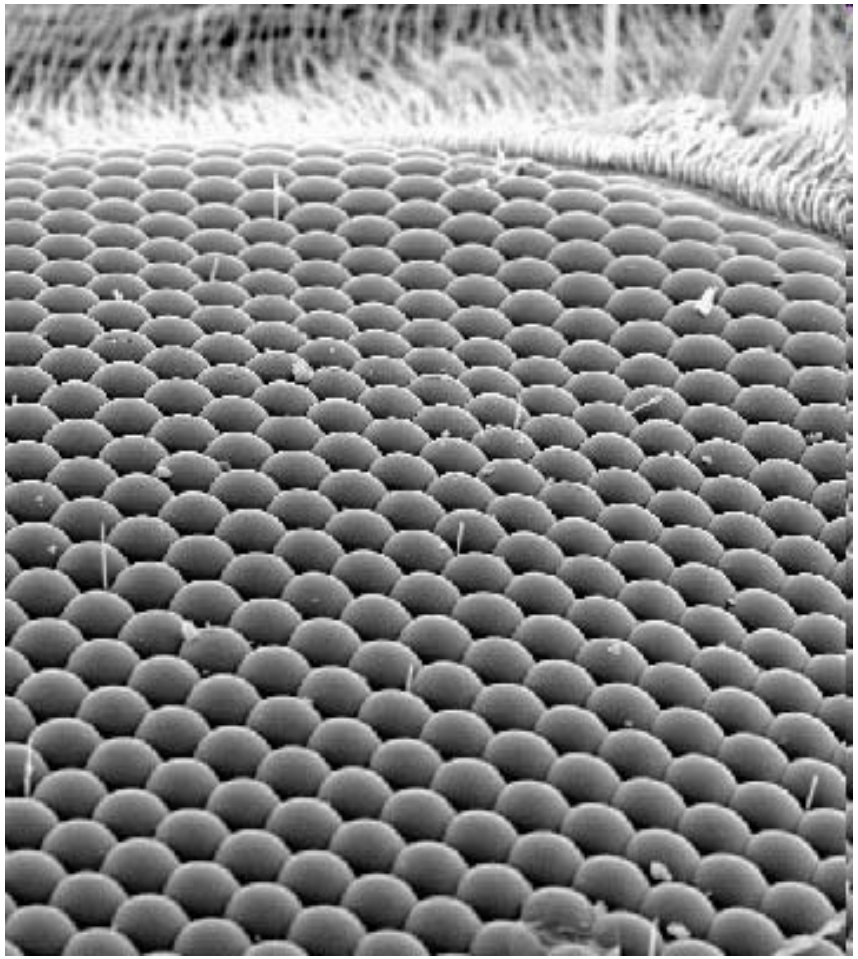
Understanding Size



- 100 micrometres

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

Understanding Size



