What is Nanotechnology?

“Nanos“ Greek: “Dwarf“

$1\ nm = 10^{-9}\ m$

Earth

Euro Coin

ϕ = 16 mm

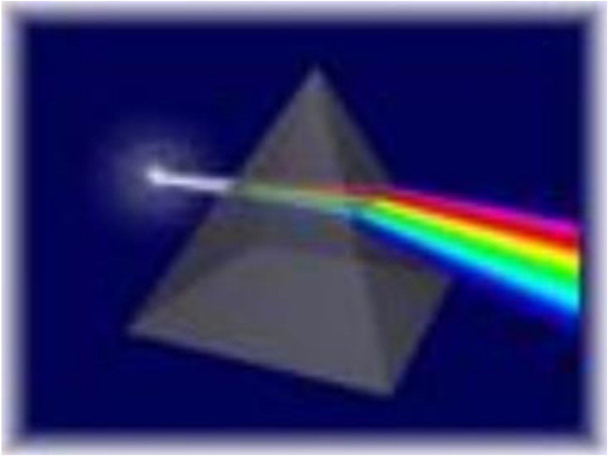
Nanotechnology

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

Properties of a Material

A property describes how a material acts under certain conditions.

- **Types of properties:**
  - Optical (e.g. color).
  - Electrical (e.g. conductivity).
  - Physical (e.g. melting point).
  - Chemical (e.g. reaction rate).



- **Properties are usually measured by looking at large (~10^{23}) aggregations of atoms or molecules.**

What’s interesting about the nanoscale?

- Nanosized particles exhibit different properties than larger particles of the same substance.

- Nanosized particles exhibit size & shape dependent properties.

Length Scale: Changes Properties

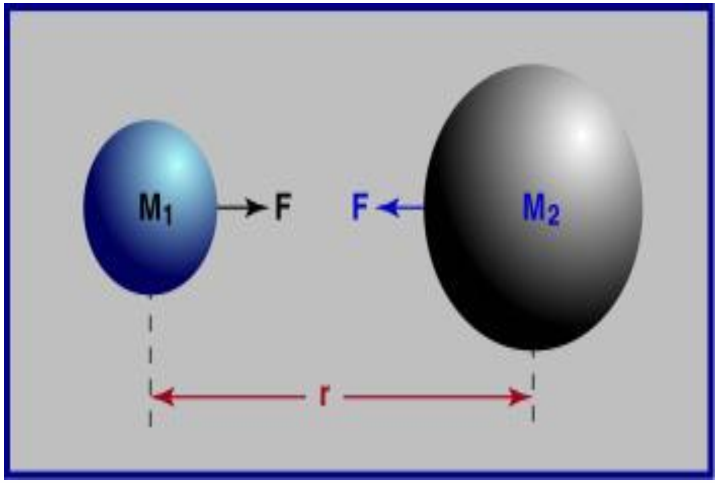
Three important ways in which Nanoscale materials may differ from macro scale materials

1. Gravitational forces become negligible and electromagnetic forces dominate.
2. Quantum mechanics is the model used to describe motion and energy instead of the classical mechanics model.
3. Greater surface to volume ratios.

Dominance of Electromagnetic Forces

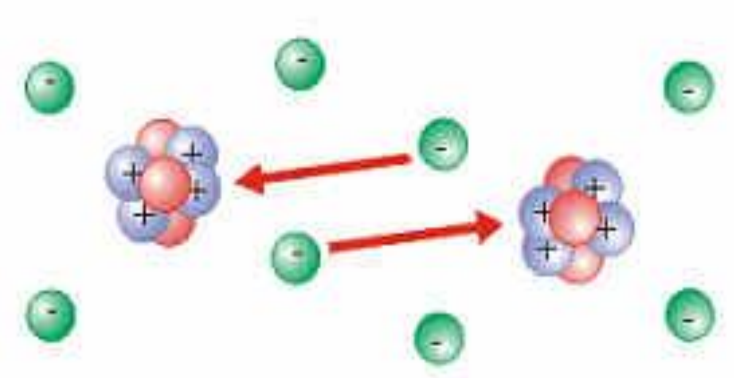
- **Gravitational force**

is a function of **mass** and distance and is ***weak*** between (low-mass) Nano sized particles.



- **Electromagnetic force**

is a function of **charge** and distance is not affected by mass, so it can be very ***strong*** even when we have Nano sized particles.



Quantum Effects

Classical mechanical models that we use to understand matter at the macro scale **break down** for…

- The very small (Nanoscale) systems.

Quantum mechanics better describes phenomena that classical physics cannot, like…

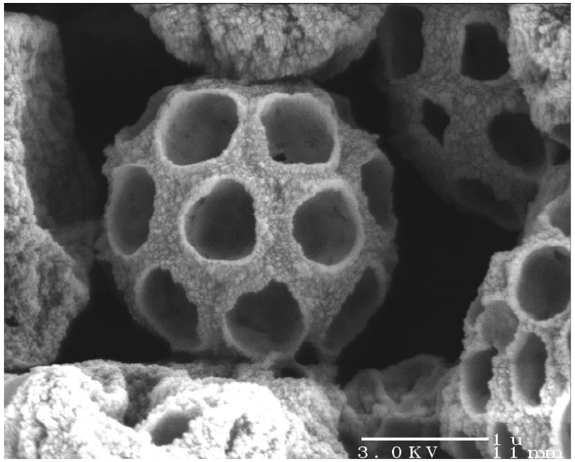
- The colors of Nano gold
- The probability (instead of certainty) of where an electron will be found.
- Below a certain length scale (that depends on interaction strengths) systems must be described using quantum mechanics.

Why Nanotechnology?

At the nanoscale, the physical, chemical, and biological properties of materials **differ** in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter.

Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these **new properties**.

In Other Words….



Small photonic crystals: titanium dioxide micro-sphere 1-50 µm in diameter

Working at the atomic, molecular and supra-molecular levels, in the length scale of approximately ***1 – 100 nm range***, through the control and manipulation of matter at the atomic and molecular level in order to design, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure.

Courtesy: National Science Foundation
Credit: *S. Klein, F. Lange and D. Pine, UC Santa Barbara*

Two main Reasons:
Difference in materials properties at the Nanoscale

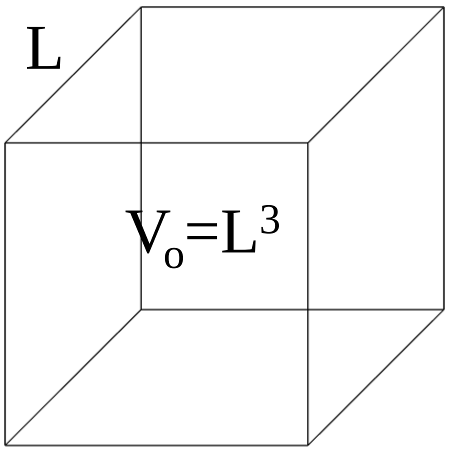
- **First**, Nanomaterials have a **relatively larger surface area** when compared to the same mass of material produced in larger form.

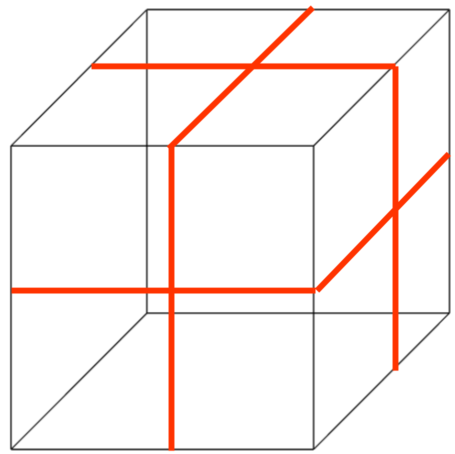
  - Nanoparticles can make materials **more chemically reactive** and affect their ***strength or electrical properties***.

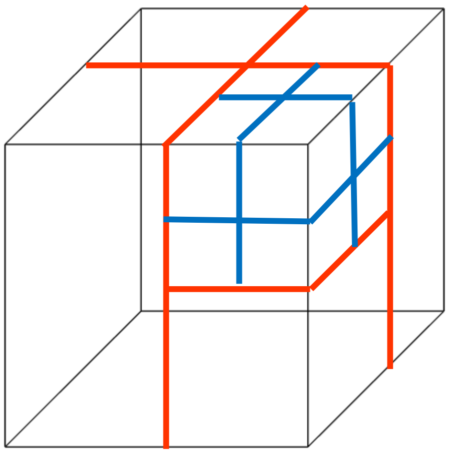
- Seconds, **quantum effects** can begin to dominate the behavior of matter at the Nanoscale.

Specific Area: Surface Area to Volume Ratio

in dependence upon particle size







$n_L=1$ $n_{L/2}= 2x2x2 =8$ $n_{L/4}= 4x4x4 =64$

$S_o=6L^2$

$S_{L/2}=6(L/2)^2 \text{ x } (2x2x2) =12L^2$

$SA= S_o/V_o$

$= 6L^2/L^3$

$= 6/L$

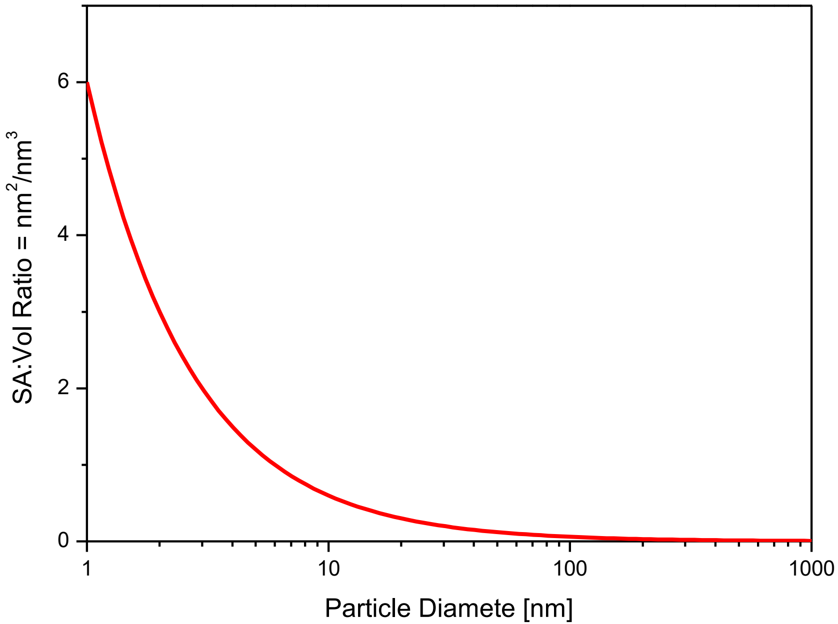
$S_{L/4}=6(L/4)^2 \text{ x } (4x4x4)=24L^2$

$n_{L/8}= 8x8x8 =512$

$S_{L/8}=6(L/8)^2 \text{ x } (8x8x8)=48L^2$

Specific Area: Surface Area to Volume Ratio

Size of cube side (m)	Number of cubes	Total Surface Area (m^2)
1	1	6
10^{-1}	10 x 10 x 10 (= 10^3)	60 (=6 x 10)
10^{-2} (= 1 cm)	100 x 100 x 100 (= 10^6)	600 (6 x 10^2)
10^{-3} (= 1 mm)	10^9	6,000 (6 x 10^3)
10^{-6} (= 1 µm)	10^{18}	6 x 10^6
10^{-9} (= 1 nm)	10^{27}	6 x 10^9



The ratio increases dramatically when the nanoparticle diameter drops ***below about 100 nm***

Specific Area: Surface Area to Volume Ratio

Some example calculations for volume and surface area of nanoparticles. These calculations use nm as unit of length.

Nanoparticle Diameter (nm)	Volume (nm^3)	Surface Area (nm^2)	SA:Vol Ratio (nm^2/nm^3)
1	0.524	3.14	6
10	524	314	0.6
100	523598	31416	0.06
1000	5.24E+08	3.14E+06	0.006
10000	5.24E+11	3.14E+08	0.0006
100000	5.24E+14	3.14E+10	0.00006
1000000	5.24E+17	3.14E+12	0.000006

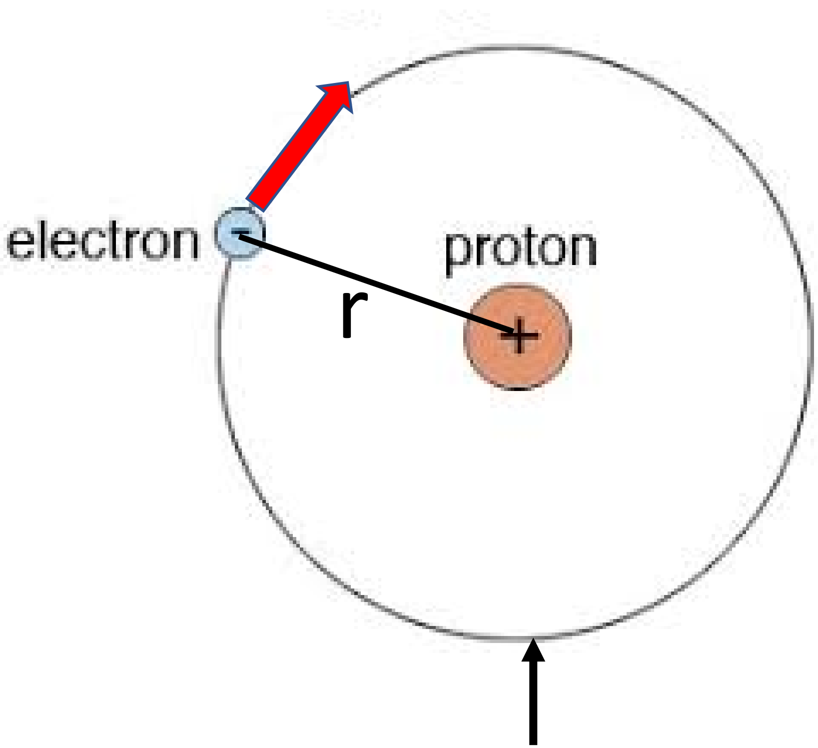
$$V_p = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3 = \frac{\pi D^3}{6}$$

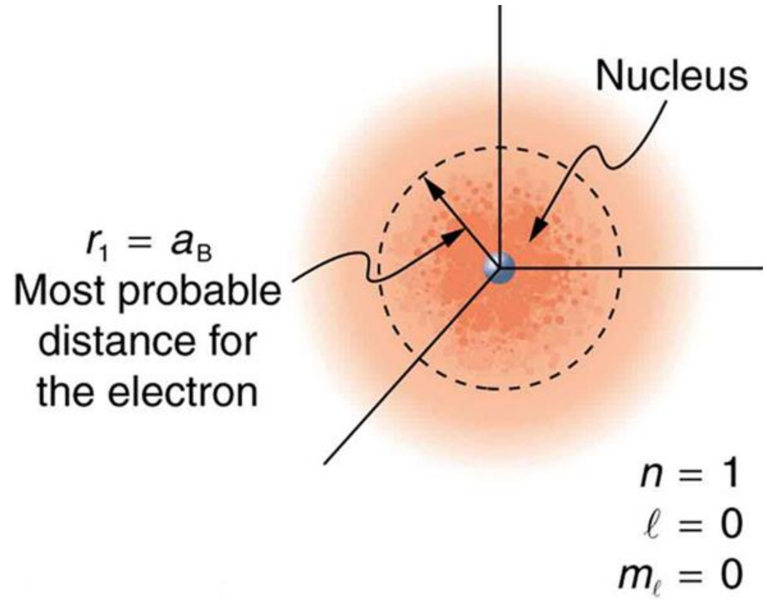
$$\text{S : V Ratio} = \frac{\pi D^2}{\pi D^3 / 6} = \frac{6}{D}$$

$$S = 4\pi r^2 = 4\pi\left(\frac{D}{2}\right)^2 = \pi D^2$$

The Bohr Model

Hydrogen Atom





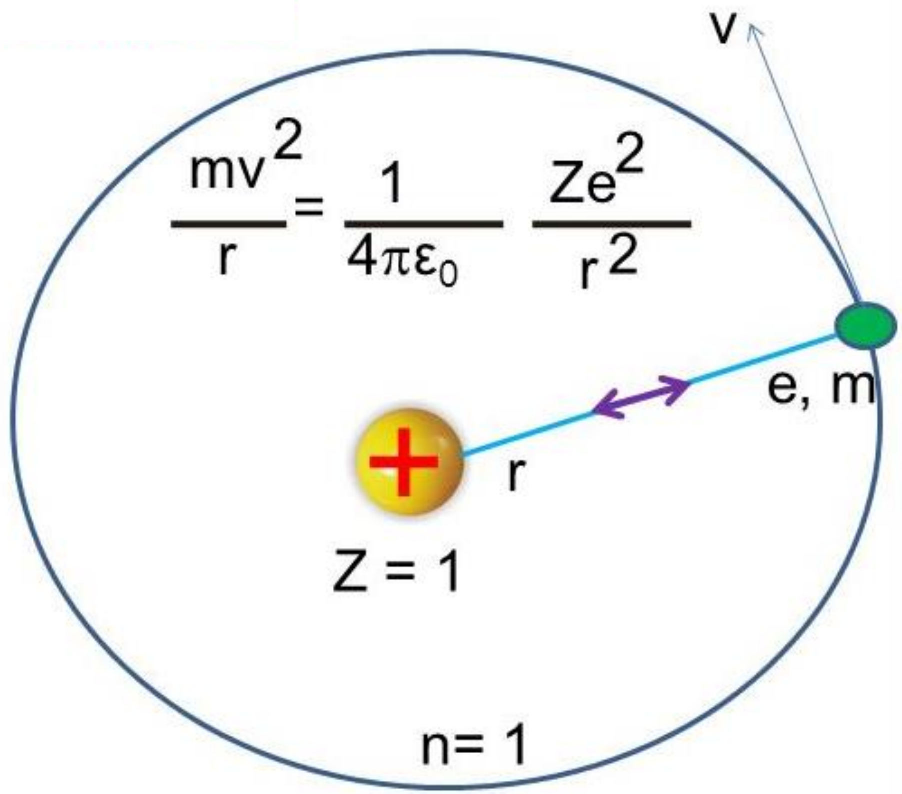
Bohr Radius

$$L = \frac{nh}{2\pi}$$

but $L = mvr$ So

$$mvr = \frac{nh}{2\pi}$$

$$r = \frac{nh}{2\pi mv} \quad ....(1)$$



Putting $v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$

$$r = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2}$$

This is called the Bohr radius, represented by the symbol a_0.

