NANOSCIENCE AND NANOTECHNOLOGY

Introduction

- **Nanoscience** is concerned with the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales.

- **Nanotechnology** is the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanometer scale.

- It studies the materials with morphological features on the nanoscale.

Richard Feynman - “Grandfather” of Nanotechnology

- 1959 - Richard Feynman - Nobel Prize in Physics
- “There’s plenty of room at the bottom” - an invitation to enter a new field of physics
- As things get smaller, gravity would become less important, surface tension molecule attraction would become more important.

RICHARD FEYNMAN predicted the rise of nanotechnology in a landmark 1959 talk at Caltech. "The principles of physics," he said, "do not speak against the possibility of maneuvering things atom by atom." But he also anticipated that unique laws would prevail; they are finally being discovered today.

Classification of nanomaterials

Nanomaterials could be organized into four forms:

- One Dimension
- Two Dimensions
- Three Dimensions

Perspective of Length Scale

Top Down

1 km — Aircraft Carrier

Boeing 747

Car

1 m — **Humans**

Laptop

Butterfly — Size of a Microprocessor

1 mm — **Gnat** — Resolving power of the eye ~ 0.2 mm

Micromachines

Biological cell

Nucleus of a cell

1 μm — Wavelength of Visible Light

Smallest feature in microelectronic chips

Nanostructures & Quantum Devices

Proteins

Width of DNA

1 nm — Size of an atom

Bottom Up

What are Nanostructures?

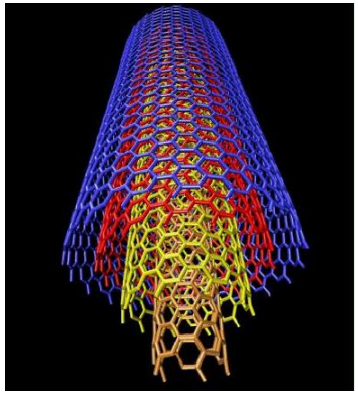
At least one dimension is between 1 - 100 nm

2-D structures (1-D confinement):

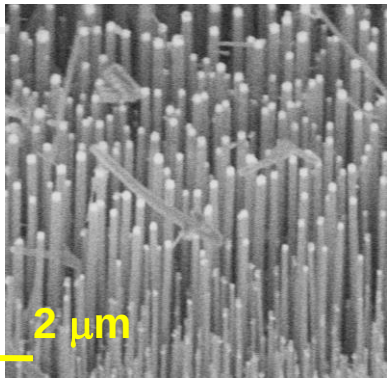
- Thin films

1-D structures (2-D confinement):

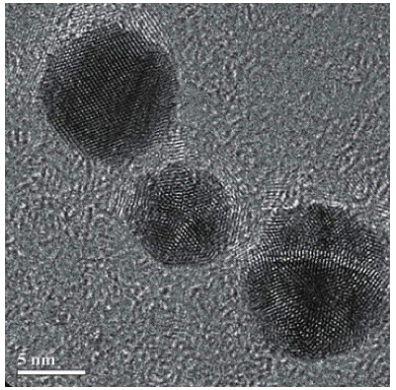
- Nanowires
- Nanorods
- Nanotubes



Multi-wall carbon nanotube



Si Nanowire Array



Ag nanoparticle

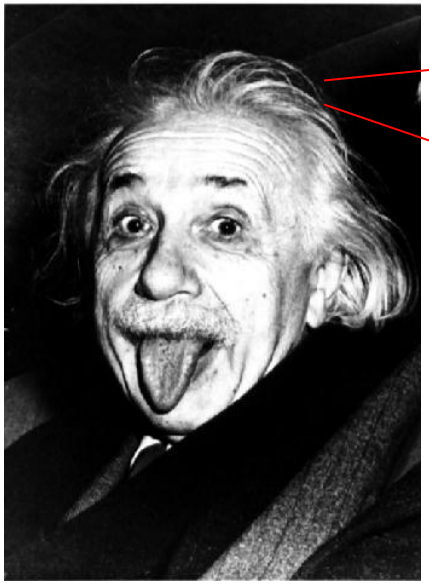
0-D structures (3-D confinement):

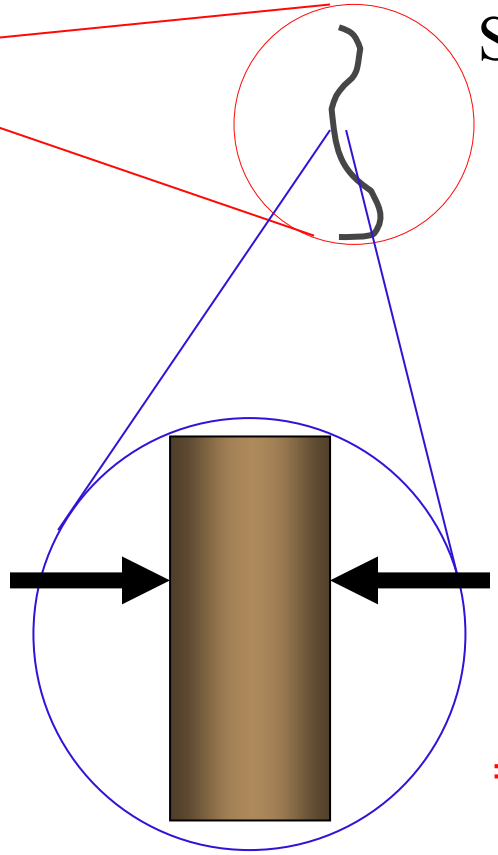
- Nanoparticles
- Quantum dots

Dimensionality, confinement depends on structure:

- Nanocomposites

How small are nanostructures?