- 10 micrometres

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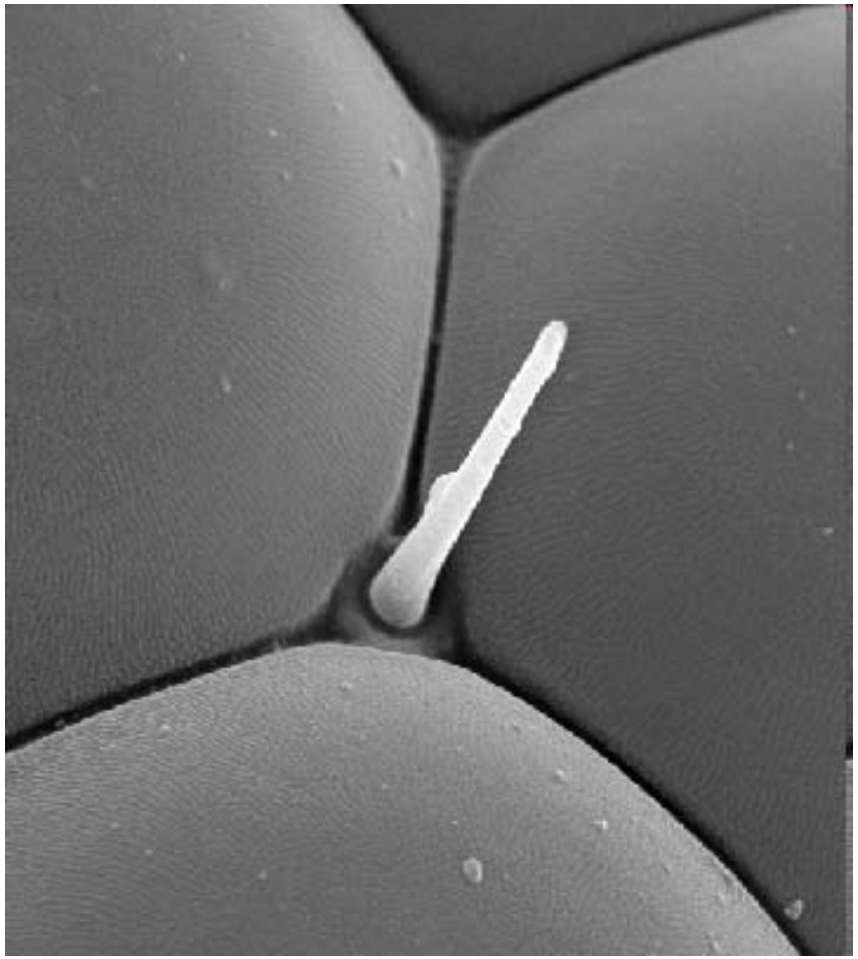
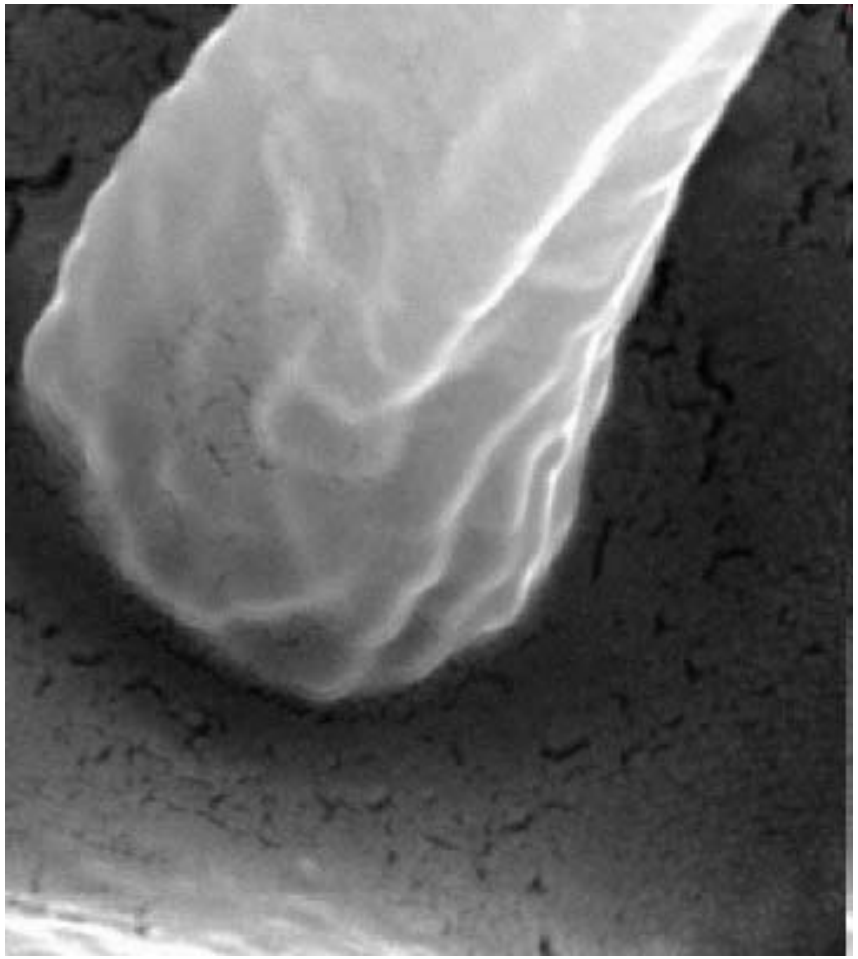
Understanding Size