$$a_0 = \frac{\varepsilon_0 h^2}{\pi m e^2} = 5.29 \times 10^{-11}\ \text{m}$$

Bohr Radius

- The diameter of the hydrogen atom for stationary states is

$$r_n = \frac{4\pi\varepsilon_0 n^2 \hbar^2}{me^2} \equiv n^2 a_0$$

Where the **Bohr radius** is given by

$$a_0 = \frac{4\pi\varepsilon_0 \hbar^2}{me^2} = \frac{(1.055\times10^{-34}\ \mathrm{J\cdot s})^2}{\left(8.99\times10^9 \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)(9.11\times10^{-31}\ \mathrm{kg})(1.6\times10^{-16}\ \mathrm{C})^2} = 0.53\times10^{-10}\ \mathrm{m}$$

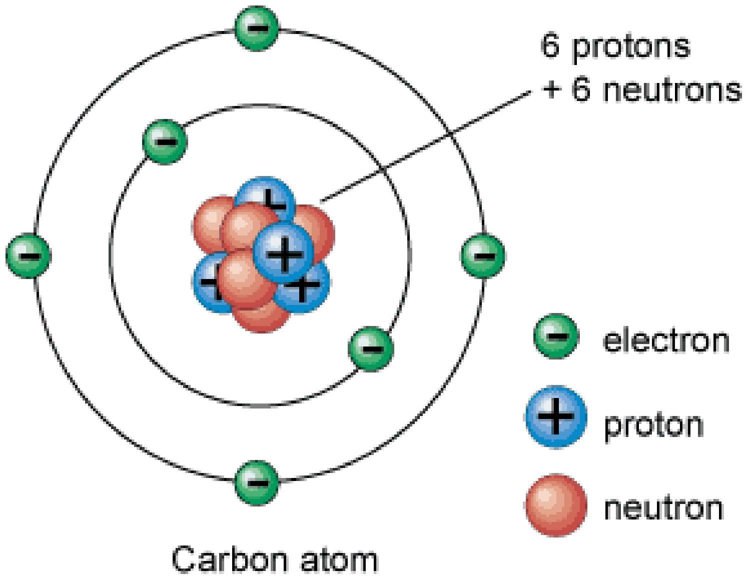
- The smallest diameter of the hydrogen atom is

$$2r_1 = 2a_0 \approx 10^{-10}\,\mathrm{m}$$

- n = 1 gives its lowest energy state (called the "ground" state)

Length Scale

- Bohr radius = **0.5292Å ≈ 0.05** nm
- C atom (VdW radius)=**0.17** nm
- In a 1nm line: **3C** atoms
- In a 1nm x 1nm surface: **9C** atoms
- In a 1nm x 1nm x 1nm cube: **27 C** atoms
- In a 100 nm x 100 nm x 100 nm cube: **27 x 10^6 C** atoms



- In a 1m x 1m x 1m cube: **2.7 x 10^{28} C** atoms

Surface Atoms to Bulk Atoms Ratio in Macroscale

A typical material possesses:

$\sim 10^{23}$ atoms/cm^3 (volume density)

$\sim 10^{15}$ atoms/cm^2 (surface density)

Assume that we have a cube with side of length = 1 cm.

Total number of atoms $\sim 10^{23}$ atoms/cm^3 $\times$ (1 cm)^3 $\sim 10^{23}$

Total number of surface atoms $\sim 10^{15}$ atoms/cm^2 $\times 6 \times$ (1 cm)^2 $\sim 6\times10^{15}$

Ratio of surface to total atoms $\sim 6\times10^{15}/10^{23} \sim 6\times10^{-8}$

$6x10^{-8}$

Surface Area to Volume Ratio in Nanoscale

A typical material possesses:

$\sim 10^{23}$ atoms/cm^3 (volume density)

$\sim 10^{15}$ atoms/cm^2 (surface density)

Assume that we have a cube with side of length = 1 nm = 10^{-7} cm.

Total number of atoms $\sim 10^{23}$ atoms/cm^3 $\times$ $(10^{-7}$ cm$)^3$ $\sim$ 100

Total number of surface atoms $\sim 10^{15}$ atoms/cm^2 $\times 6 \times$ $(10^{-7}$ cm$)^2$ $\sim$ 60

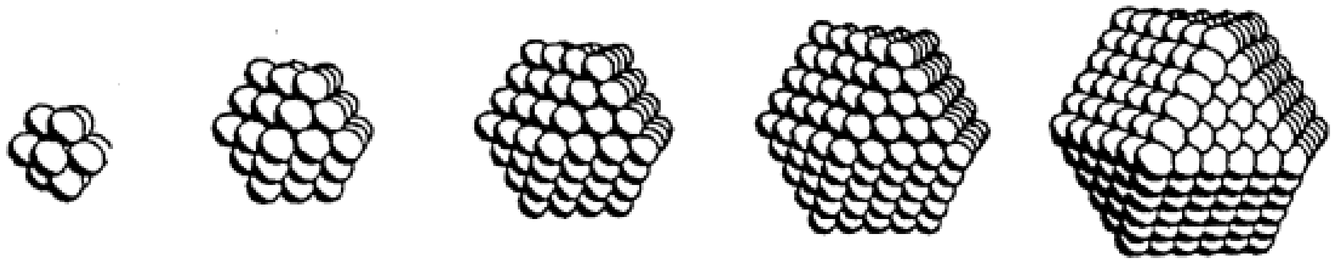
Ratio of surface to total atoms ~ 60/100 ~ 0.6

cm Scale → **nm Scale**

6×10^{-8} **10^7** **6×10^{-1}**

Clos-packed Magic Number

Full-shell "magic number" clusters

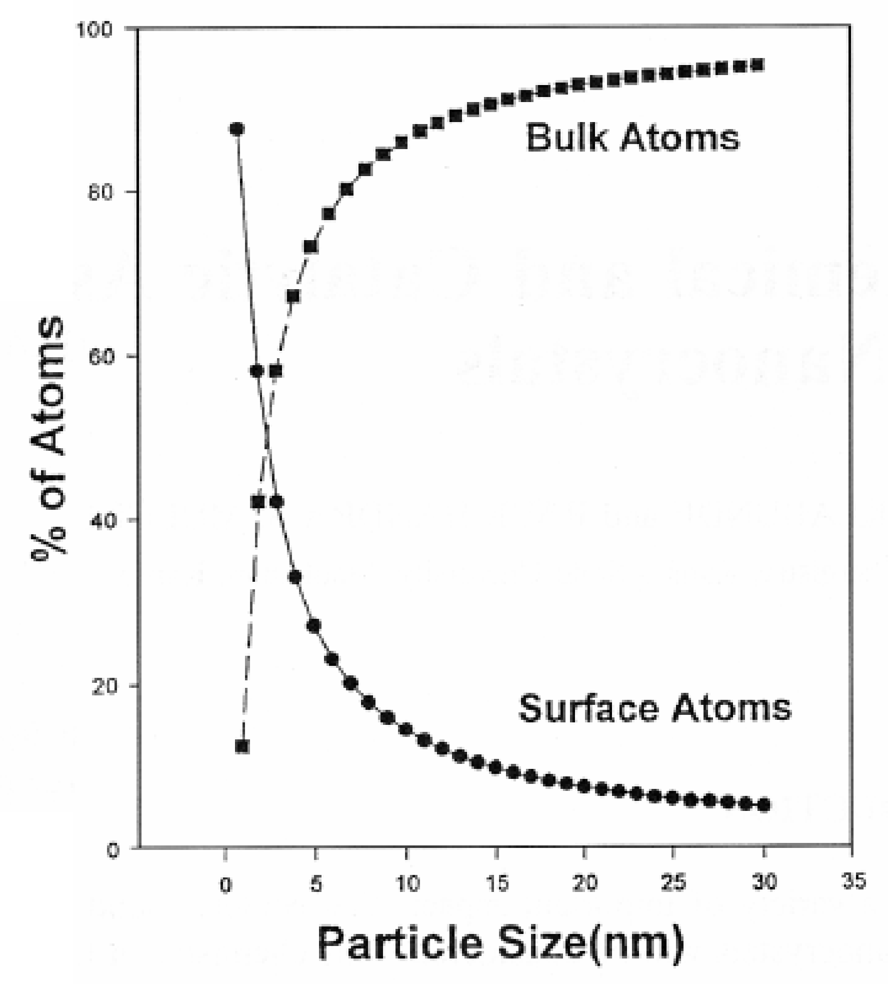


Number of shells	1	2	3	4	5
Number of atoms in cluster	13	55	147	309	561
Percentage of surface atoms	92	76	63	52	45

- Magic Number = Cluster has a complete, regular outer geometry
- Formed by successively packing layers around a single metal atom.
- Number of atoms (y) in shell (n): $y = 10n^2 + 2$ *(n = 1,2,3…)*
- Maximum number of nearest neighbors (metal-metal hcp packing)
- Decreasing percentage of surface atoms as cluster grows

J. D. Aiken III, R. G. Finke, *J. Mol. Catal.* 1999, 145, 1

Surface Atoms vs. Bulk Atoms



The number of surface atoms increases with reducing size of the particles

Surface Area to Volume Ratio

- Generally accepted material properties are derived from the bulk, where the percentage of atoms at the surface is miniscule. These properties change at the nanoscale.

- As the surface area to volume ratio increases so does the percentage of atoms at the surface and surface forces become more dominant.

Surface Energy

Surface atoms possess more energy than bulk atoms.

↓

Consequently, surface atoms are more chemically reactive.

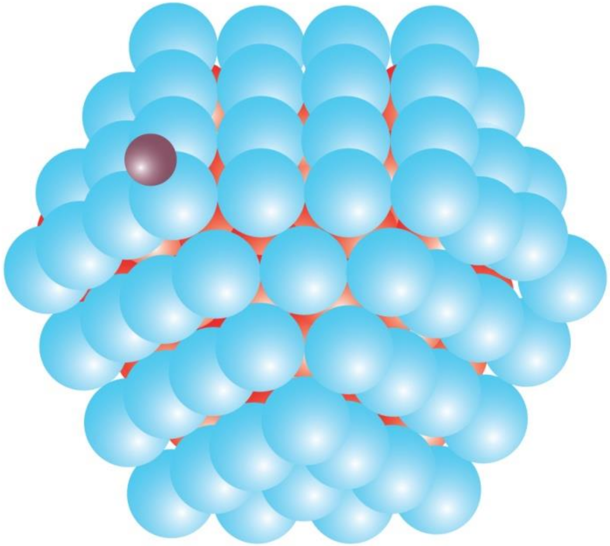
↓

Nanoparticles possess enhanced chemical reactivity.

The Surface

…is where the <u>interactions that result in changes in physical and chemical properties occur.</u>

…is where <u>chemical reactions</u> take place.



Nanoparticles

What factors account for the increase in reaction rates of chemical processes at the nanoscale level?

As the <u>size</u> of nanoscale particles <u>decreases</u>,

the <u>surface area to volume ratio increases.</u>

<u>Therefore, the surface energy increases!</u>

Increase the rates of chemical reactions

Unique Characteristics of Nanoparticles

- **Large surface to volume ratio**
- **High percentage of atoms/molecules on the surface**
- **Surface forces are very important**, while bulk forces are not as important.

- Semiconductor nanoparticles may exhibit confined energy states in their electronic band structure (e.g., quantum dots)
- Can have unique chemical and physical properties
- Same size scale as many biological structures

Size Effect: Color

<u>The gold we know:</u>

Material properties don't change with size
- resistivity
- melting point
- optical absorption

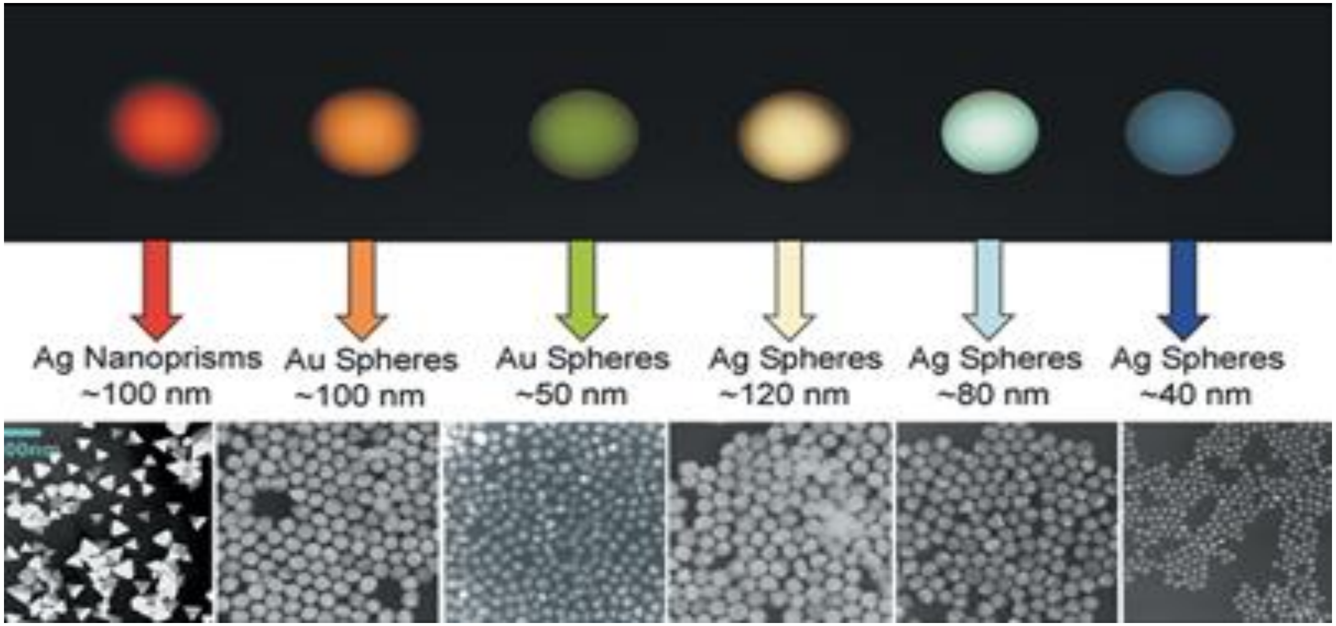
<u>The gold we are discovering:</u>

Material properties (such as optical Absorption, shown here) change with the size of the gold nanoparticle.

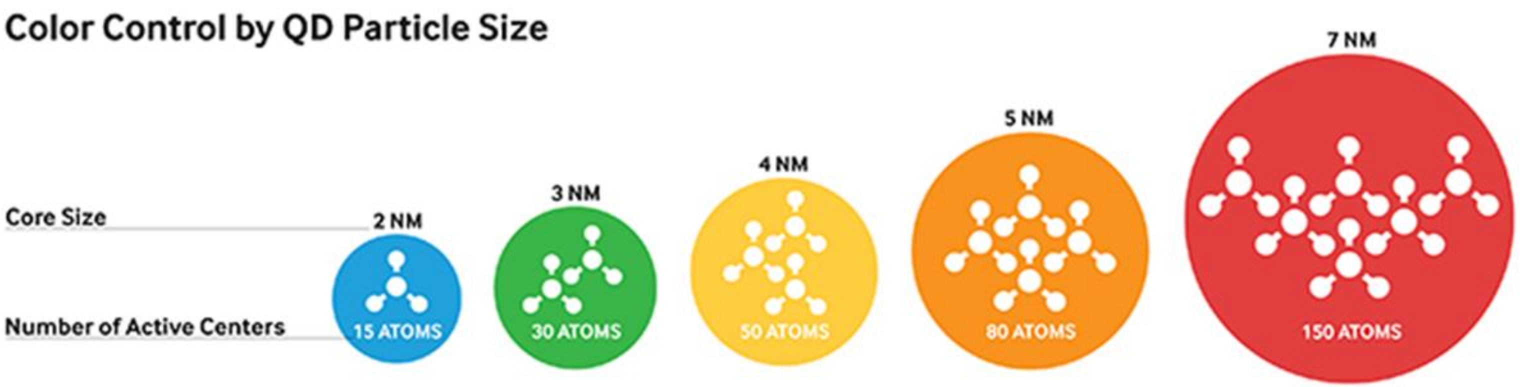
Size is a Material Property !