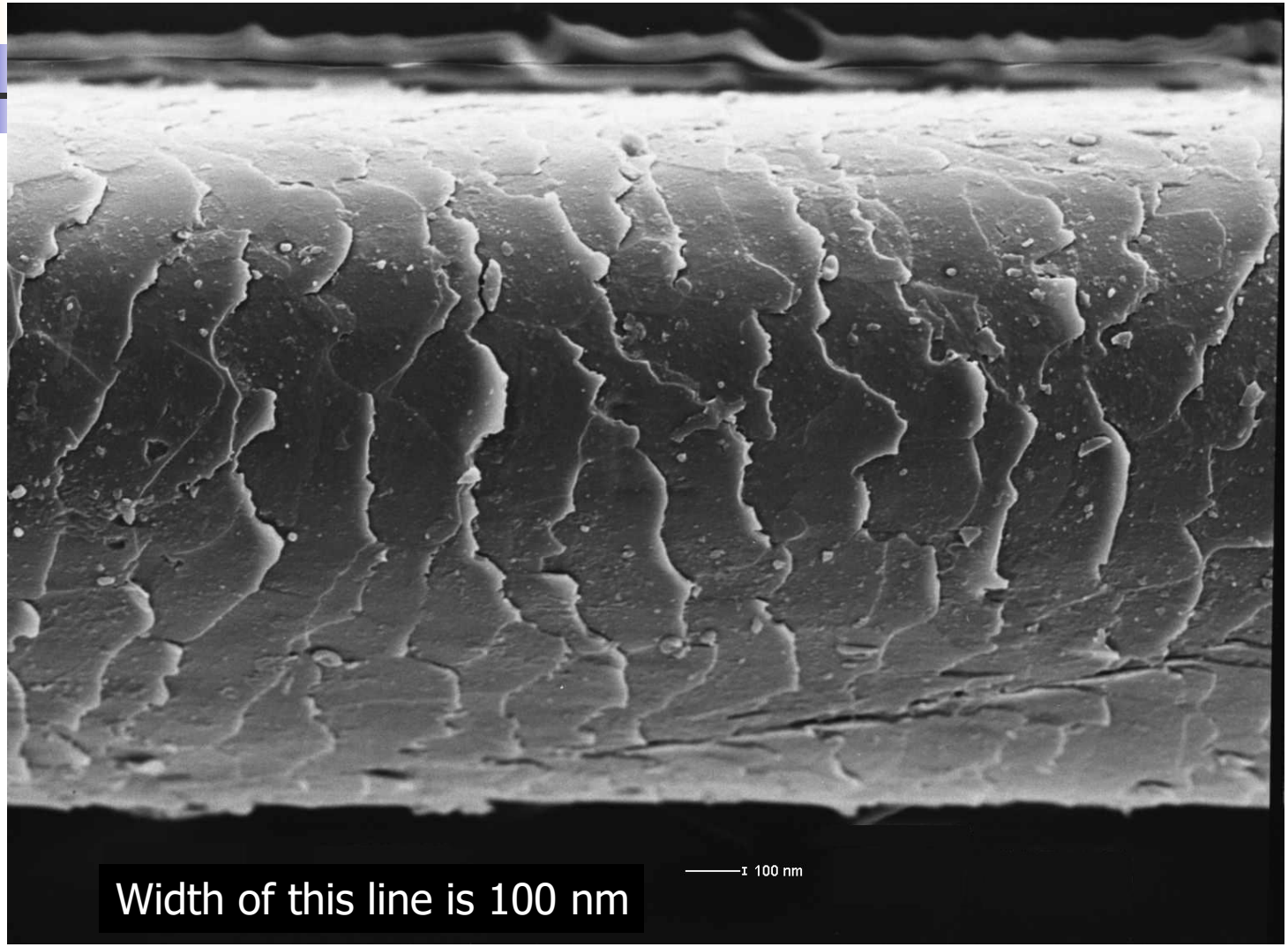
Single Hair

Width = 0.1 mm

= 100 micrometers

= 100,000 nanometers !

Closer Look at a Human Hair



http://www.aber.ac.uk/bioimage/image/uwbl-0411-w.jpg

Why do we want to make things at the nanoscale?

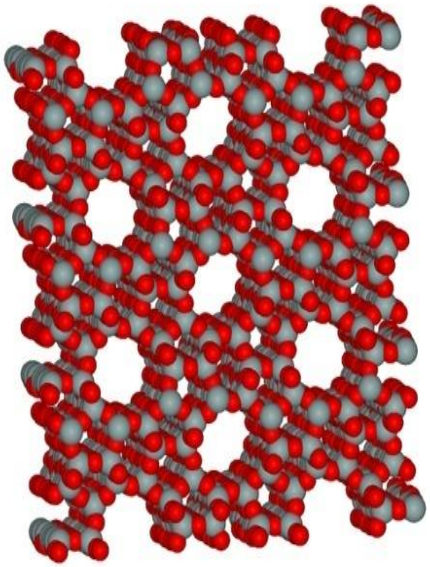
- To make better products: smaller, cheaper, faster and more effective. (Electronics, catalysts, water purification, solar cells, coatings, medical diagnostics & therapy, and more)

- To introduce completely new physical phenomena to science and technology. (Quantum behavior and other effects.)

For a **sustainable** future!

Some special nanomaterials

Zeolites (Crystalline microporous material)

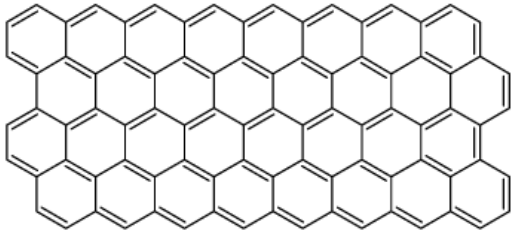


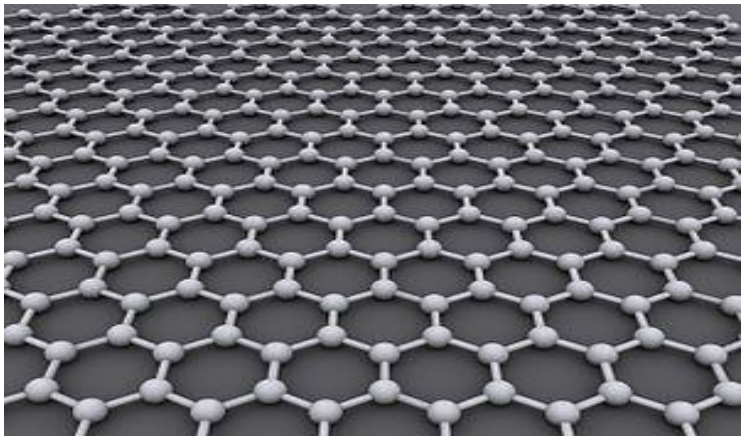
- Zeolites are crystallin aluminosilicates generating network of pores and cavities

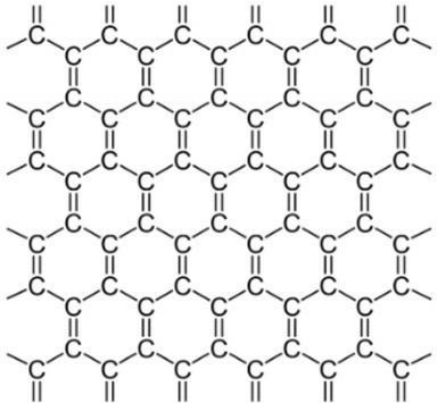
- Molecular dimension are less than 100 nm. There are 34 naturally and 100 synthetic types of zeolite.

- Molecular sieving, high thermal stability, acidity, adsorption capacities, shape selectivity, ion exchange & physicochemical properties.

Graphene







- Graphene is the basic structural element of carbon allotropes like graphite, charcoal, carbon nanotubes and fullerenes.