- 1 micrometre

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

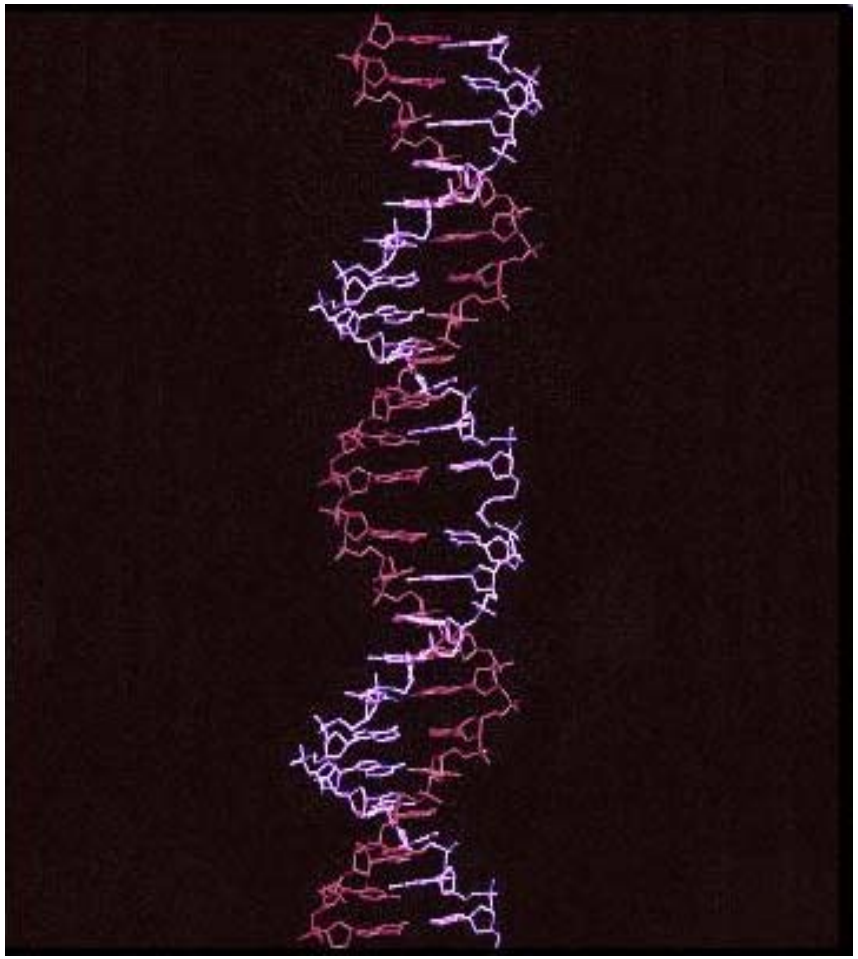
Understanding Size



- 100 nanometres

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

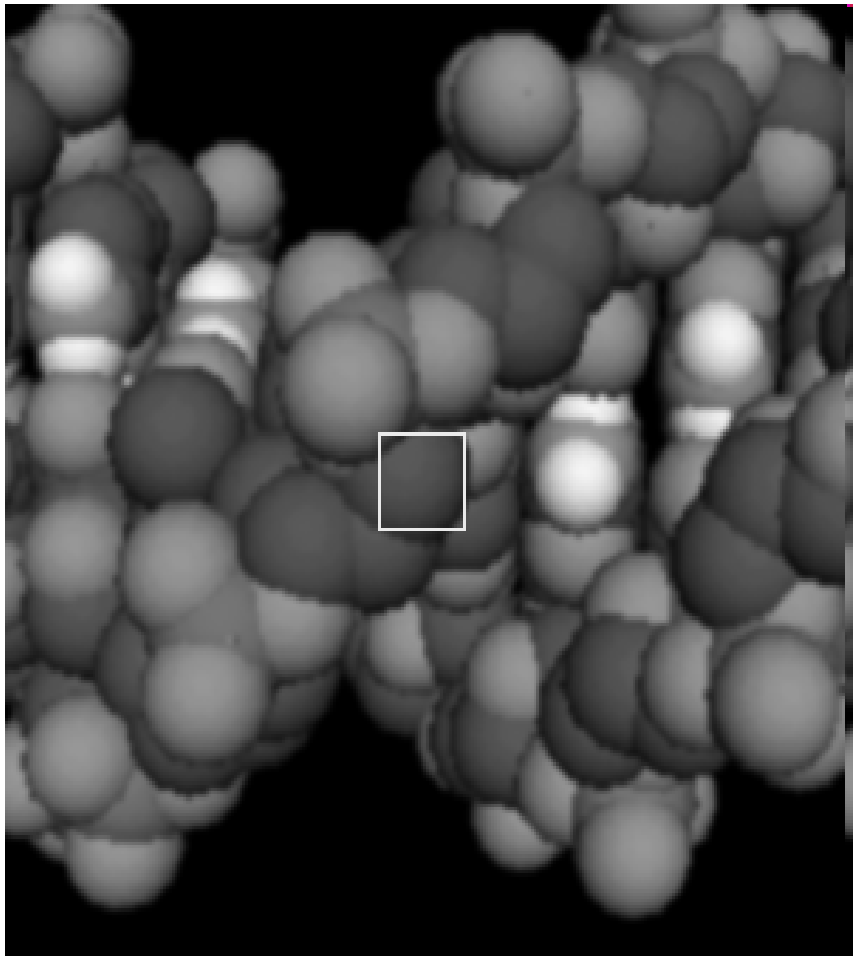
Understanding Size



- 10 nanometres

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

Understanding Size

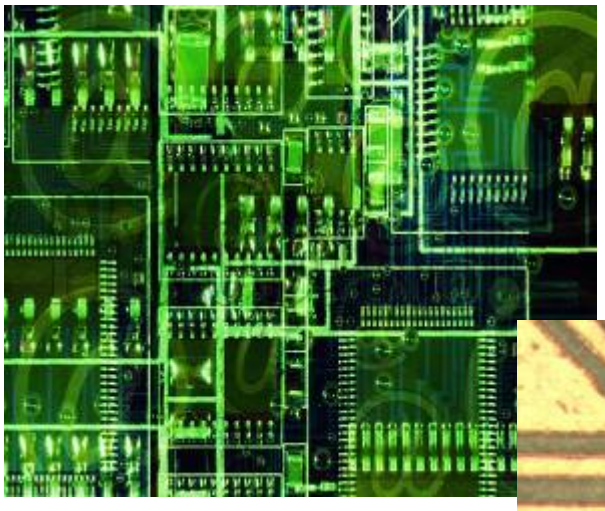


- 1 nanometre

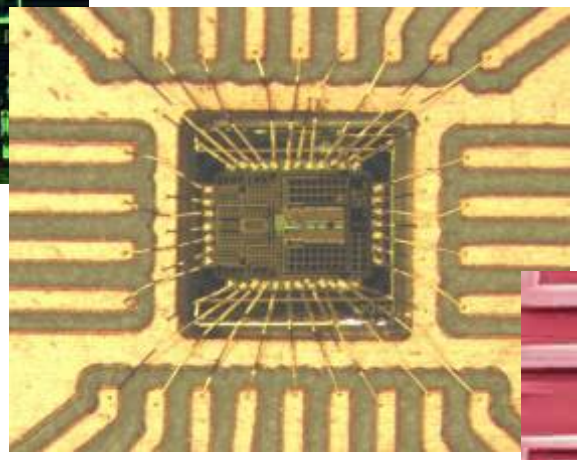
source: CERN http://microcosm.web.cern.ch/microcosm