Size Effect: Color

- As the percentage of atoms at the surface increases, the mechanical, optical, electrical, chemical, and magnetic properties change.
  - For example optical properties (color) of gold and silver change, when the spatial dimensions are reduced and the concentration is changed.

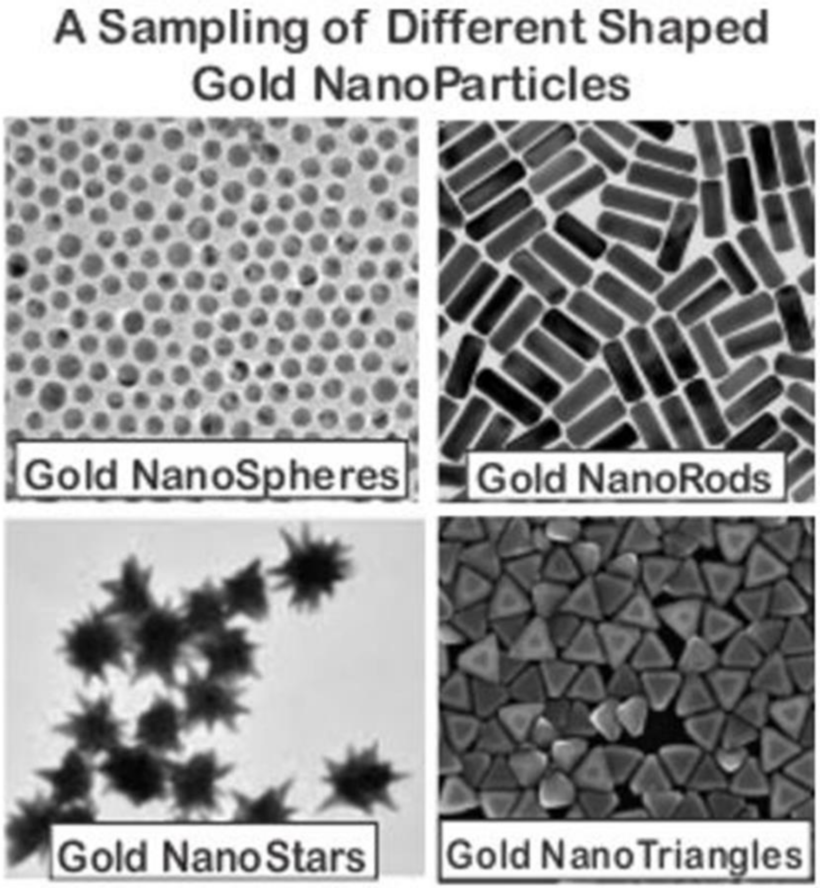


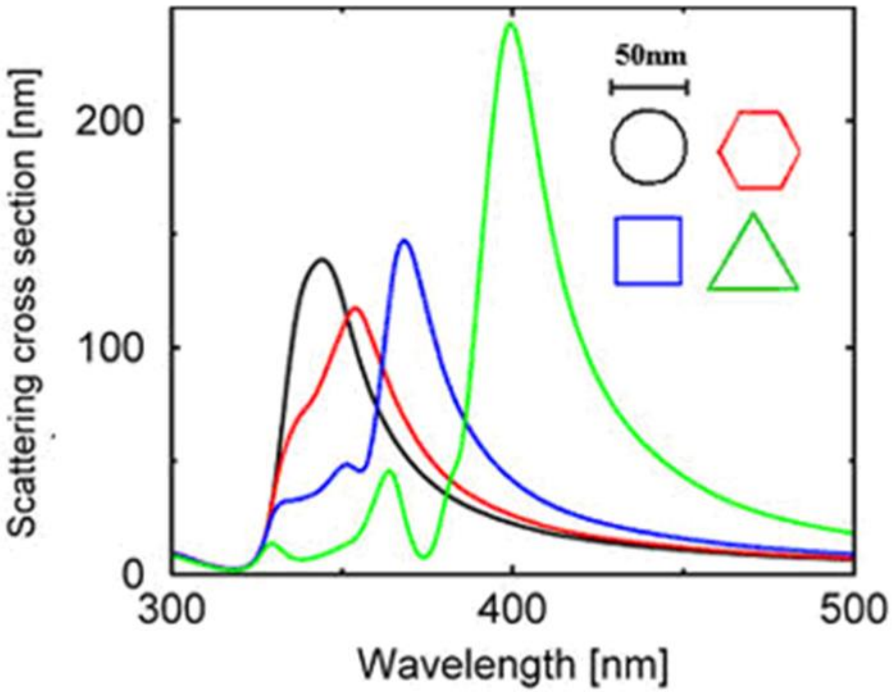
Size Effect: Color



Depending on size,
quantum dots emit different color light
due to quantum confinement.
Illustrated is the range of QDs with emission
gradually stepping from violet to red.

Shape Effect: Color





Shape Effect: Color

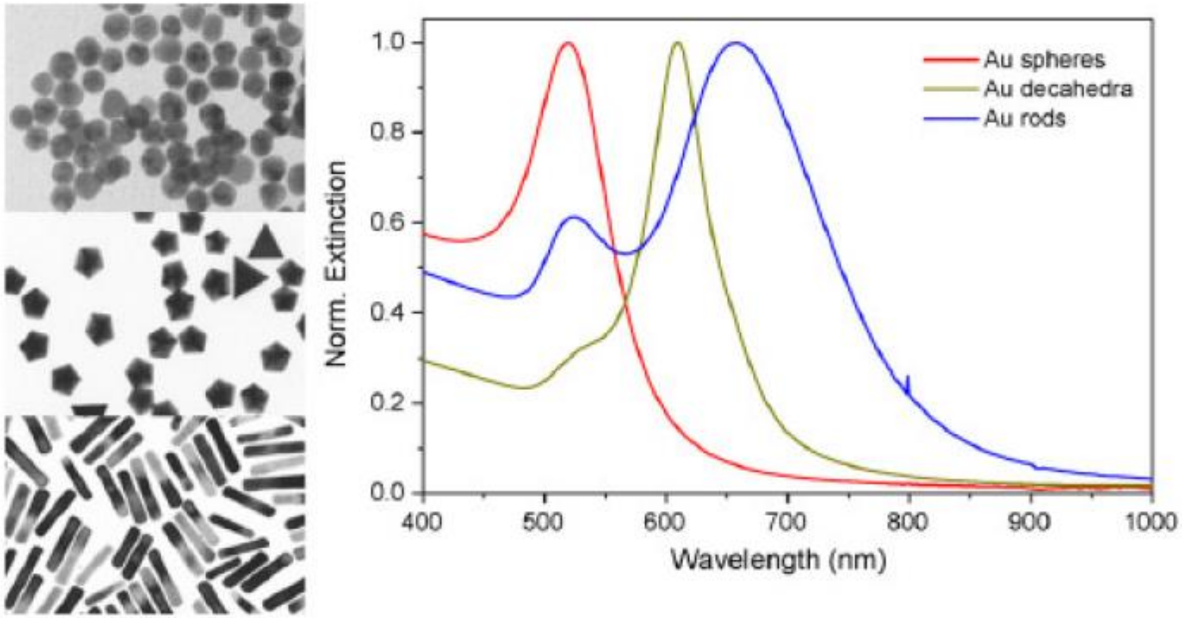
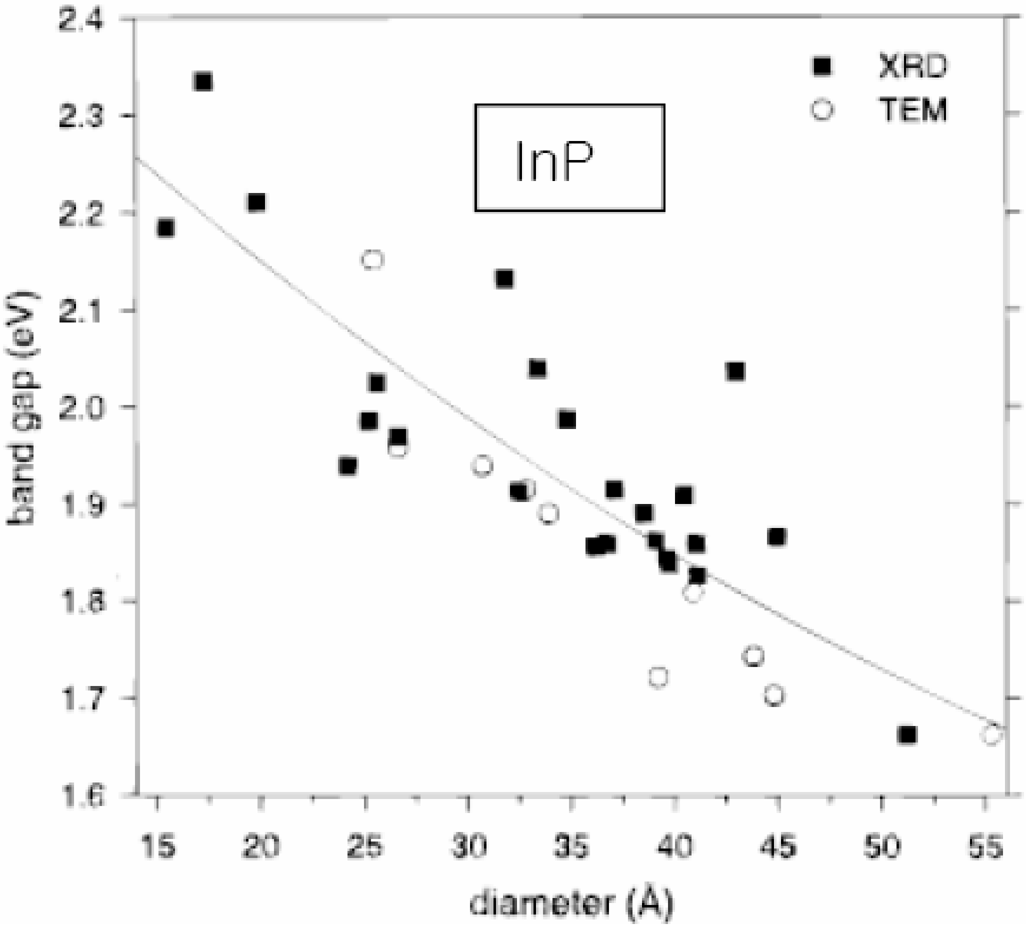


Figure 10. Transmission electron micrographs and UV—Vis spectra of gold nanoparticle colloids with various geometries: (top) spheres, (middle) decahedra and (bottom) rods. (Image credit: Reprinted from: Borja Sepúlveda et al., "LSPR-based Nanobiosensors", Nano Today (2009), 4 (3), 244-251, with permission from Elsevier).

Size Effect: Band Gap



The band gap is increases with reducing the size of the particles

Size Effect: Band Gap

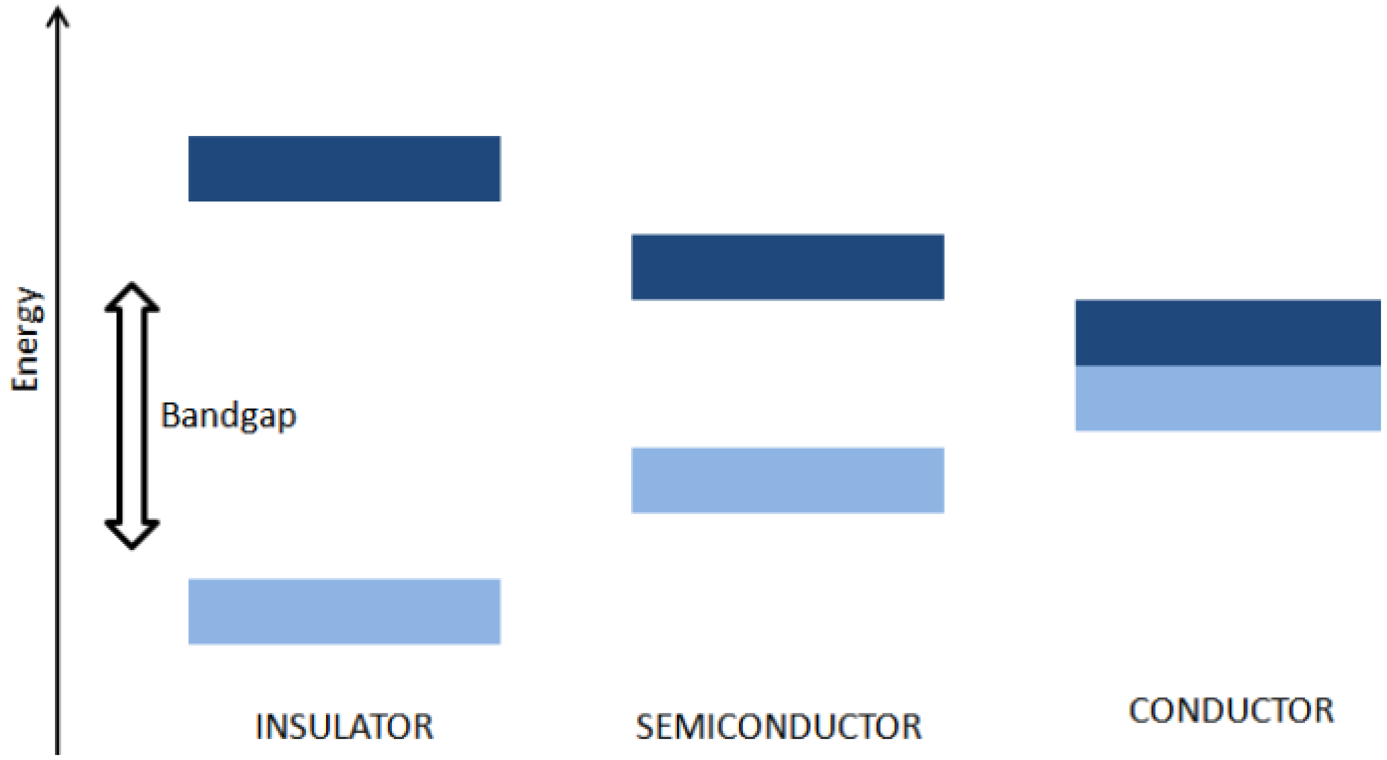


Figure 8. Schematic illustration of the valence and conduction bands in the three kinds of materials, insulator, semiconductor and conductor. (Image credit: L. Filipponi, iNANO, Aarhus University, Creative Commons ShareAlike 3.0)