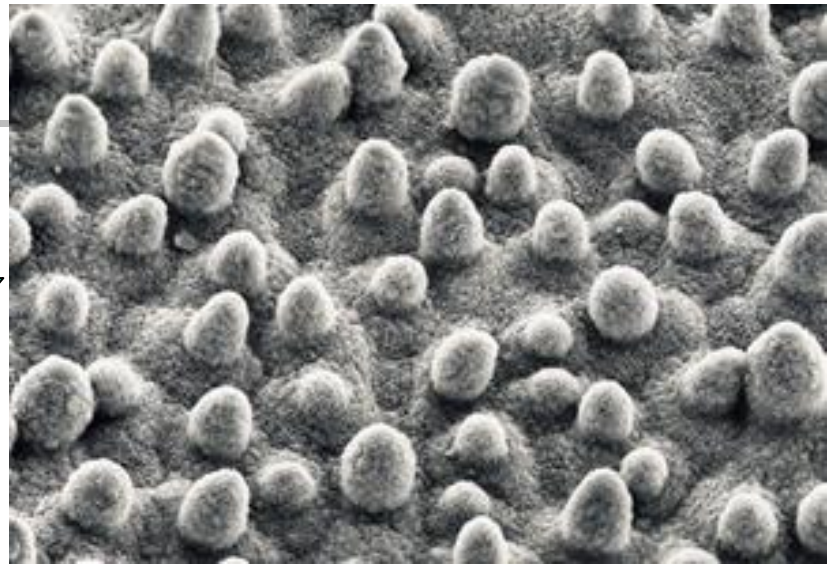
- It is visualized as an atomic scale chicken wire made up of carbon atoms and their bonds.

- The crystalline form of graphite consist of many graphene sheet stacked together.

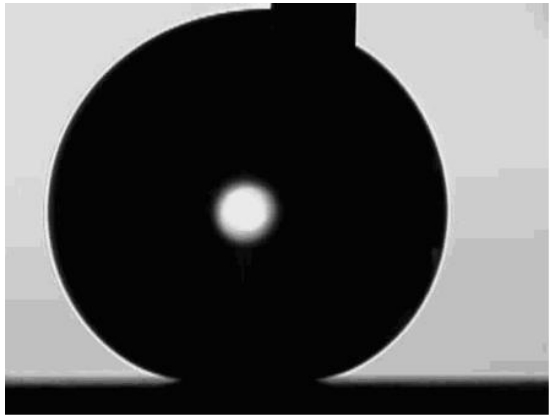
Application of nano-materials in Engineering

- Material technology
- Information technology
- Bio-medical
- Energy storage
- Automotive industry
- Chemical industry
- Medicine
- Textile industry
- Cosmetics industry
- Food industry
- Sports industry
- Application in construction

Super-Repellent Nano-Materials



Lotus leaf surface is superhydrophobic

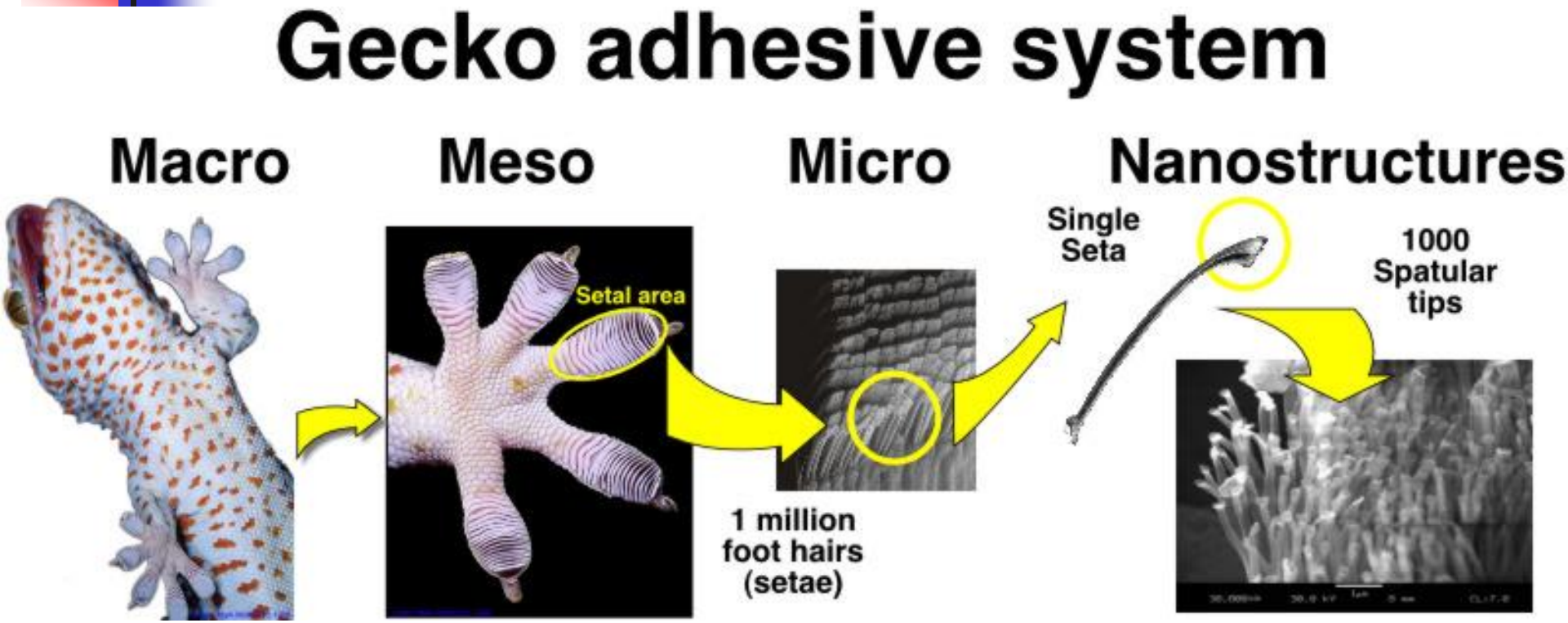


$\theta_A/\theta_R = 156°/151°$

http://cjmems.seas.ucla.edu/members/changhwan/main.html
http://www.engineer.ucla.edu/magazine/fall06/noslip.htm