Top-down

microelectronics

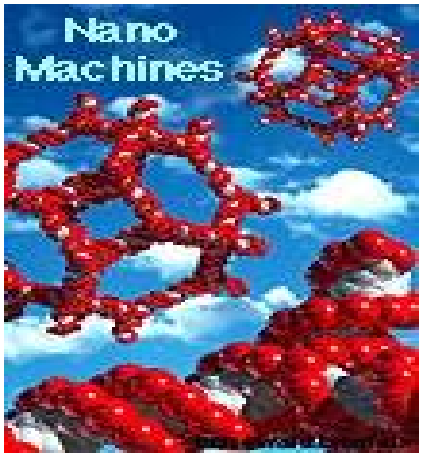


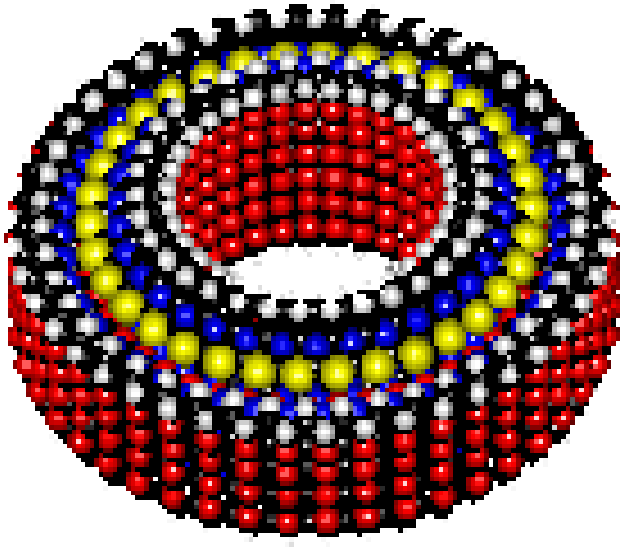
Nanotechnology is the next step after miniaturisation.



nanoelectronics

Bottom-up





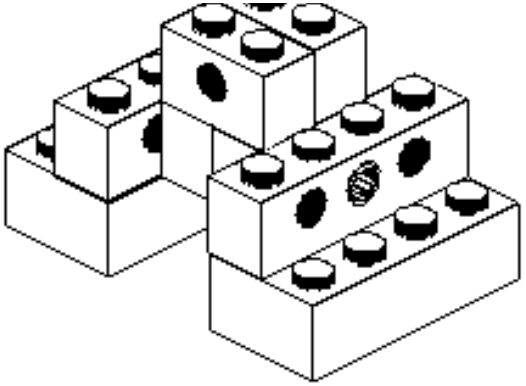
Arranged one way, atoms make up soil, air and water. Arranged another way they make up strawberries or smoke.

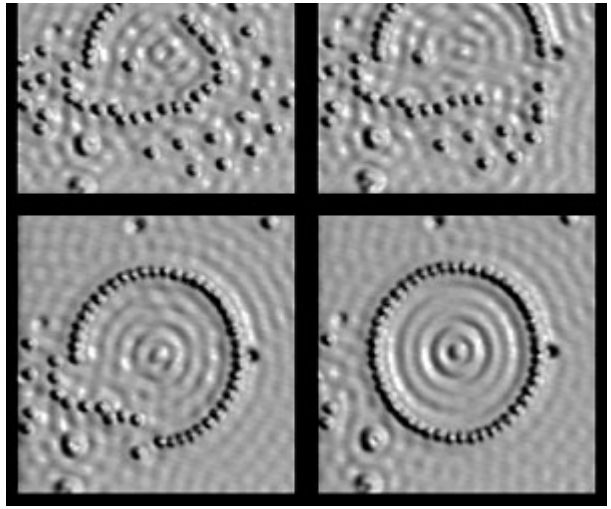
Ultimate Nanotechnology would be to build at the level of one atom at a time and to be able to do so with perfection.

Nature’s Toy box.