Size Effect: Band Gap

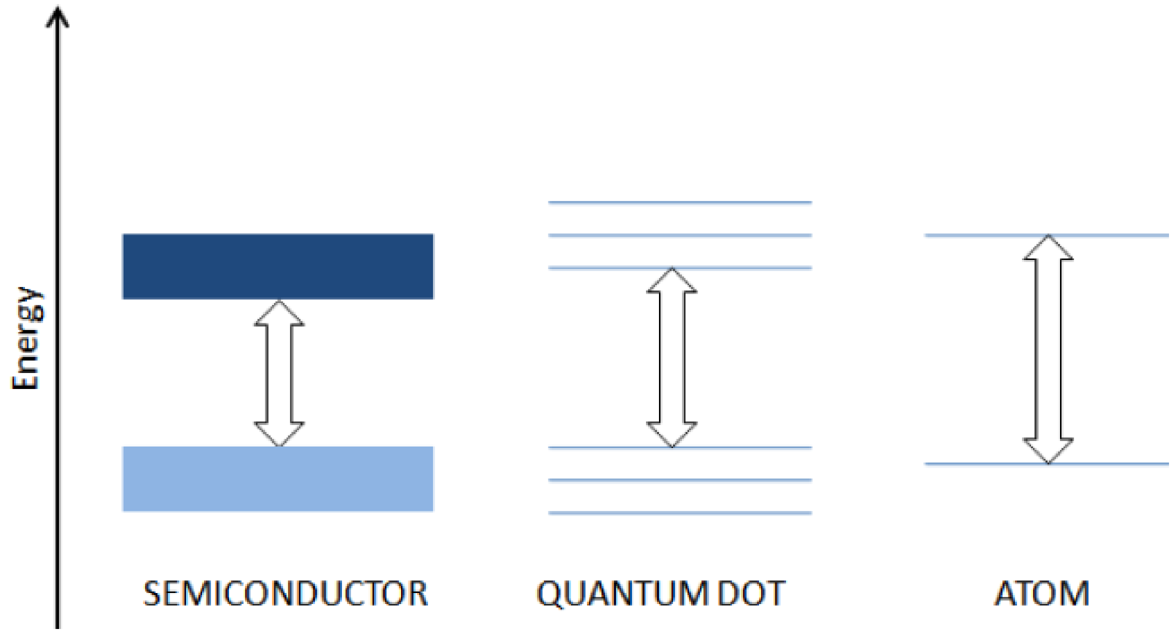
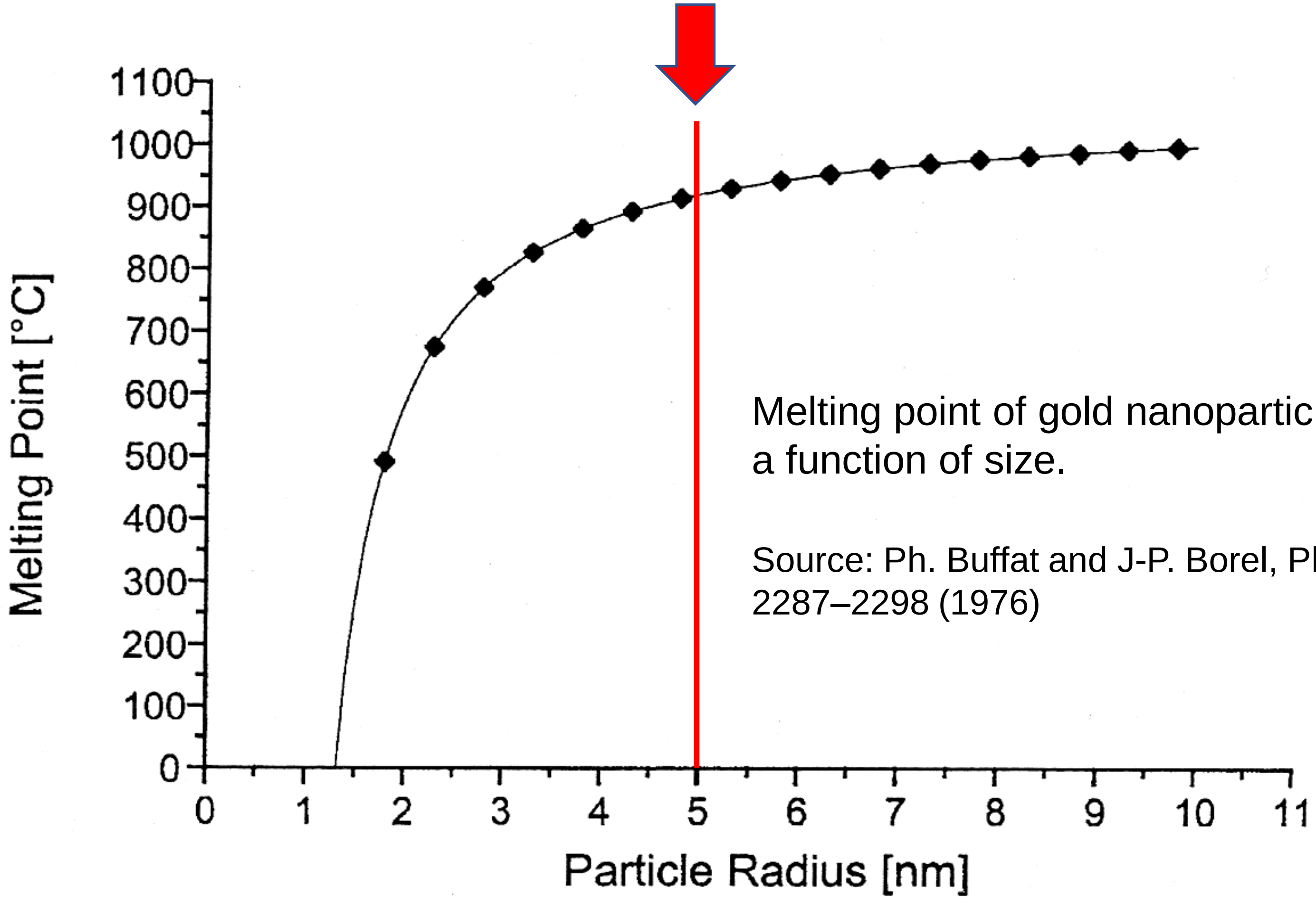


Figure 9. The image compares the energy of the bandgap (arrow) in a bulk semiconductor, in a quantum dot and in an atom. As more energy states are lost due to the shrinking size, the energy bandgap increases. (Image credit: L. Filipponi, iNANO, Aarhus University, Creative Commons ShareAlike 3.0)

Size Effect: Melting Point

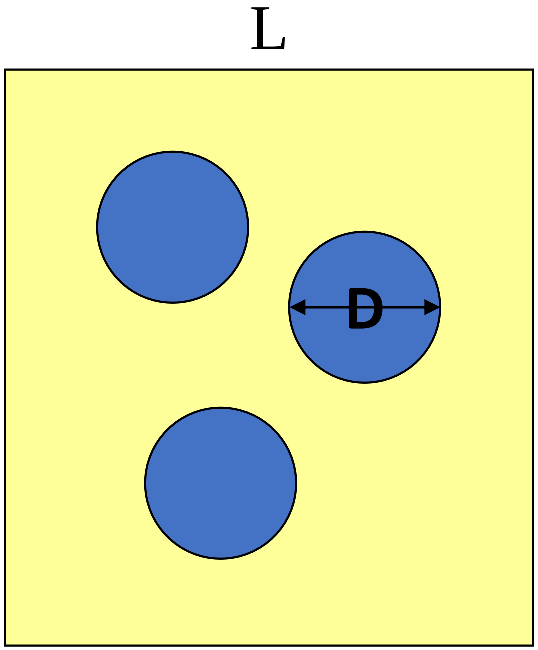


Melting point of gold nanoparticles as a function of size.

Source: Ph. Buffat and J-P. Borel, Phys. Rev. A 13, 2287–2298 (1976)

The melting point decreases dramatically as the particle size gets below 5 nm

Particle Volume Fraction



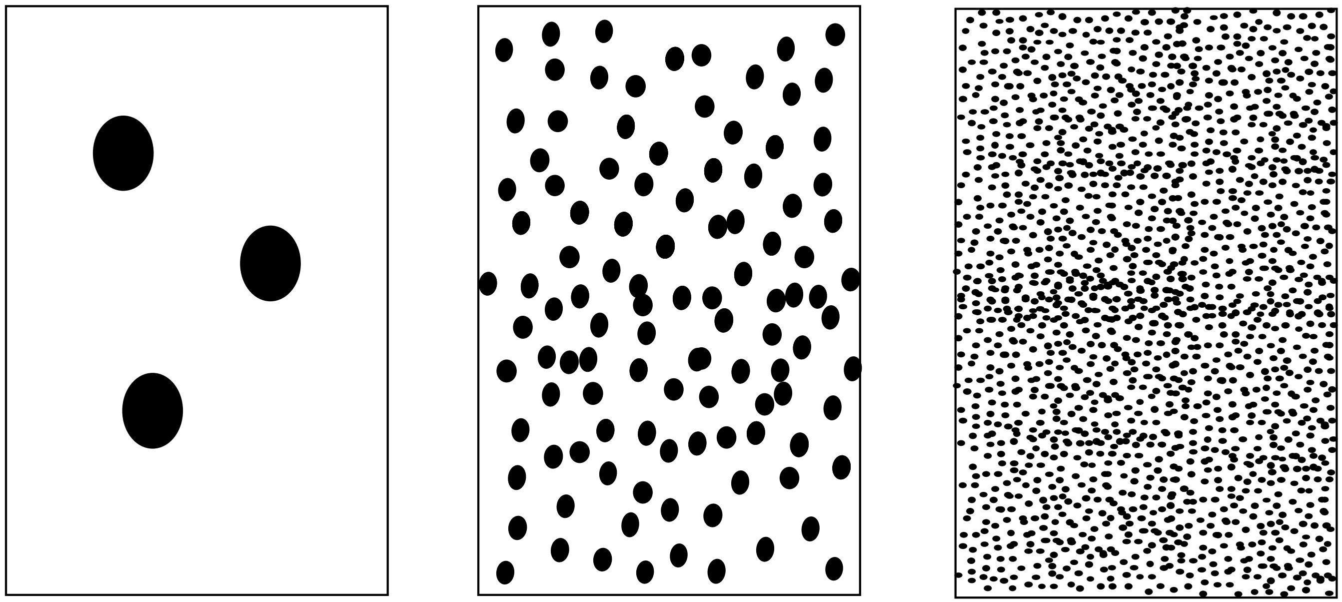
$$\phi_P = \frac{\pi D^3 / 6}{L^3} \bullet \text{\# of particles}$$

Why Nanocomposites?

„Nanos“ Greek: „Dwarf“

50.000x smaller than human hair radius

3 Vol.-%

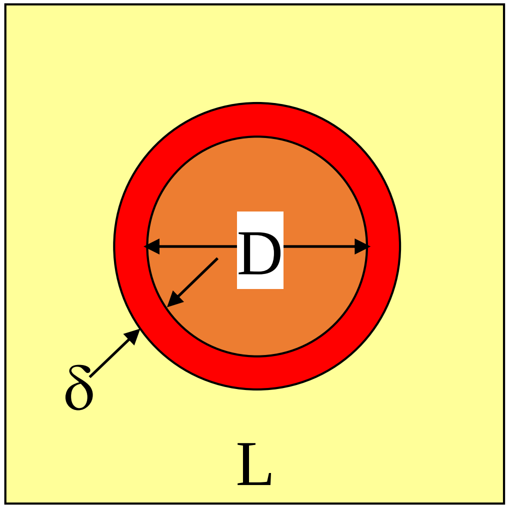


Particle size:	10 µm	1 µm	100 nm
Number of particles:	3	3000	3 000 000

Small but Great Effect !

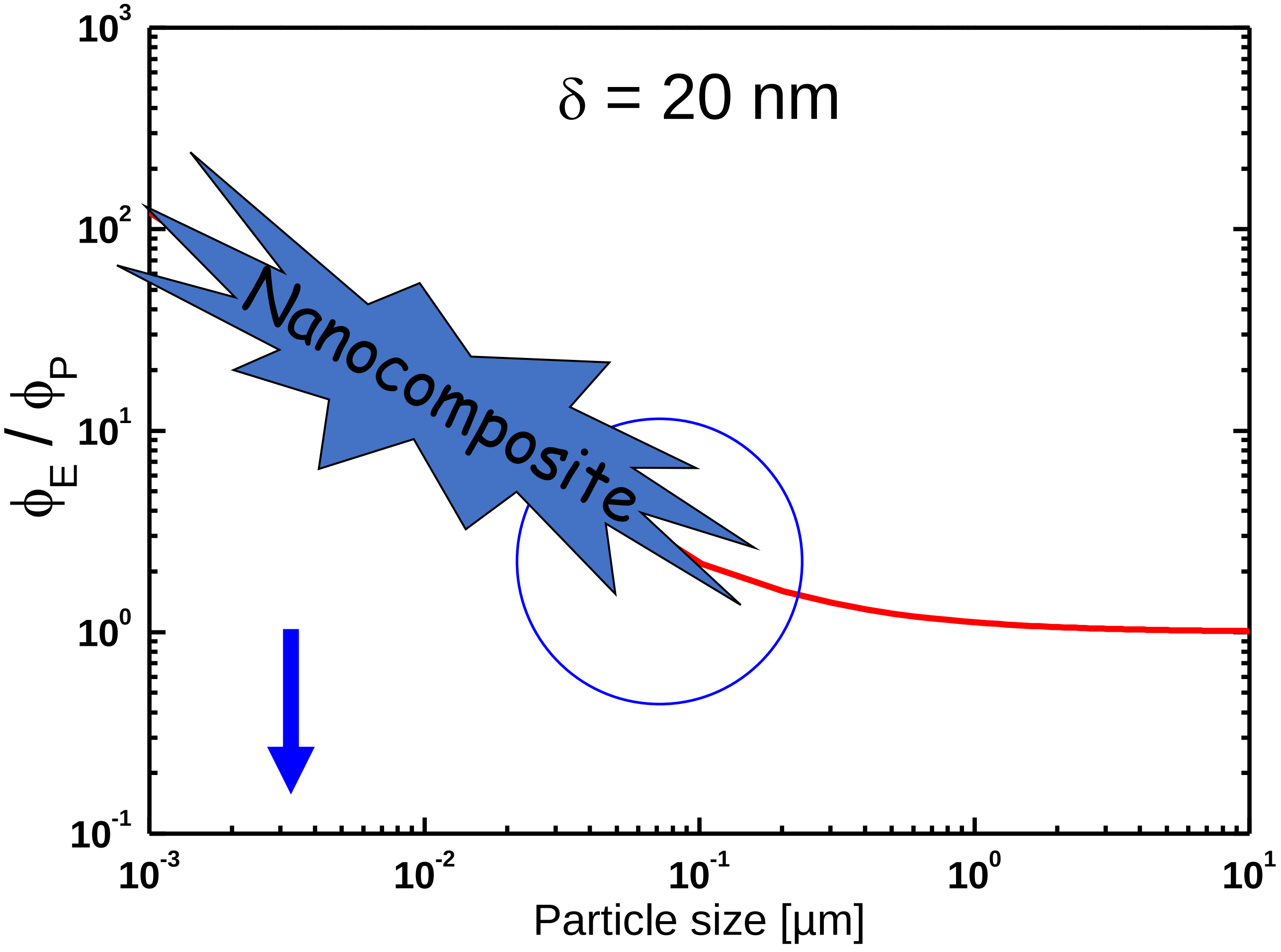
Effect of Interface (Boundary Layer)

$$\text{Specific Volume} = \frac{\text{Effective Volume Fraction}}{\text{Particle Volume Fraction}} = \frac{\phi_E}{\phi_P} = \left(1 + \frac{6\delta}{D}\right)$$

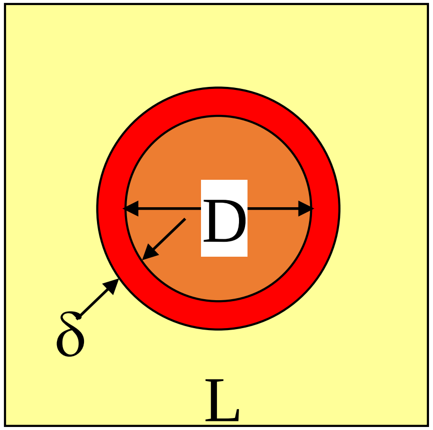


Effective Volume:

$$V_E = V_p + V_I$$



Particle Volume: $V_p = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3 = \frac{\pi D^3}{6}$



Partcle Volume Fraction: $\phi_P = \frac{\pi D^3/6}{L^3}$

Interface (Influence Zone) Volume:

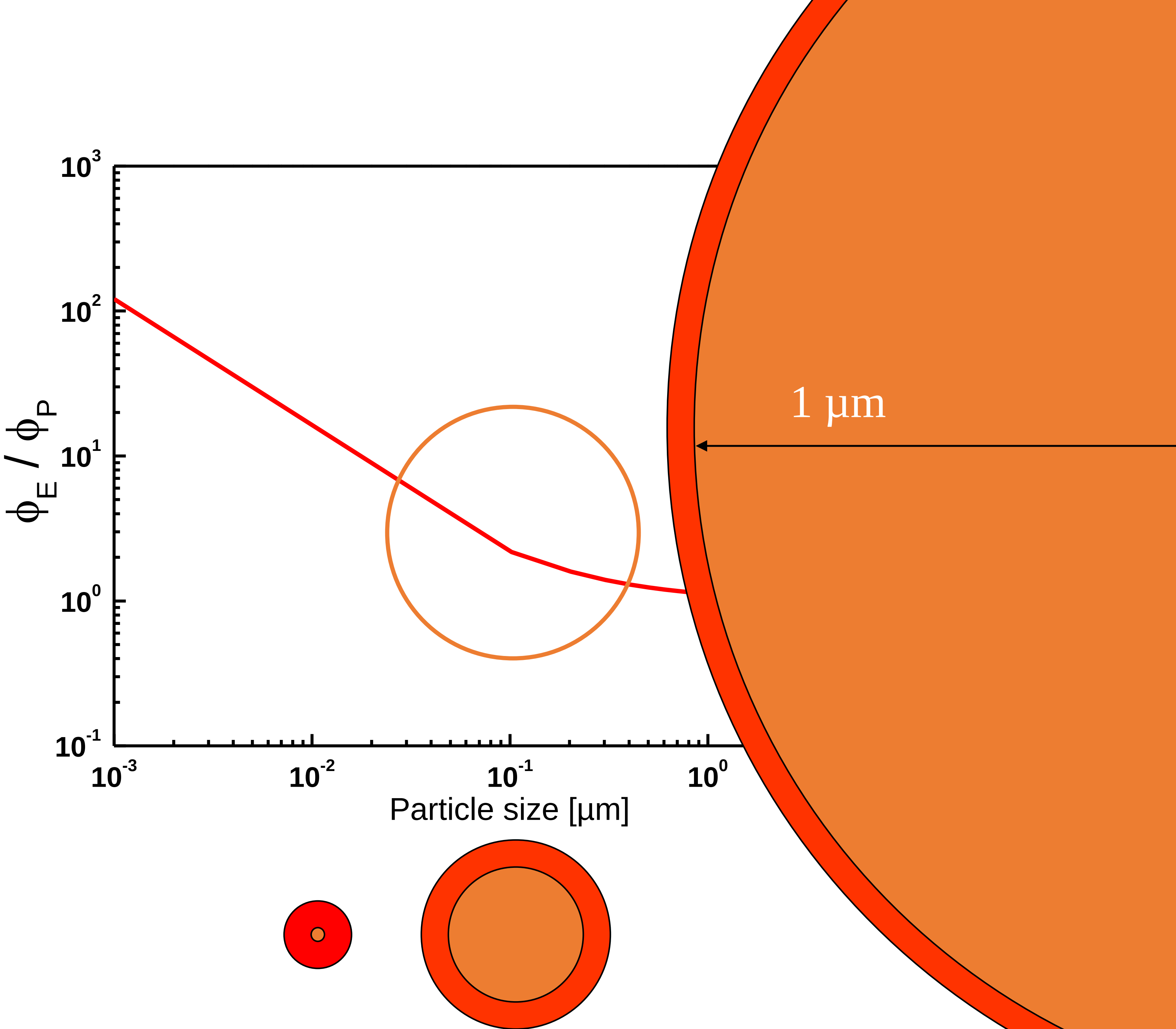
$$V_I = \frac{4}{3}\pi\left(\frac{D}{2}+\delta\right)^3 - \frac{\pi D^3}{6} = \frac{4}{3}\pi\left(\frac{D^3}{8} + \frac{3}{4}D^2\delta + \frac{3}{2}D\delta^2 + \delta^3\right) - \frac{4}{3}\pi\left(\frac{D}{2}\right)^3 = \pi D^2\delta$$

$$V_I = \pi D^2 \delta$$

Effective Volume: $V_E = V_p + V_I$

Effective Volume Fraction: $\phi_E = \frac{V_p + V_i}{L^3} = \frac{\pi D^3/6 + \pi D^2\delta}{L^3} = \phi\left(1 + \frac{6\delta}{D}\right)$

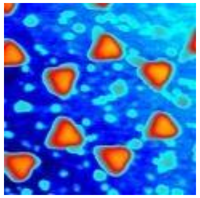
$$\text{Specific Volume} = \frac{\text{Effective Volume Fraction}}{\text{Particle Volume Fraction}} = \frac{\phi_E}{\phi_P} = \left(1 + \frac{6\delta}{D}\right)$$

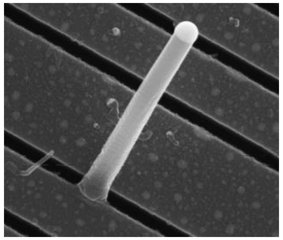


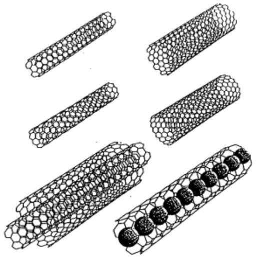
1 µm
10^3
10^2
10^1
10^0
10^-1
10^-3
10^-2
10^-1
10^0
ϕE / ϕP
Particle size [µm]

Definition of Nanoparticle

- A structure with at least 1 dimension less than 100nm.
- Examples:
  - Sphere-like particles
    - Ag nanoparticles, buckyballs
  - Rod-like particles
    - Si & Ni nanowires
  - Tube-like particles
    - Carbon nanotubes
    - TiO_2 nanotubes



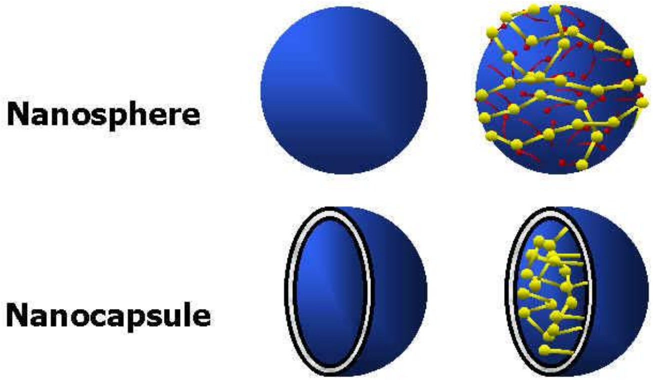


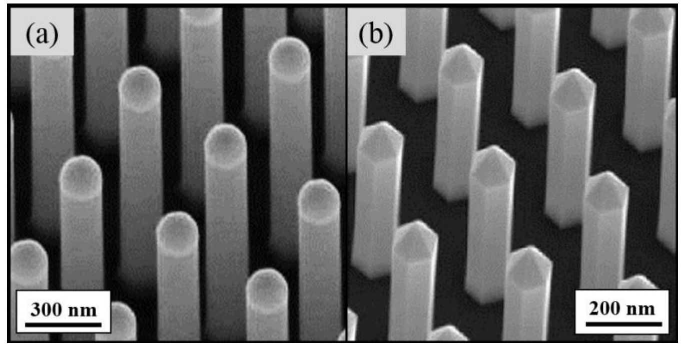


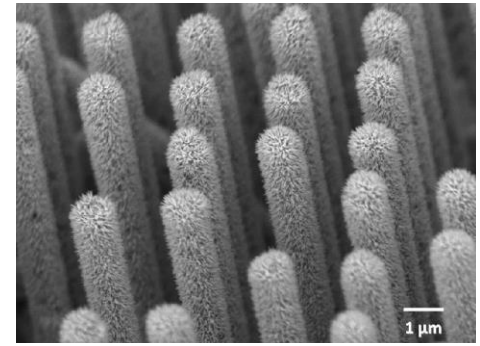
Various Nanomaterials

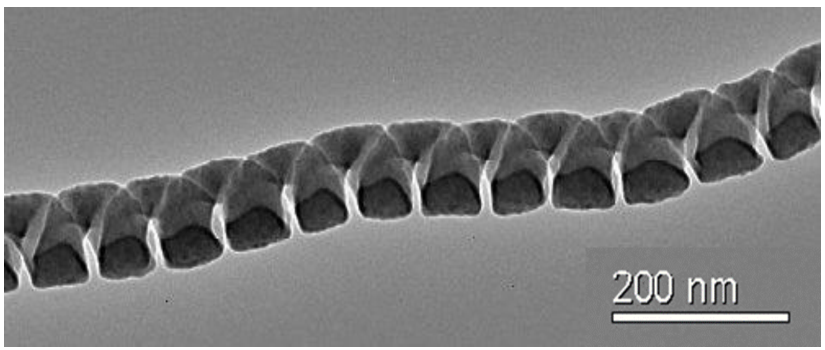
Based on the size and shape, the Nanomaterials are classified as follows:

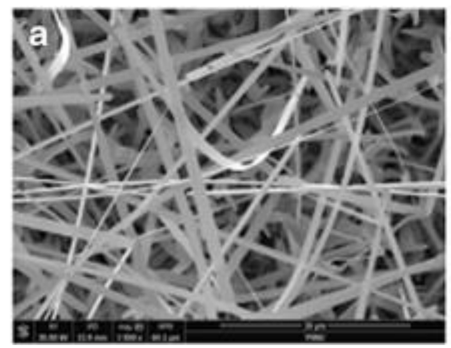
- Nanoparticles
- Nanocapsules
- Nanofibers
- Nanowires
- Fullerenes (carbon 60)
- Nanotubes
- Nanosprings
- Nanobelts
- Quantum dots
- Nanofluidies

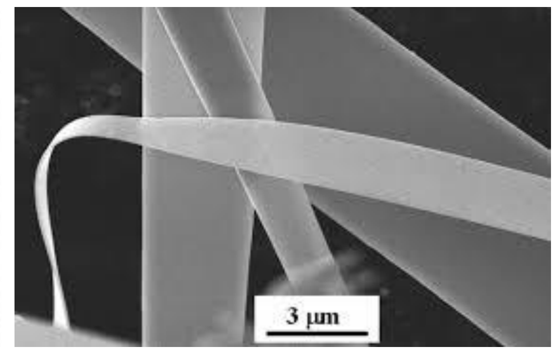

Nanosphere
Nanocapsule

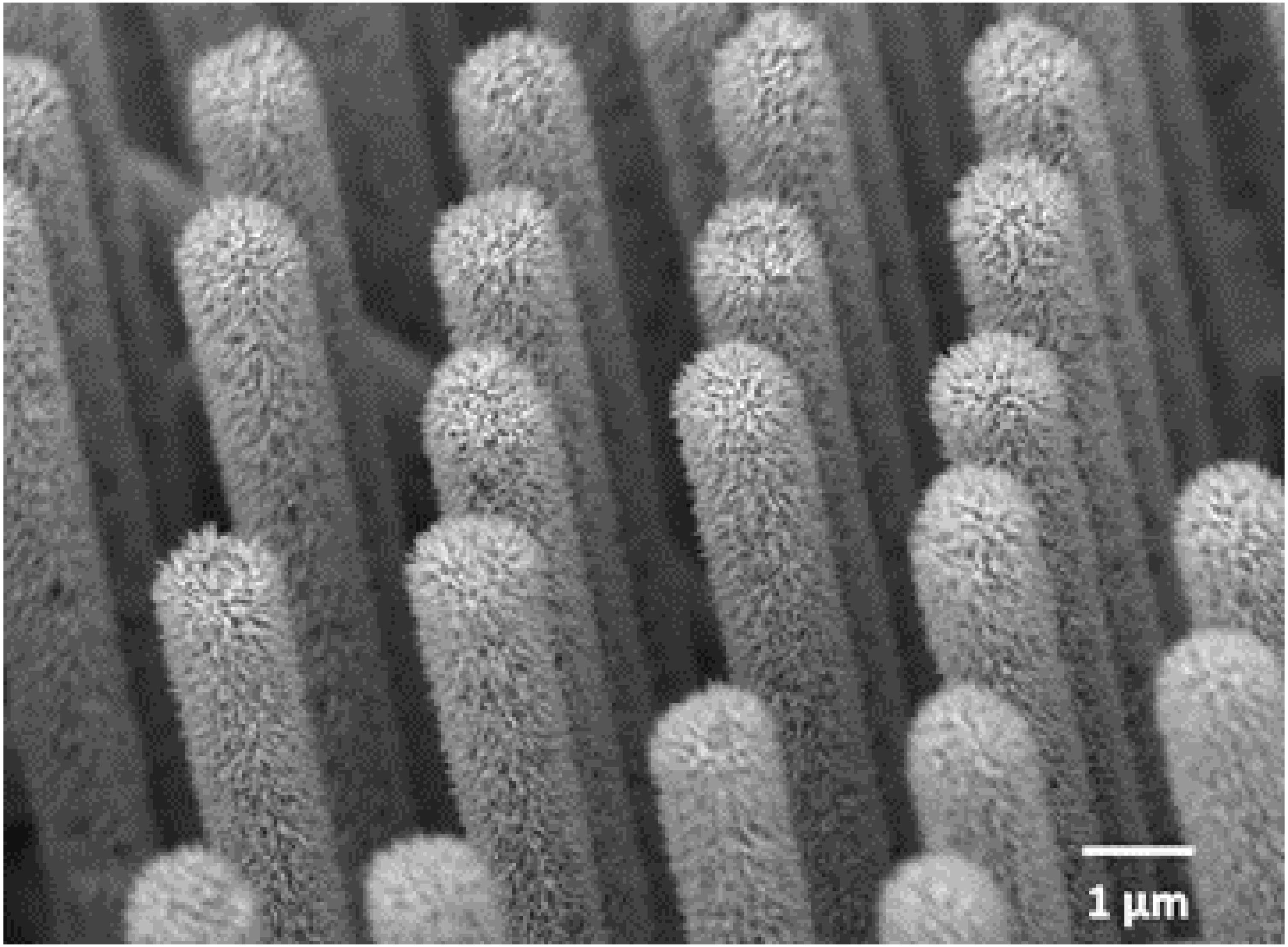

(a)
(b)
300 nm
200 nm


1 µm


200 nm


a

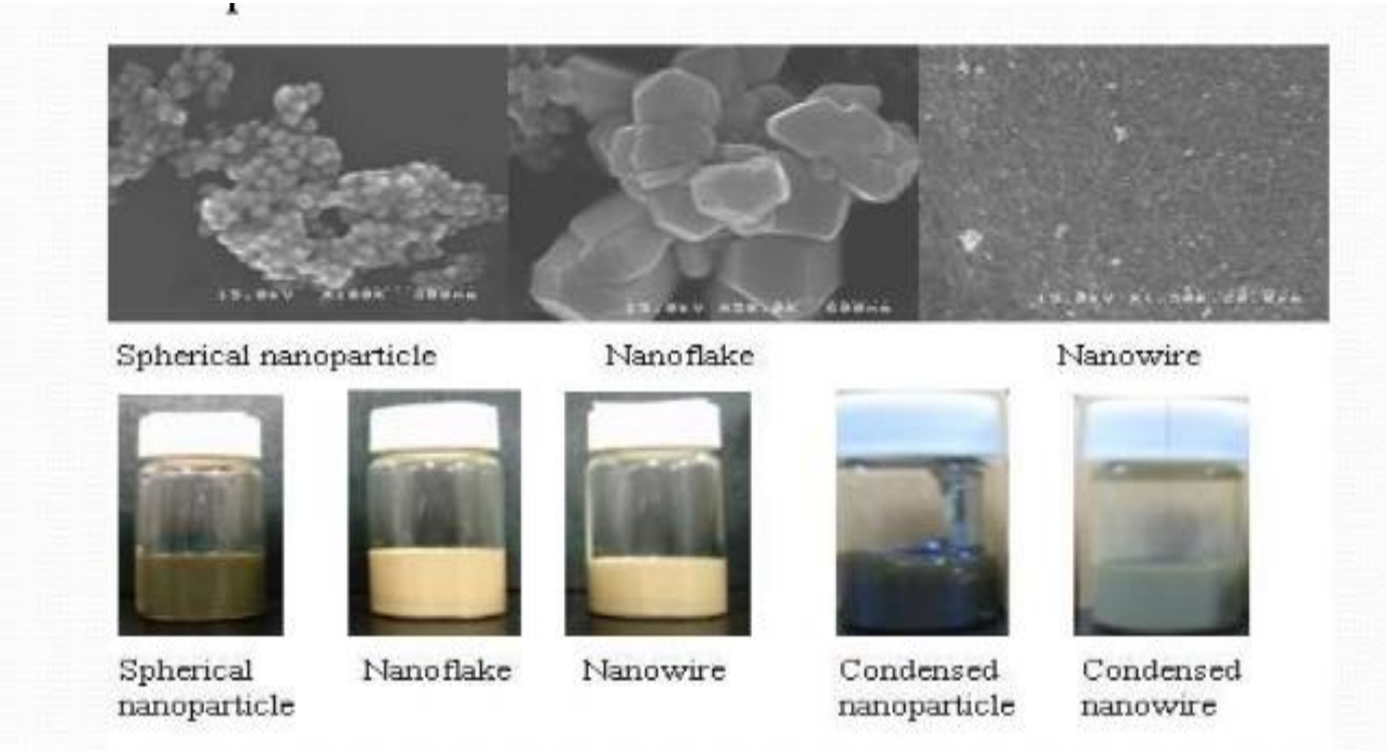

3 µm



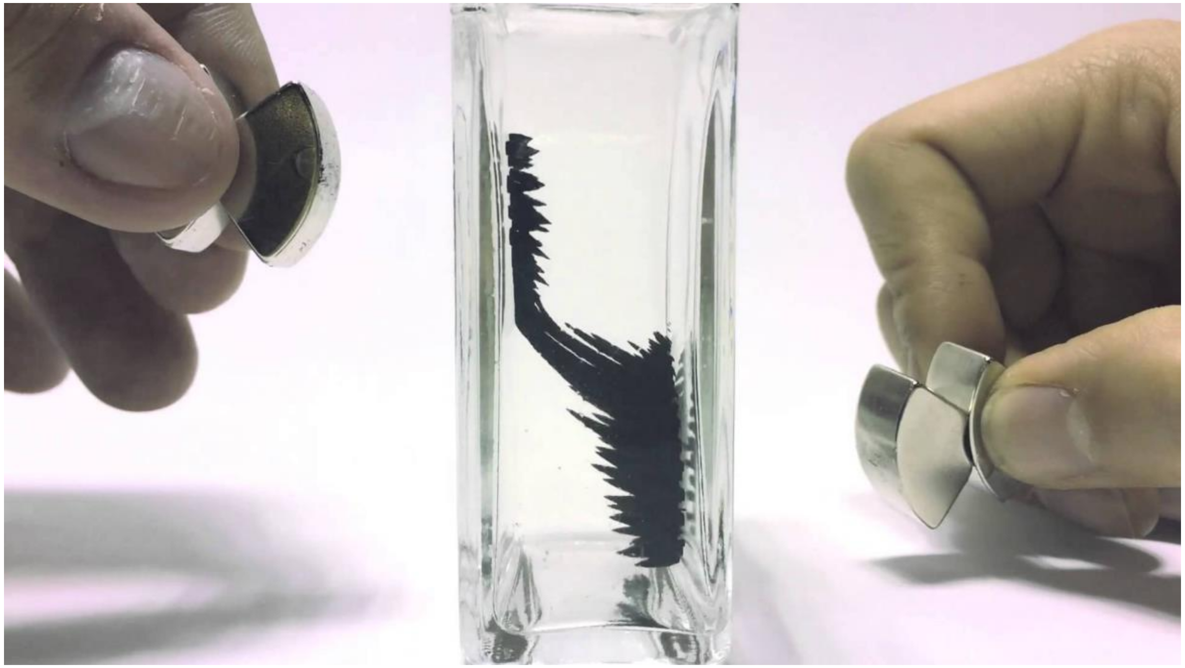
Nanowires

What are Nanofluids?