Geckos Walk on Walls

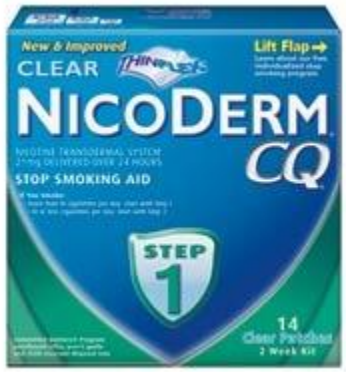
Nano-Finger Tips Allow Geckos to Stick



http://robotics.eecs.berkeley.edu/~ronf/Gecko/index.html

How Nano Effects You

Nanotech products are already on the market



Example: Data storage capacity of the iPod

10 GB
2001

20 GB
2002

40 GB
2004

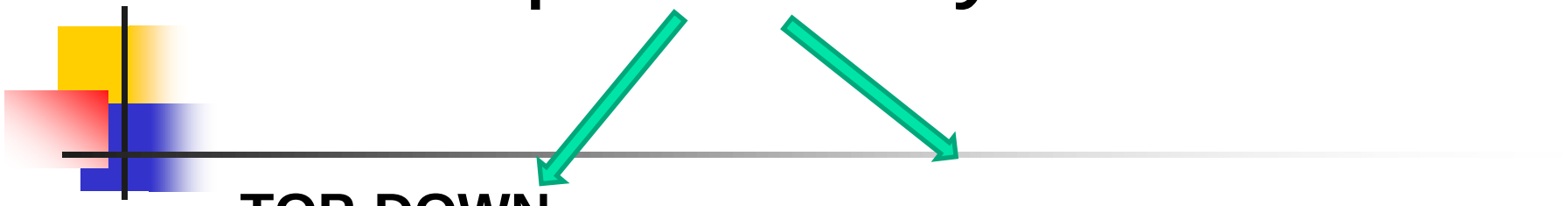
80 GB
2006

160 GB
2010

Hard drive
Magnetic data storage

Uses nanotechnology!

Nanoparticle Synthesis



TOP-DOWN

Via attrition(erosion) and milling
Involves mechanical thermal cycles Yields
- broad size distribution (10-100 nm)
- varied particle shape or geometry
- impurities

- Application:
- Nano-composites and Nano-grained, bulk materials.

BOTTOM UP

Via
- Pyrolysis
- Inert gas condensation
- Solvothermal Reaction
- Sol-gel Fabrication

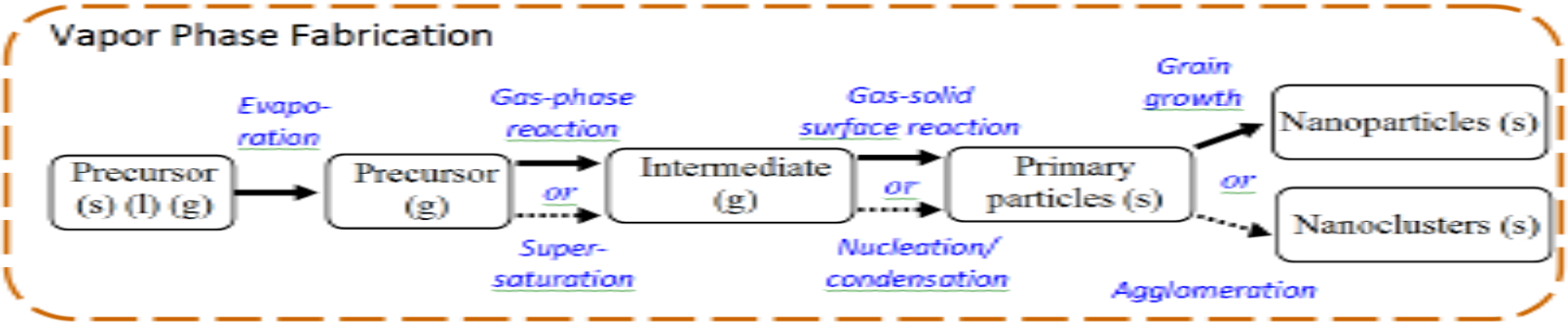
Physical Vapour Deposition (Bottom – Up Synthesis):

In this method thin film is deposited onto various surfaces by condensation of a vaporized form of material under high vacuum condition.

- The shape, size and chemical composition of a nano structured material is controlled.

- Various methods of Physical Vapour Deposition involves – Evaporation, Sputtering, glow discharge, RF Sputtering etc.

Process of Execution:



(i) precursor vaporization (typically involves a catalyst)
(ii) nucleation, and
(iii) growth stage

Effectiveness demands:

- simple process
-low cost
-continuous operation
Methods
- High yield

Aerosol Spray

(e.g., Spray Pyrolysis)