ATOMIC LEGO

Molecular assembly is like a Lego set of 90 atoms that we can use to build anything from the bottom up! You just use every atom that you want. All of the elements in the periodic table can be mixed and matched,



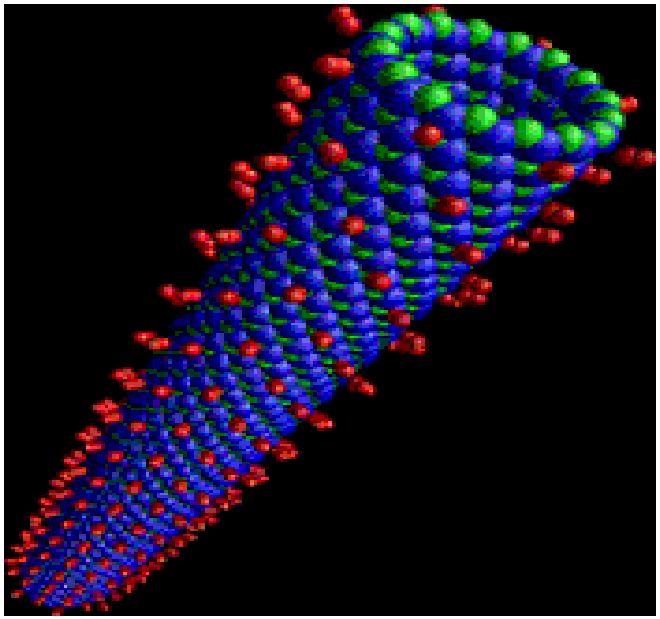


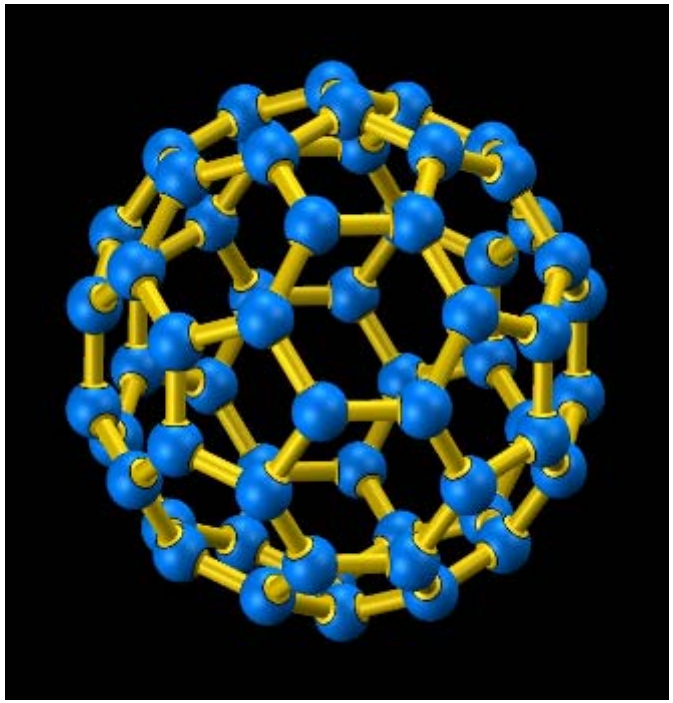
Nanoscience would probably be boring if small things were just like big things.

But they aren't. Pencil lead, for example takes on all sorts of shapes if kept from becoming a solid.

When carbon is a pure solid it is found as graphite or diamond.

On the nano scale. Carbon takes on very different structures.





Size Matters

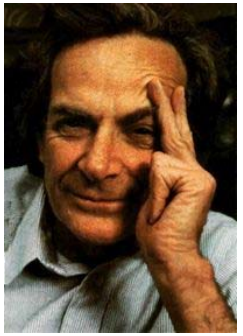
- It’s not just how big you are
- It’s what you can do with it

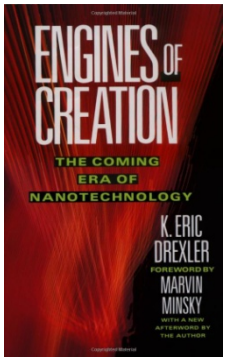
Early microscopes

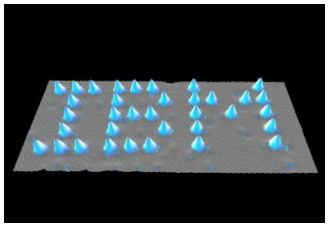
The *Nanotechnology* continues to change our lives