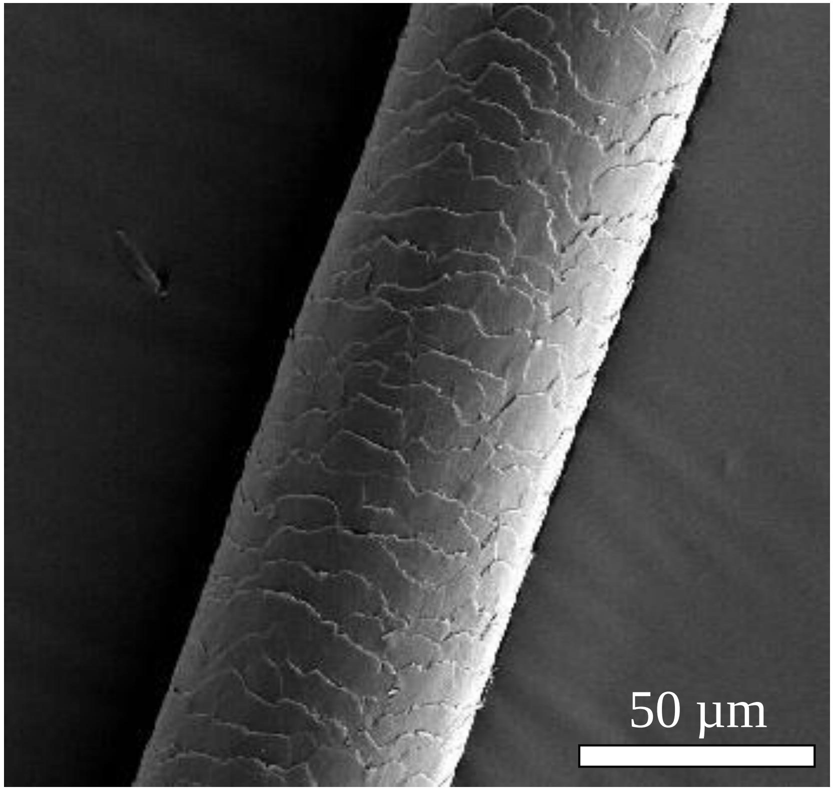
- A ***Nanofluid*** is a fluid containing nanometer-sized particles.
- These fluids are engineered ***colloidal suspensions*** of nanoparticles in a base fluid.

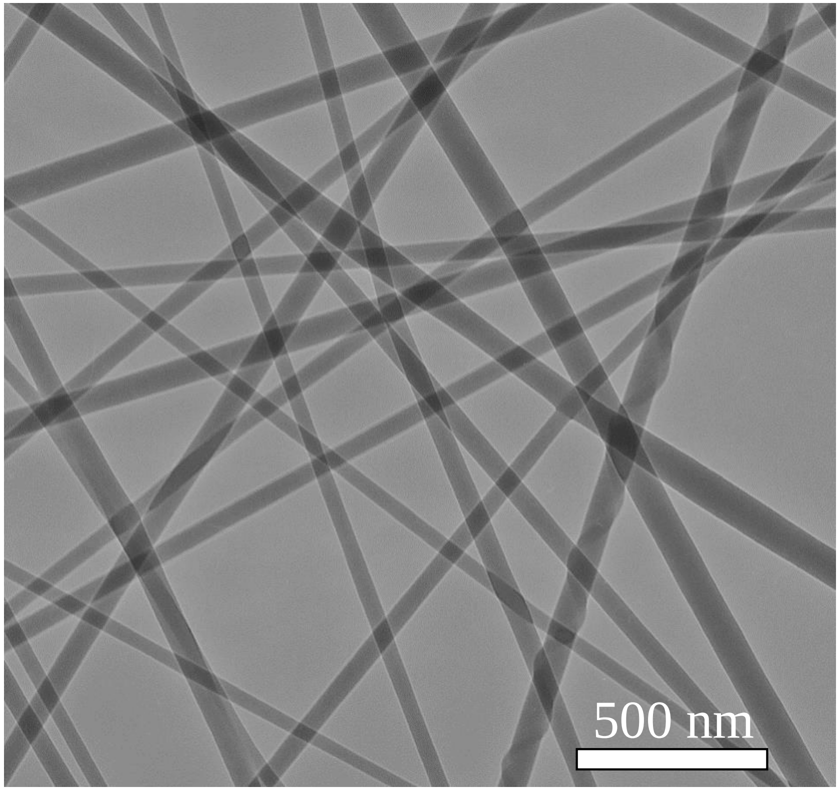


Magnetic Nanofluids: Ferrofluid



What is Nanofiber?



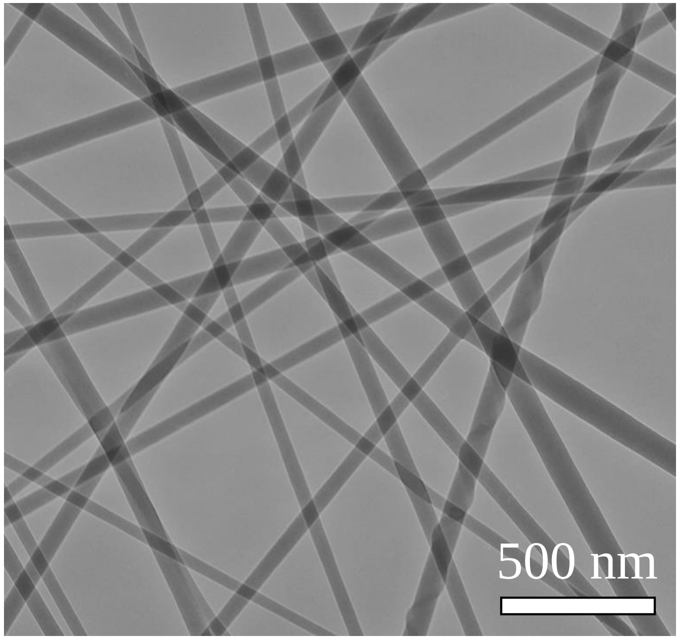


Human hair (~ 60 µm)

PA6-Nanofiber (~ 50nm)

Large specific area and high aspect ratio !

What a nanofiber can mean?

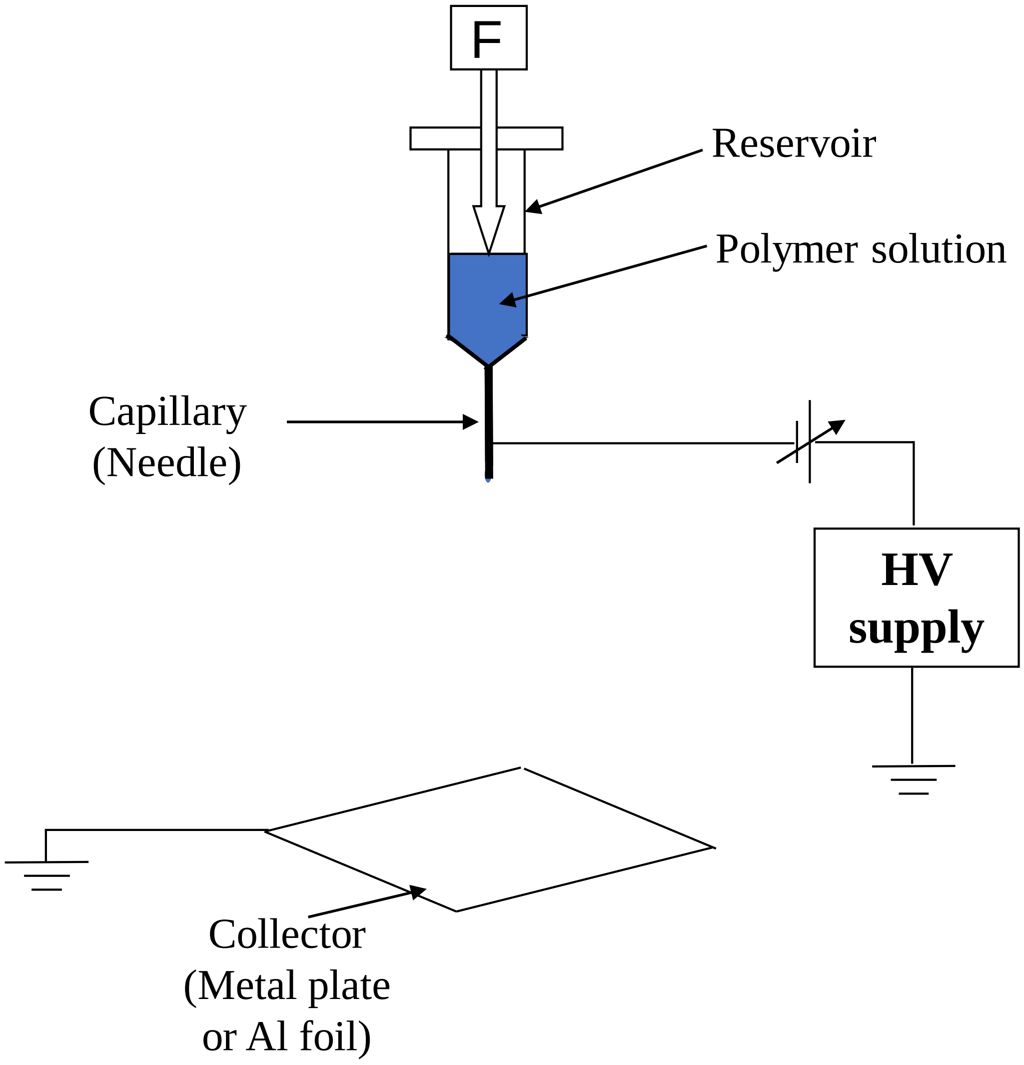


$$3\ \text{g (polymer)} = V \bullet \rho = (\pi r^2 L)\rho = \pi\ (50\text{nm})^2 \bullet L \bullet (1\text{g/cm}^3)$$

$L \approx 381{,}972$ km

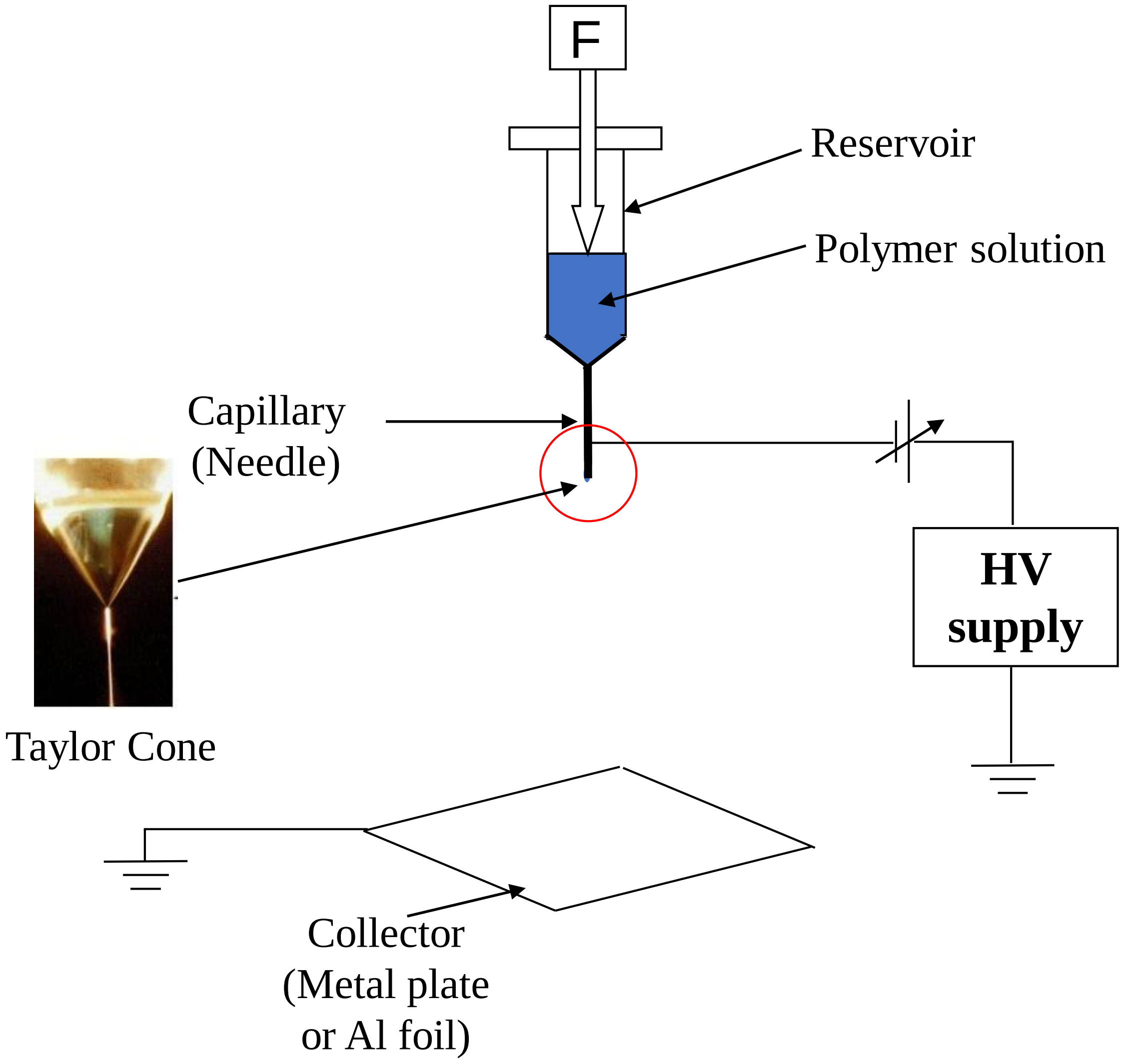
How to produce Nanofibers?

Electrospinning Process



How to produce Nanofibers?