Sol-gel Process

- Formation of stable sol solution

- Gelation via a polycondensation or polyesterification reaction

- Gel aging into a solid mass causes contraction of the gel network, also

  (i) phase transformations and

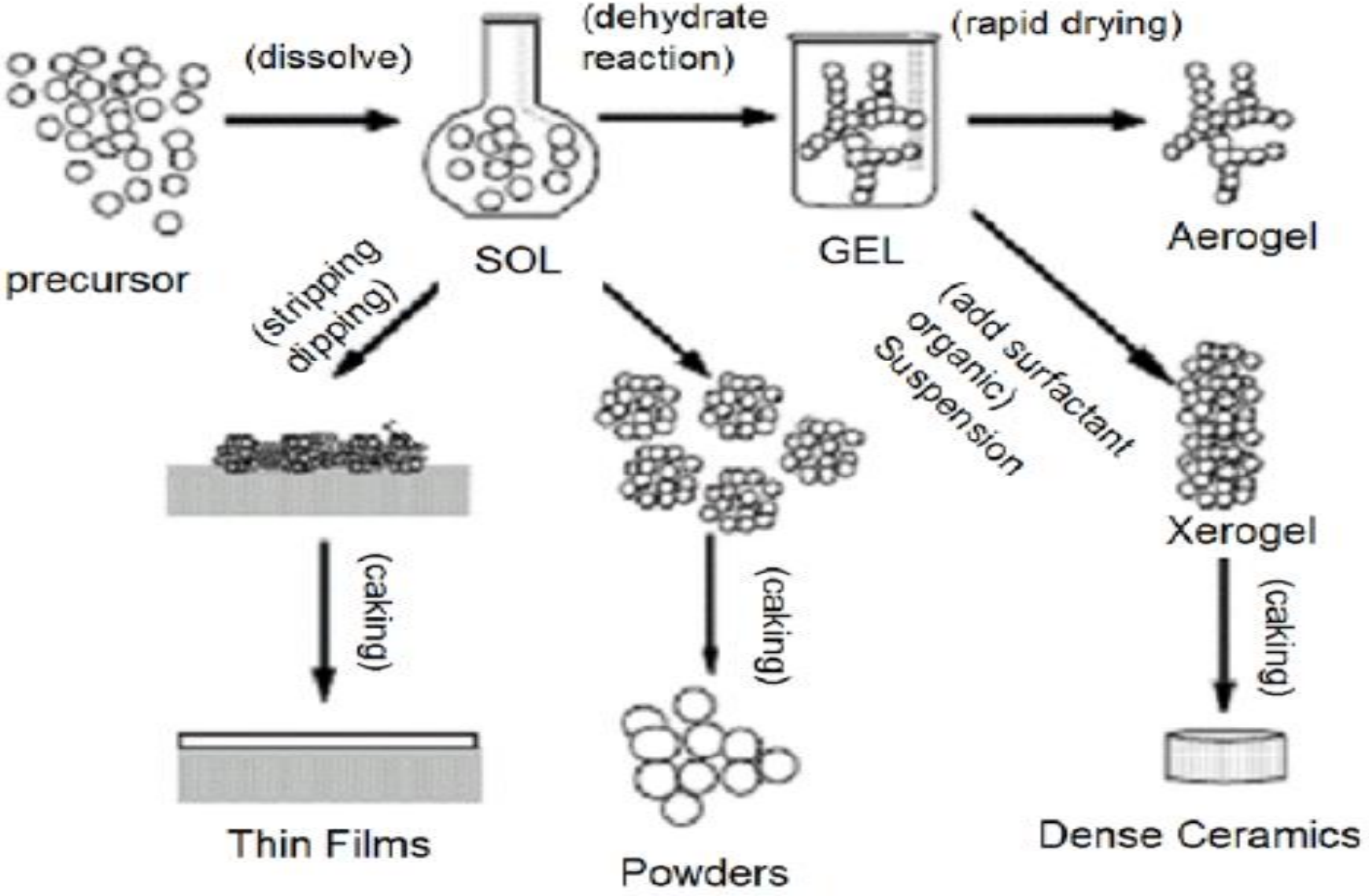
  (ii) Ostwald ripening

- Drying of the gel to remove liquid phases can lead to fundamental changes in the structure of the gel.

- Dehydration at temperatures as high as 800^{o}C, used to remove M-OH groups for stabilizing the gel, i.e., to protect it from rehydration.

- Densification and decomposition of the gels at high temperatures (T > 800^{o}C), i.e., to collapse the pores in the gel network and to drive out remaining organic contaminants.

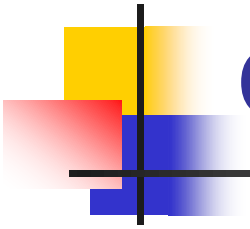
Sol-gel Process



Big Idea – Tools and Instrumentation

Development of new tools and instruments helps drive scientific progress. Recent development of specialized tools has led to new levels of understanding of matter by helping scientists detect, manipulate, isolate, measure, fabricate, and investigate nanoscale matter with unprecedented precision and accuracy.

How do we "see" nanoscale objects?

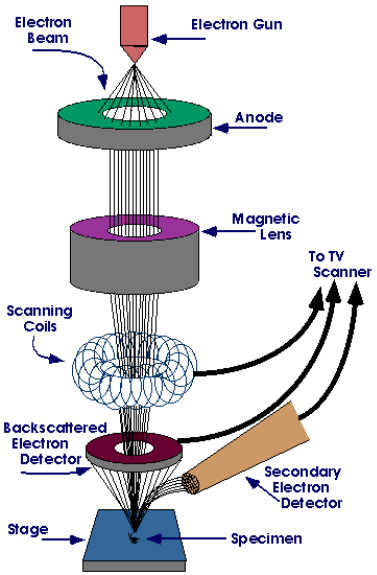


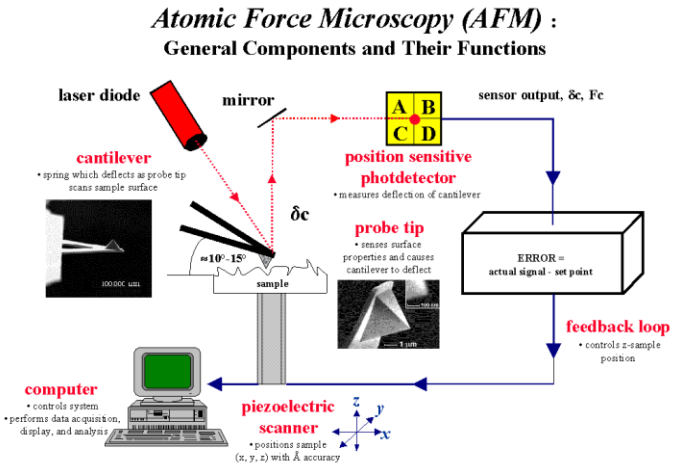
- Nanoscale is below the range of visible light so cannot use optical microscopes
- Special tools
  - Scanning Probe Microscopy
    - Atomic Force Microscope
  - Scanning Electron Microscope

How do we "see" nanoscale objects?

Specialized tools are required to detect, measure, and investigate the nanoscale world because structures on this scale are too small to be seen with optical microscopes.