History of Nanotechnology

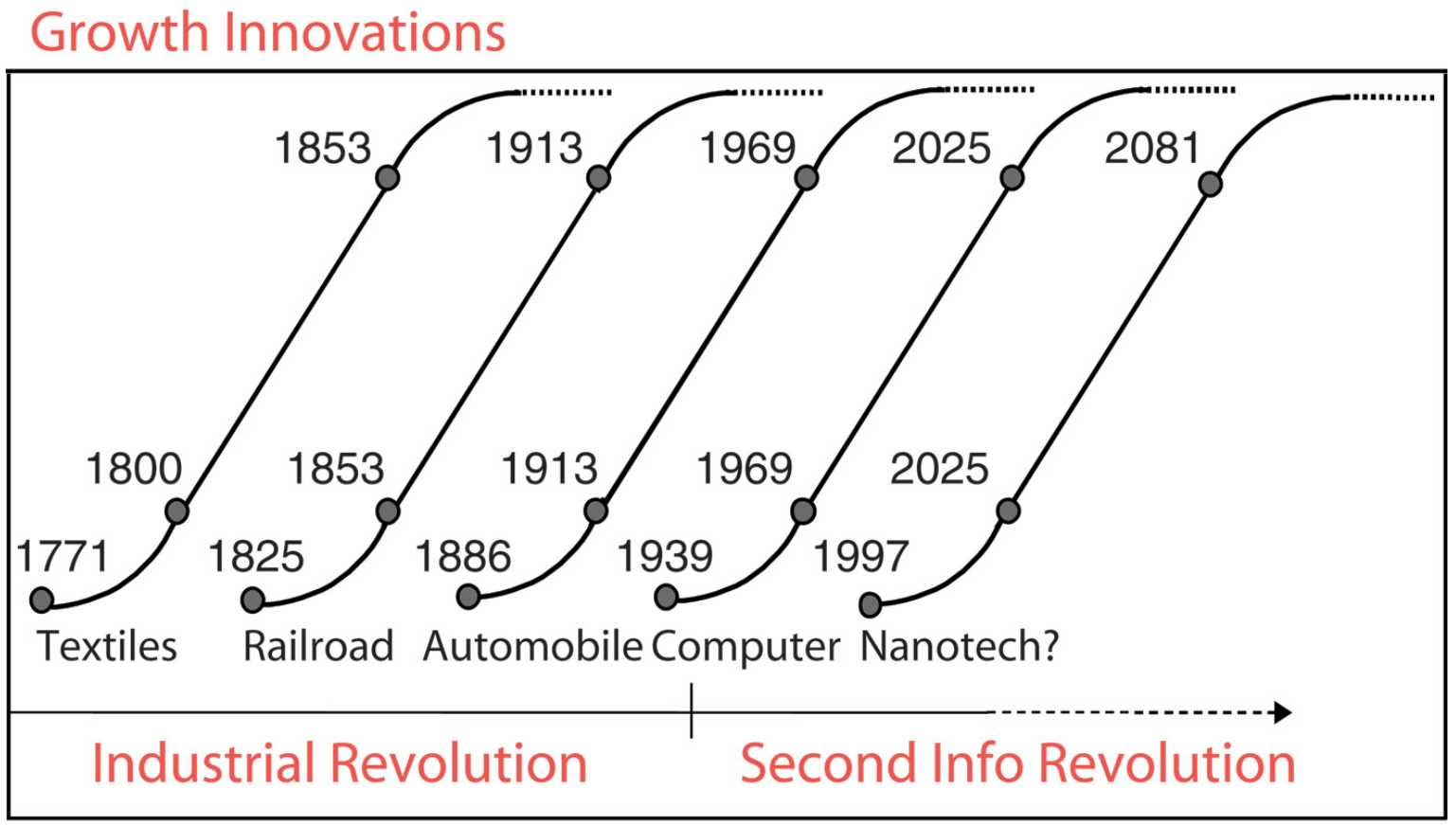
- **~ 2000 Years Ago** – Sulfide nanocrystals used by Greeks and Romans to dye hair
- **~ 1000 Years Ago (Middle Ages)** – Gold nanoparticles of different sizes used to produce different colors in stained glass windows
- **1959** – "There is plenty of room at the bottom" by R. Feynman
- **1974** – "Nanotechnology" - Taniguchi uses the term nanotechnology for the first time
- **1981** – IBM develops Scanning Tunneling Microscope
- **1985** – "Buckyball" - Scientists at Rice University and University of Sussex discover C_{60}
- **1986** – "Engines of Creation" - First book on nanotechnology by K. Eric Drexler. Atomic Force Microscope invented by Binnig, Quate and Gerbe
- **1989** – IBM logo made with individual atoms
- **1991** – Carbon nanotube discovered by S. Iijima
- **1999** – "Nanomedicine" – 1st nanomedicine book by R. Freitas
- **2000** – "National Nanotechnology Initiative" launched





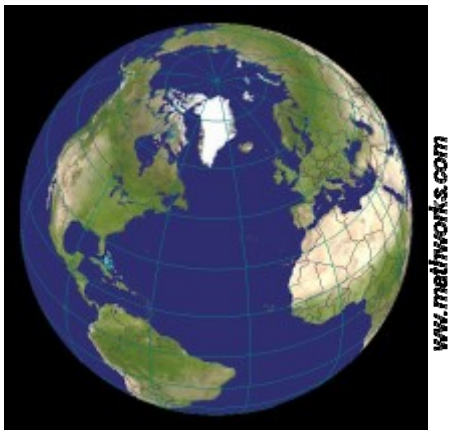


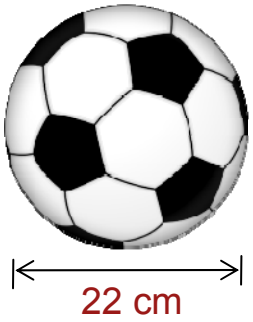
Nanotechnology Growth

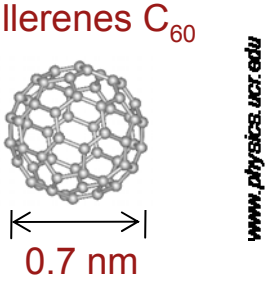


Sources: Norman Poire, Merrill Lynch

What is Nanoscale







1.27 × 107 m **0.22 m** **0.7 × 10-9 m**

10 millions times smaller

1 billion times smaller

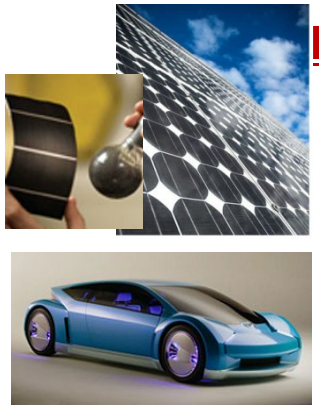
Nanoscale Size Effect

- Realization of miniaturized devices and systems while providing more functionality
- Attainment of high surface area to volume ratio
- Manifestation of novel phenomena and properties, including changes in:
  - Physical Properties (e.g. melting point)
  - Chemical Properties (e.g. reactivity)
  - Electrical Properties (e.g. conductivity)
  - Mechanical Properties (e.g. strength)
  - Optical Properties (e.g. light emission)