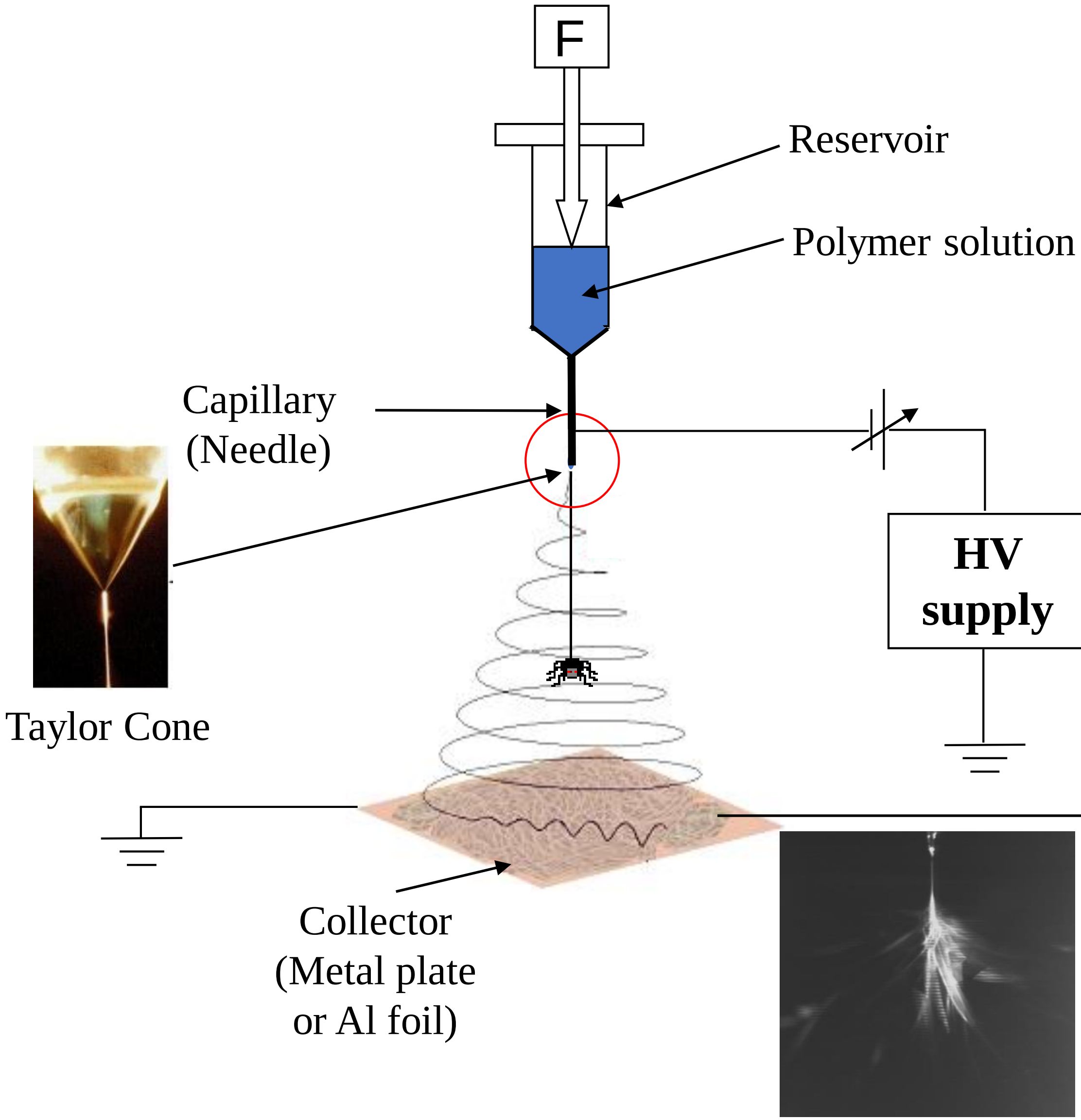
Electrospinning Process

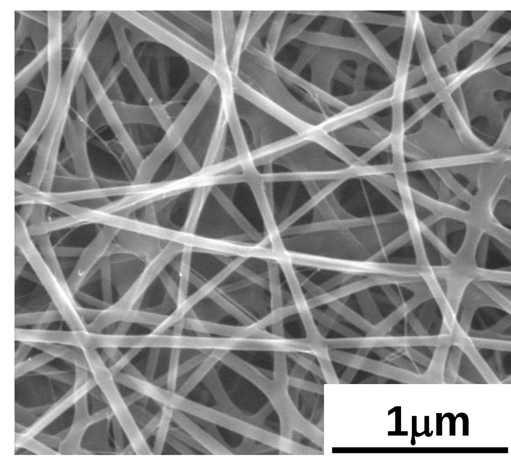


How to produce Nanofibers?

Electrospinning Process

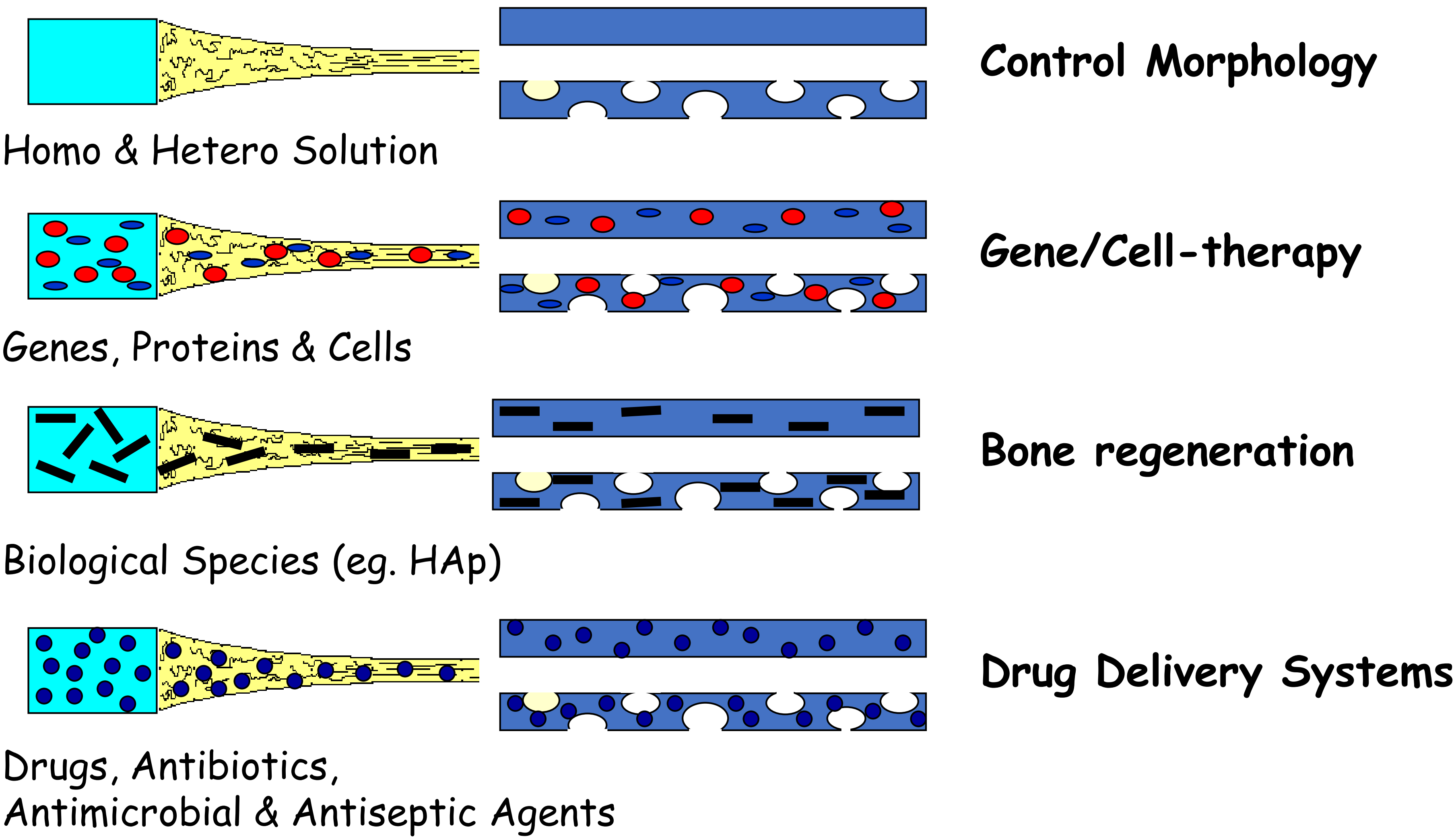
- Straightforward
- Inexpensive
- Effective





Diversity in Electrospinning Process

Multifunctional Nanofibers



Potential Applications

Polymer Nanofibers

Structural Application
- ***Reinforcing elements for composites***
  - Improvement in stiffness-toughness balance
  - Super-light weight composites
  - Noise and vibration abater
  - Electrostatic discharge protection
  - Electromagnetic interference shielding
- ***Higher efficient and functional catalysts***

Applications in Life Science
- ***Drug delivery/release systems***
- ***Scaffolds for tissue engineering***
  - Haemostatic devices
  - Wound dressing
  - Porous membrane for skin
  - Tubular shapes for blood vessels and nerve regerneration
  - 3D scaffolds for bone and cartilage regenerations

Electro-optical Applications
- ***Sensor technology***
  - Piezoelectric sensor
  - Chemical sensor
  - Florescence optical biochemical sensor
- ***Micro- & nanodivices***
  - Single electron diode and transistor
  - Photovoltaic devices (nano-solar cell)
  - Fuel cells
  - Batteries
  - LCD devices

Filter media
- Liquid & gas filtration
- Molecules & bacteria filtration
- Clean room technology

Protective Clothing

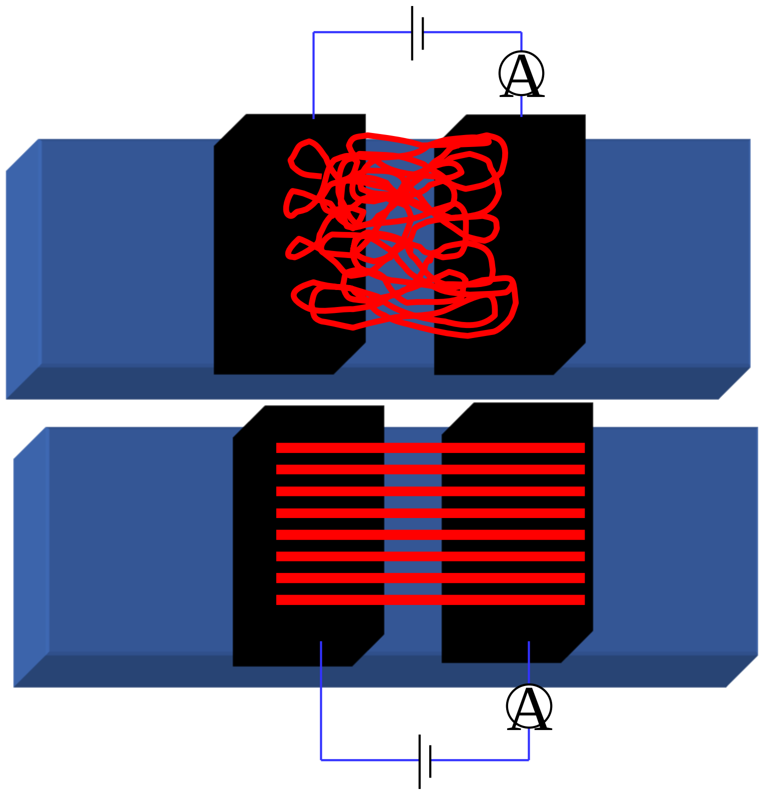
Minimal impedance to air
Efficiency in trapping nanoparticles
Anti-bio-chemical gases

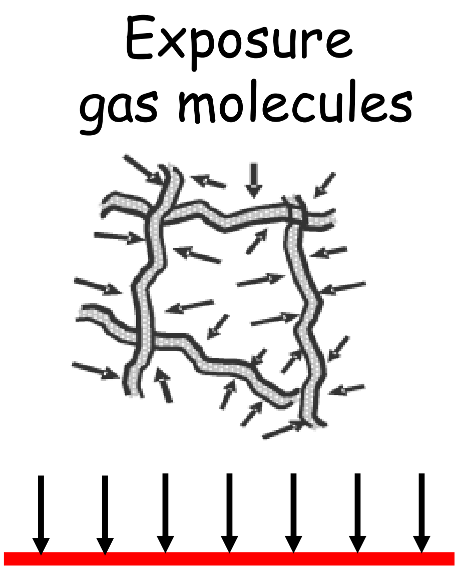
Cosmetic Skin Mask

Skin cleansing, healing & therapy

Future Works

Nanofiber Sensors

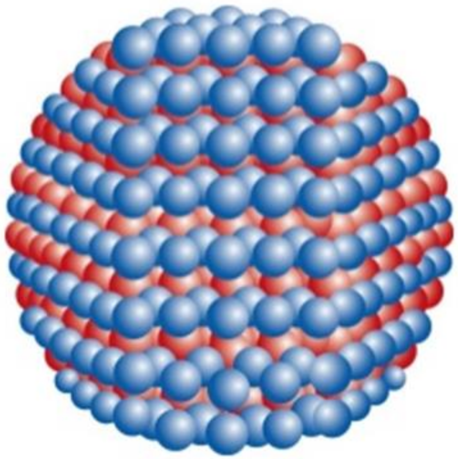




Bio-chemical Sensors

What is a Quantum Dot?

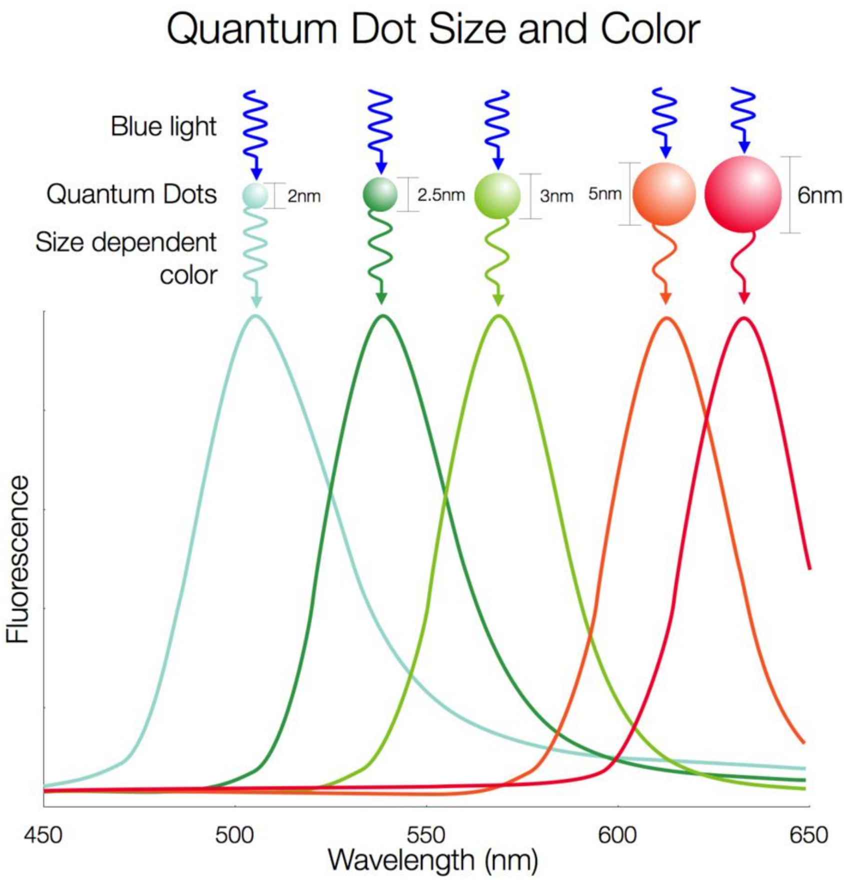
A quantum dot is a semiconductor nanostructure that *confines the motion of conduction band electrons*, valence band holes, or excitons (bound pairs of conduction band electrons and valence band holes) in all three spatial directions.