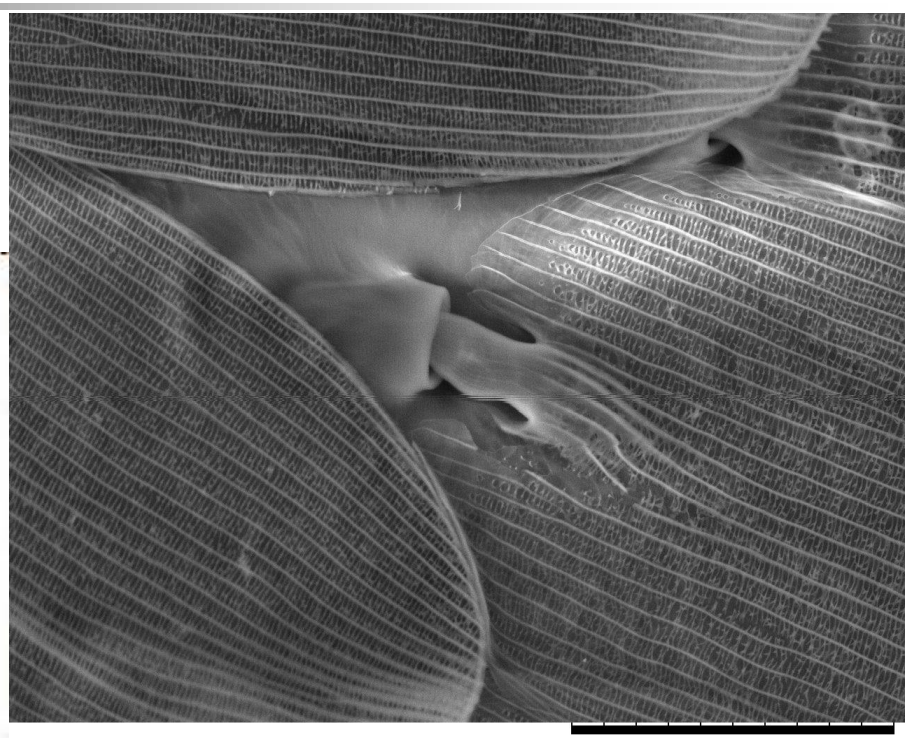
Scanning Electron Microscope





Tools that help us see micro and nano worlds

Hitachi Tabletop SEM

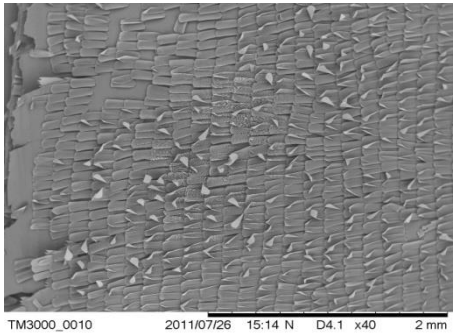


Pittcon 2010

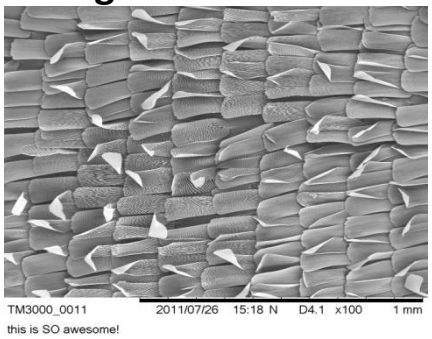
SEM Butterfly Investigation

Description: **The object is a part of a wing of a blue Morpho Butterfly. The top part is an iridescent blue while the underside is a brown shade. We will look at the blue side of the wing.**