Nanotechnology Applications

Information Technology

- Smaller, faster, more energy efficient and powerful computing and other IT-based systems



Energy

- More efficient and cost effective technologies for energy production
  - Solar cells
  - Fuel cells
  - Batteries
  - Bio fuels

Medicine

- Cancer treatment
- Bone treatment
- Drug delivery
- Appetite control
- Drug development
- Medical tools
- Diagnostic tests
- Imaging

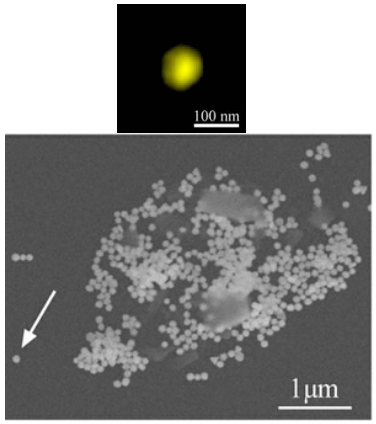
Consumer Goods

- Foods and beverages
  - Advanced packaging materials, sensors, and lab-on-chips for food quality testing
- Appliances and textiles
  - Stain proof, water proof and wrinkle free textiles
- Household and cosmetics
  - Self-cleaning and scratch free products, paints, and better cosmetics

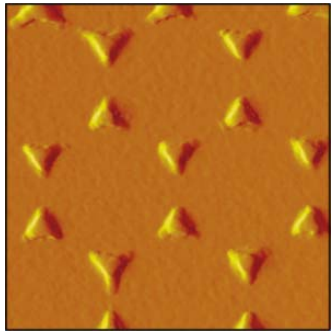
Nanoscale Materials

Nanoscale materials have feature size less than 100 nm – utilized in nanoscale structures, devices and systems

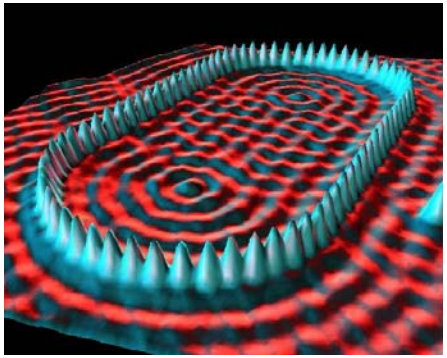
Nanoparticles and Structures



Gold nanoparticles
– TU Dresden/ESRF, 2008



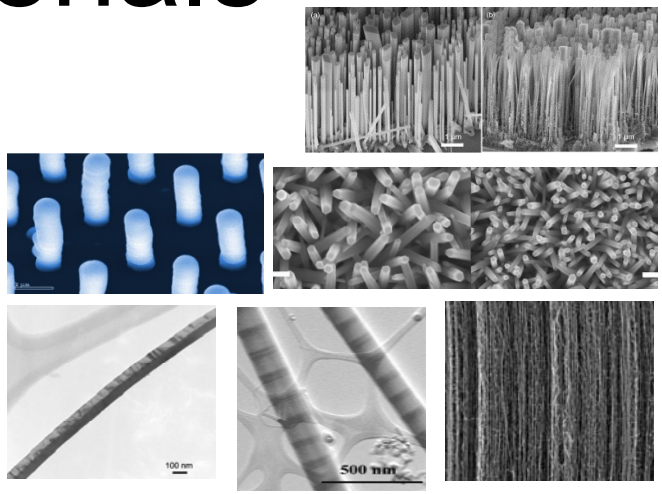
Silver nanoparticles
– Northwestern Univ., 2002



A stadium shaped “quantum corral” made by positioning iron atoms on a copper surface *– IBM Corp., 1993.*

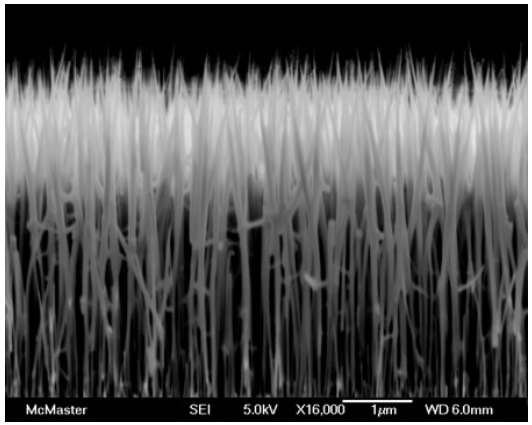
A 3-dimensional nanostructure grown by controlled nucleation of Silicon-carbide nanowires on Gallium catalyst particles
– Univ. of Cambridge, 2007

Nanoscale Materials



Nanowires and Nanotubes

- Lateral dimension: 1 – 100 nm
- Nanowires and nanotubes exhibit novel physical, electronic and optical properties due to
  - Two dimensional quantum confinement
  - Structural one dimensionality
  - High surface to volume ratio
- Potential application in wide range of nanodevices and systems
  - Nanoscale sensors and actuators
  - Photovoltaic devices – solar cells
  - Transistors, diodes and LASERs



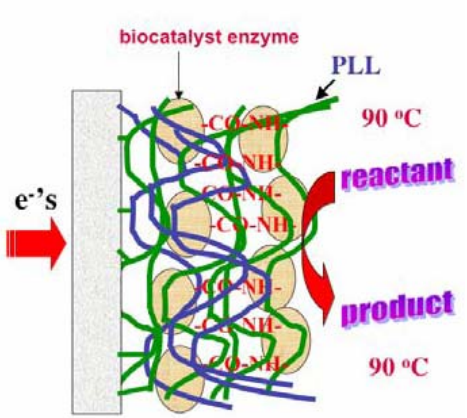
Nanowire Solar Cell: The nanowires create a surface that is able to absorb more sunlight than a flat surface – *McMaster Univ., 2008*

Nanoscale Materials

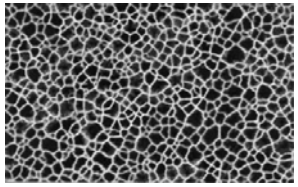
Protein

Bionanomaterials

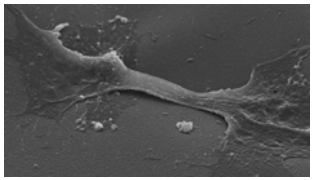
1. Biological materials utilized in nanotechnology
   - Proteins, enzymes, DNA, RNA, peptides
2. Synthetic nanomaterials utilized in biomedical applications
   - Polymers, porous silicon, carbon nan-otubes
   - Quantum Dots (range from 4~5 nm) (will be discussed in Biological application)



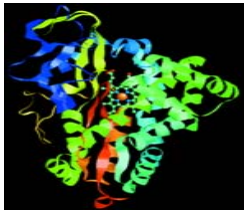
Cross-linked enzymes used as catalyst *– Univ. of Connecticut, Storrs , 2007*



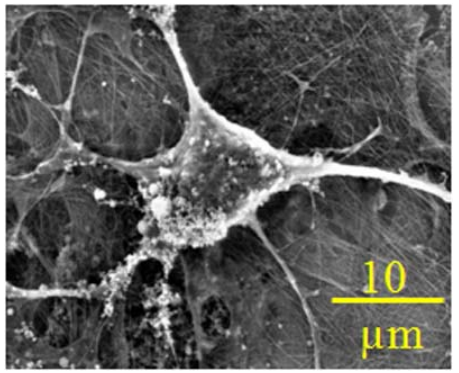
Porous silicon (PSi)



Human cell on PSi

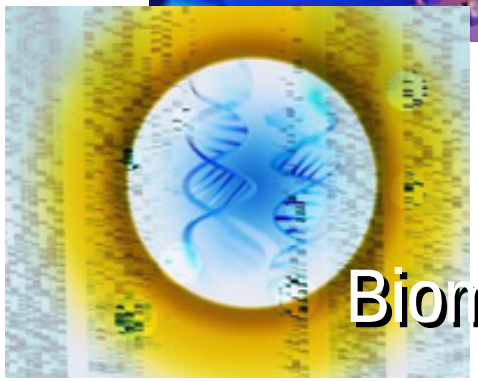


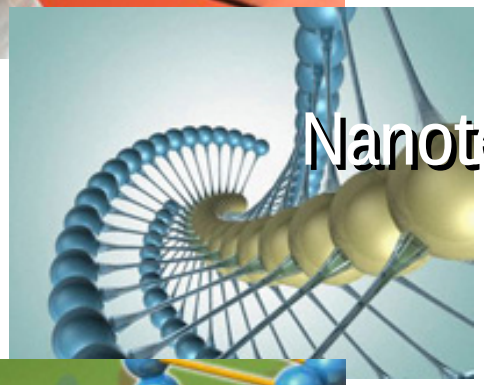
Enzymes are used as oxidation catalysts



Bone cell on porous silicon *– Univ. of Rochester, 2007*

Technology is an accelerator





…so what’s it going to take?

It’s time to bust out

…and maximize use of all tools available to us to assume new and expanded roles

When it comes to the future, there are three kinds of people: those who let it happen, those who make it happen, and those who wonder what happened.

~ John M. Richardson, Jr.

Systematic of Making Things Smaller-Pre-Quantum

1. Mechanical Frequencies increase in Small System

2. Thermal Time Constants and Temperature Differences *Decrease*

3. Viscous Forces Becomes Dominant for Small Particles in Fluid Media

4. Fractional Forces can Disappear in Symmetric Molecular Scale Systems