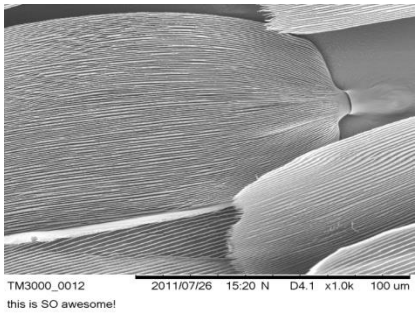
Magnification: 10 X



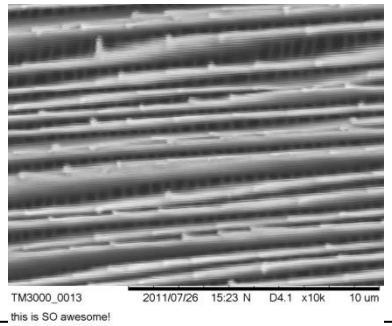
Magnification: 100 X



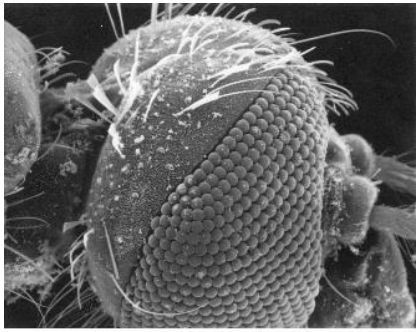
Magnification: 1,000 X

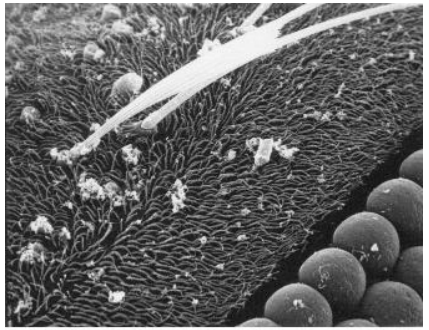


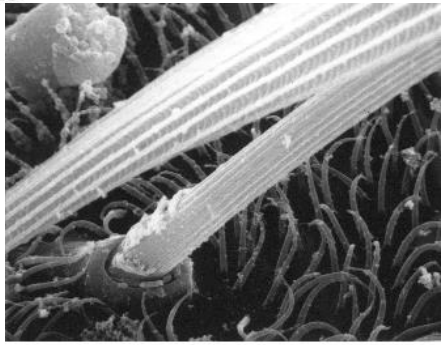
Magnification: 10,000 X

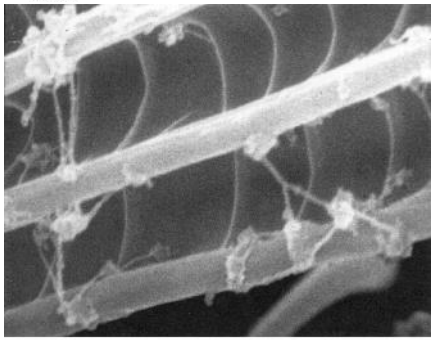


Using tools to see smaller scales



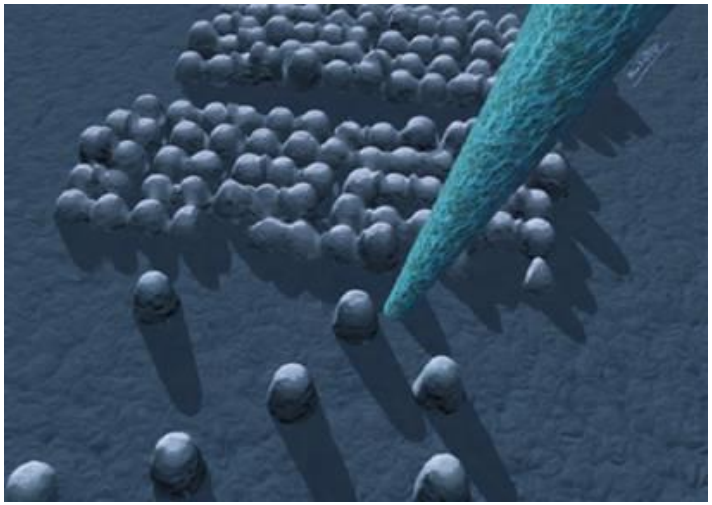


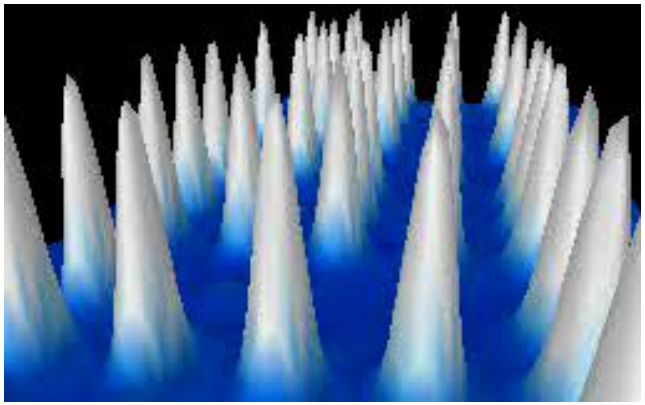


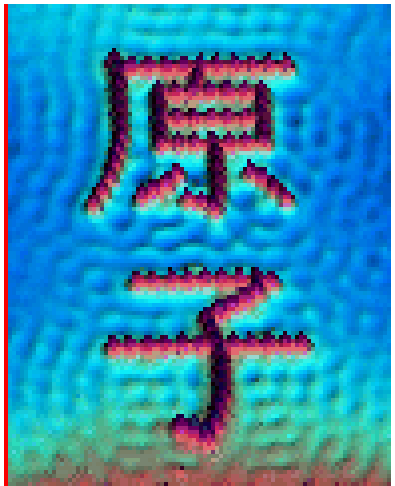


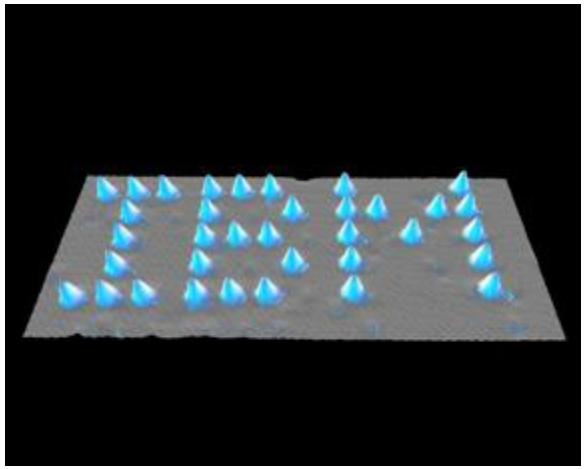
http://www.mos.org/sln/sem/tour04.html

Scanning probe microscopes: Atomic Force Microscopy

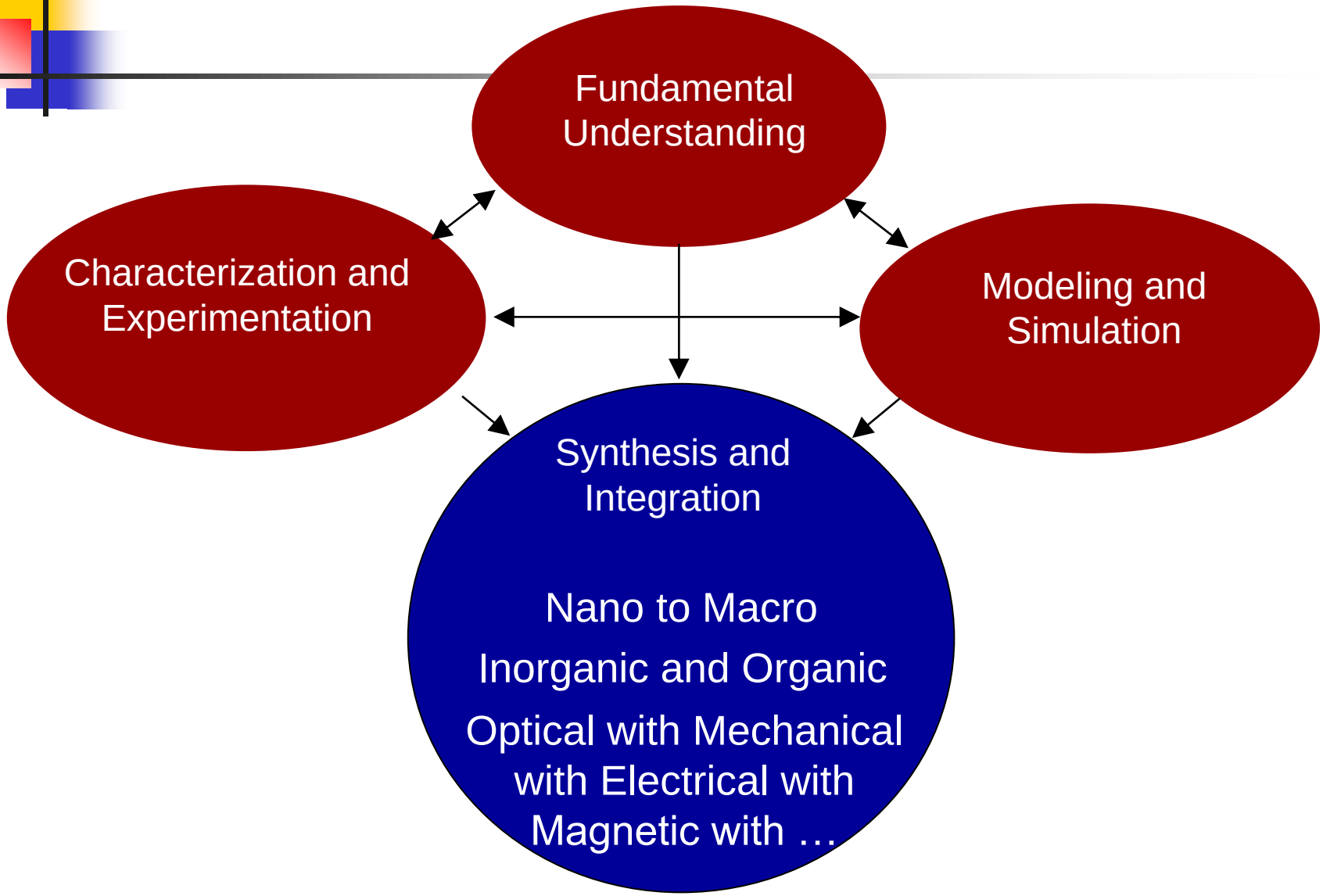








Development of Nanotechnology

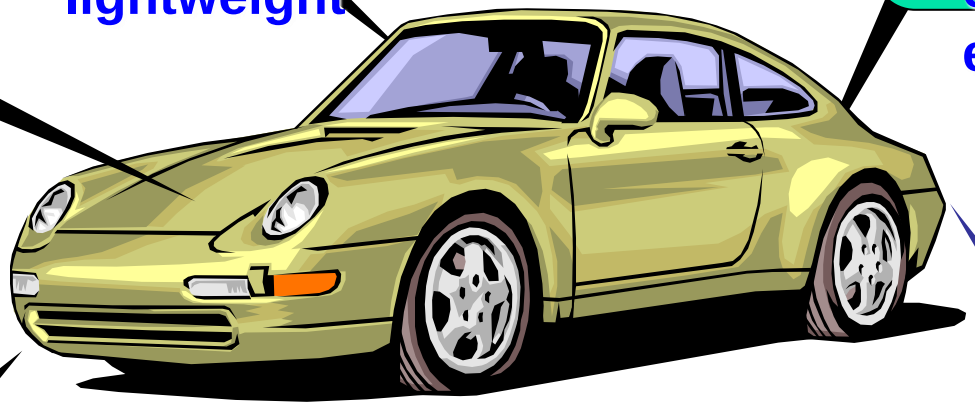


FUTURE AUTOMOBILE

Carbon nanotubes in windshields & frames to make them strong & lightweight

Nano-scale metal oxide ceramic catalysts to almost eliminate emissions

Nano-powders in paints for high gloss & durability



Nano polymer composites for lightweight high resistance bumpers

Fuel cells with nano-catalysts and membrane technologies

NANOMATERIALS IN CURRENT CONSUMER PRODUCTS

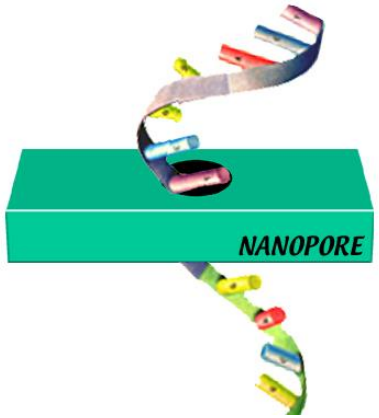
Carbon nanotubes

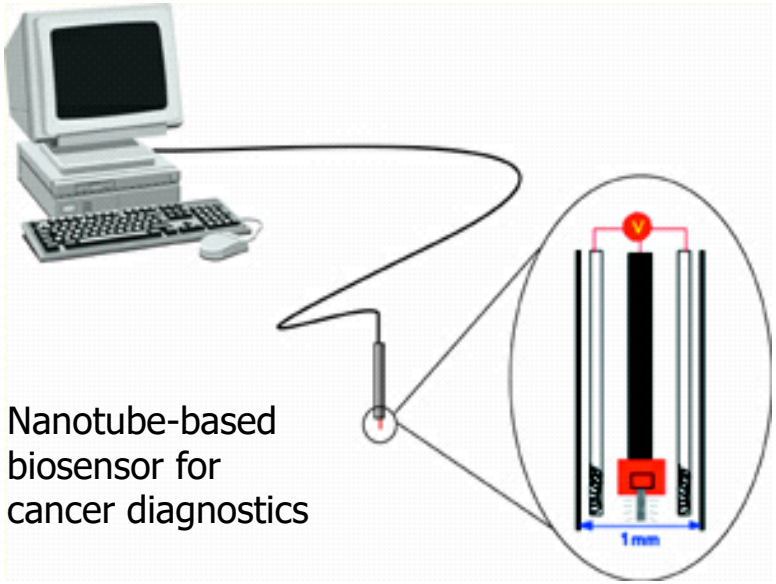
Nano polymer
Composites for stain
Resistant clothing

Cosmetics, sunscreens
Containing zinc oxide and
Titanium oxide nanoparticles

HEALTH AND MEDICINE

- Effective and less expensive health care using remote and in-vivo devices





Nanotube-based biosensor for cancer diagnostics

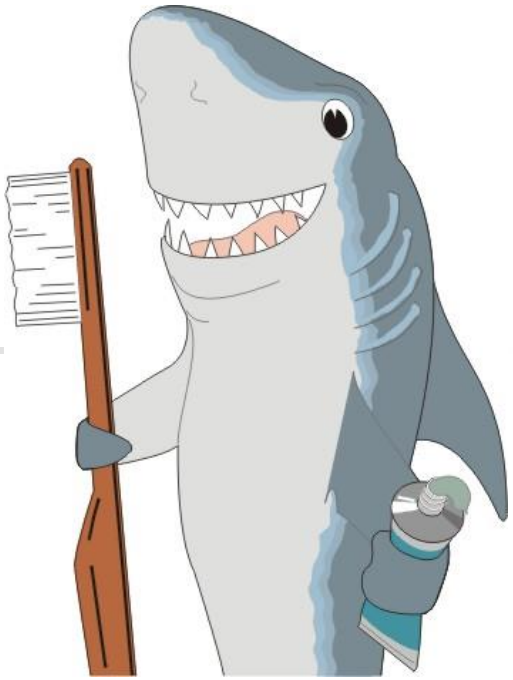
- New formulations and routes for drug delivery, optimal drug usage
- More durable, rejection-resistant artificial tissues and organs
- Sensors for early detection and prevention

Some examples concerning materials:

- ***textiles*** that change properties as a function of needs, such as keeping summer and warm in winter

- ***forks, spoons, dishes, pots, clothes,*** … that do not get dirty or wet - just like a lotus leaf when you pour a drop of water on it;

Carbon nano-tubes can be stronger than steel and lighter than plastic



- materials that can fix your ***bones*** and ***teeth*** so that you cannot tell the difference
- materials that are very resistant and very light to make ***cars***, ***aircraft*** and ***space vehicles*** able to go on longer journey with much less energy consumption
- and more in the future ***(just think that mobile phones did not exist only ten years ago!).***

Materials with finer structure or smaller grains can be stronger and lighter

SAFETY OF NANOMATERIALS

- Environmental impact
- Absorption through skin
- Respiratory ailments
- Evidence that carbon nanotubes cause lung infection in mice. Teflon nanoparticles smaller than 50 nm cause liver cancer in mice.

Impact of nano-science and nanotechnology

- Includes contributions from professionals in a variety of industries and disciplines, including science, law, ethics, business, health and safety, government regulation, and policy.

- Covers an area of increasing research and funding.

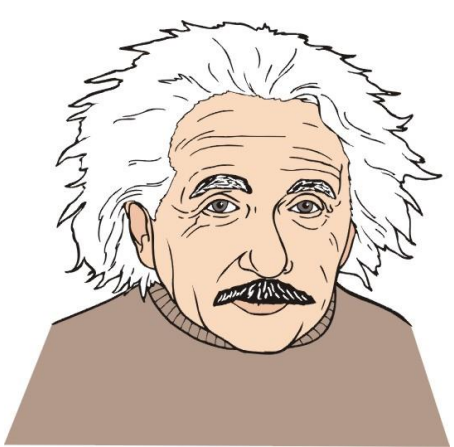
- Explores how nanomaterials affect the environment, presenting the results of investigations on living systems, including biological components, cells, simple organisms, animals, and humans.

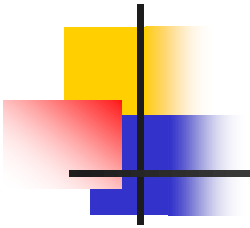
Research into nanotechnology is a particularly challenging adventure

Many of the world's best minds are engaged in this.

And we need brilliant students and scientists more than ever.

We can see and move atoms
We can see and move molecules





Students & Nanotechnology

- A Field for People Who Want to Solve Technological Challenges Facing Societies Across the World