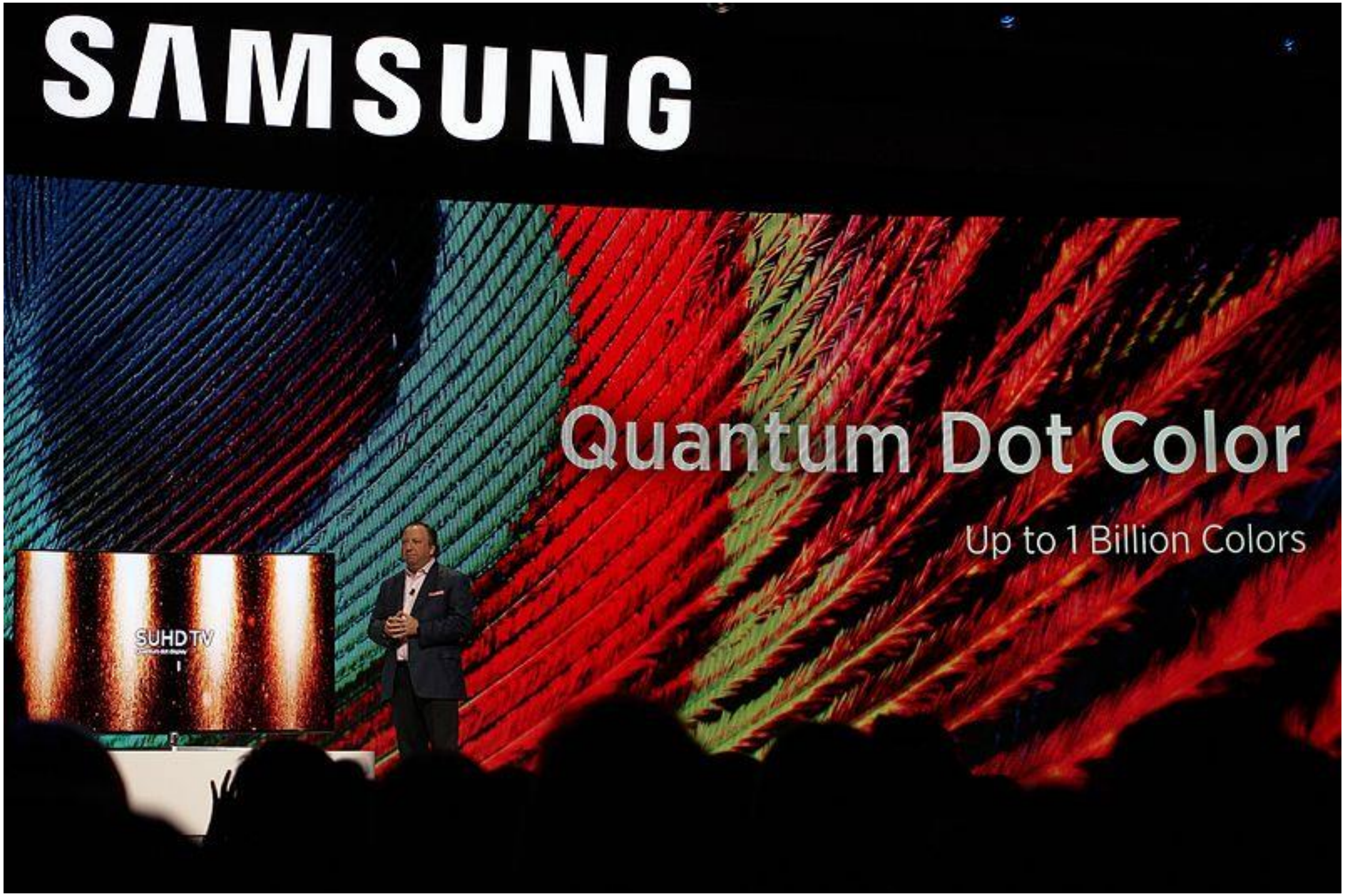
- Nanocrystals
- 2-10 nm diameter
- semiconductors

Semiconductor Quantum Dots:
CdSe, ZnSe, ZnS, ZnO

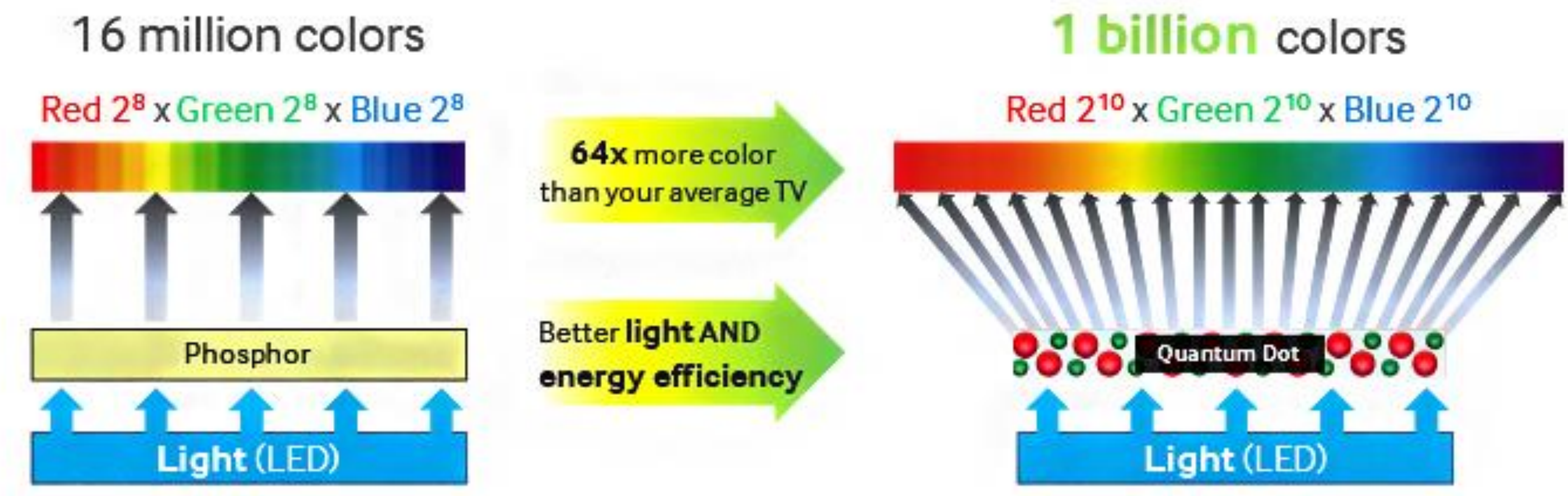
Quantum Dots

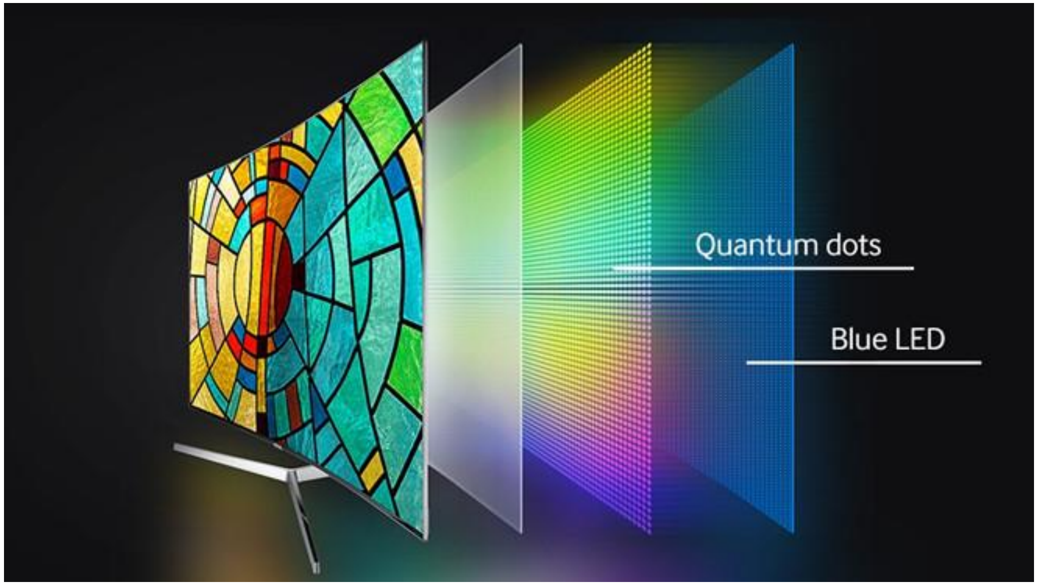


Quantum Dots: Applications



Quantum Dots in Display





Quantum Dots in Biomedical Applications

Quantum Dots

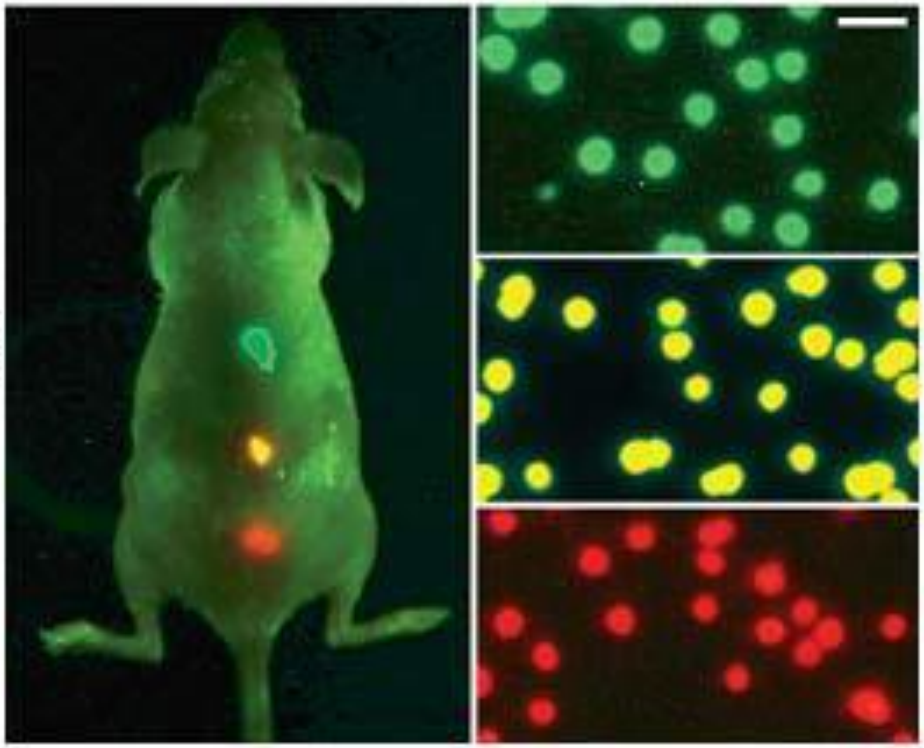
- Narrow tunable fluorescence emission
- Broad excitation profiles
- High surface-to-volume ratios
- High photostability

Fluorescence Imaging

- **In vitro**
  - Cellular Imaging
  - Biomolecular tracking
  - Tissue staining
- **In vivo**
  - Biodistribution of QDs
  - Vascular imaging
  - Tracking of cells
  - Tumor imaging

Quantum Dots in Biomedical Applications

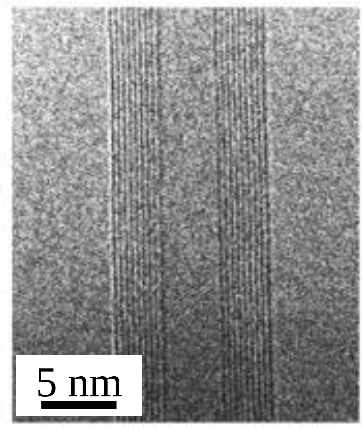
B

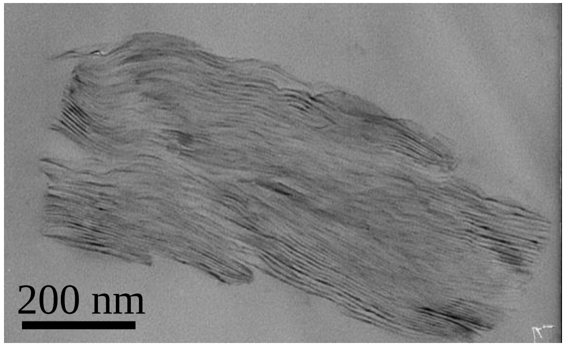


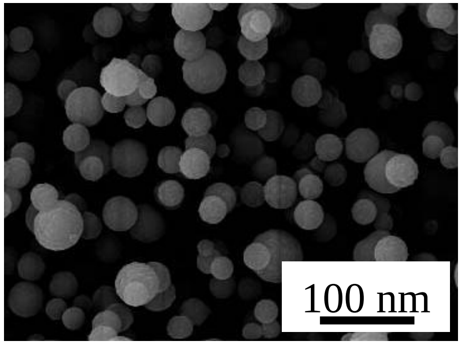
Sensitivity and multicolor capability of nanocrystal imaging in live animals. Left: a mouse with nanocrystal labeled organs.
Right: nanocrystal labeled microbeads emitting green, yellow or red light depending on the size of the nanocrystal.

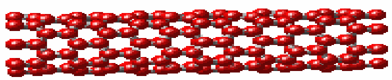
Nanoparticles:
Different Dimensionality

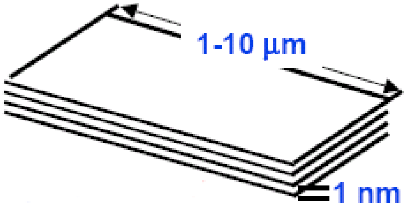
1-D | **2-D** | **3-D**

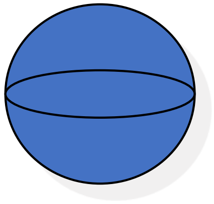






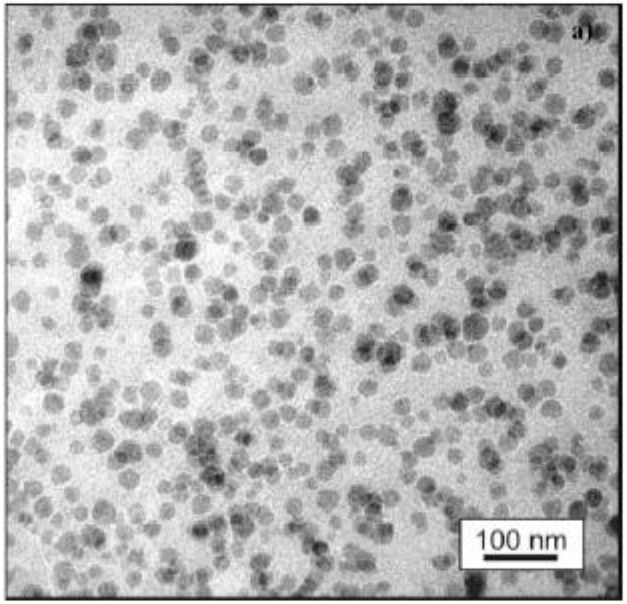


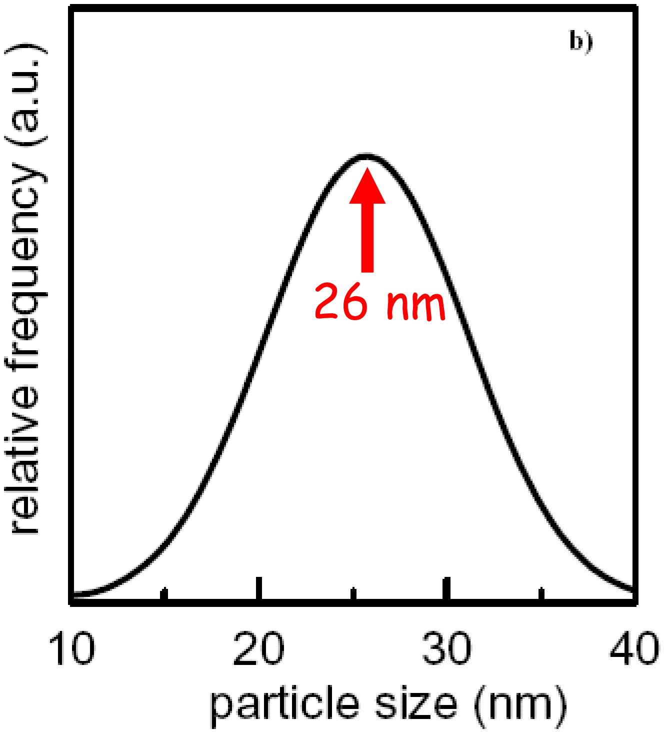




MWCNT | **Layed Silicate** | **Silica**

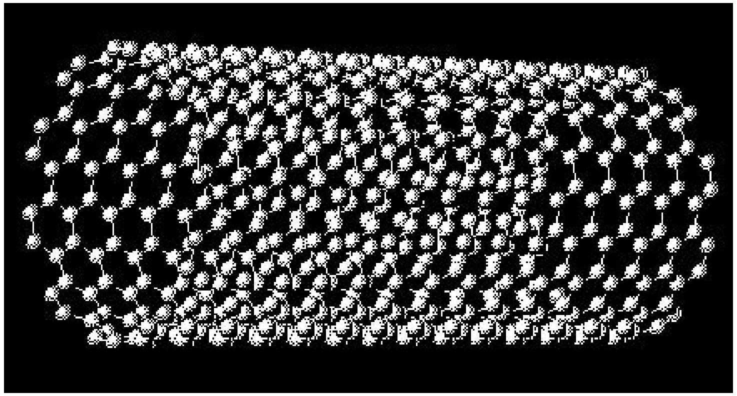
Morphology by TEM



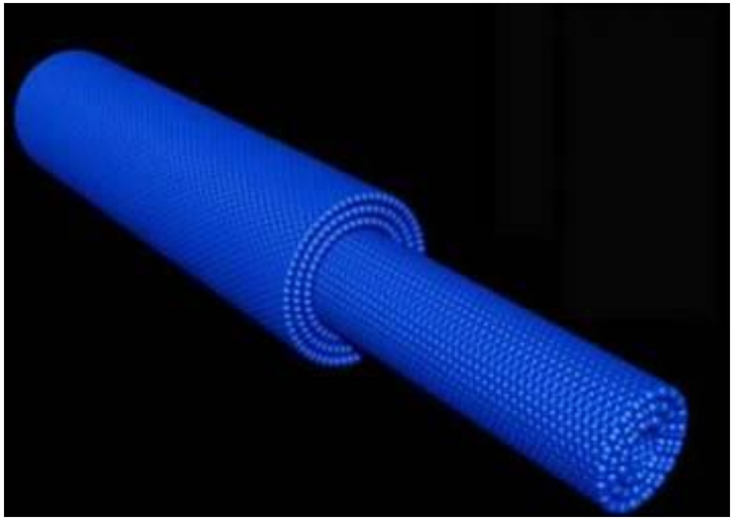


Single and Multi-wall Carbon Nanotube

- Single wall nanotube:
  - SWNT
  - single atomic layer wall, diameter of 1-5 nm
  - excellent mechanical property
  - hot topic now



- Multi wall nanotube:
  - MWNT
  - Inner diameter: 1.5 – 15 nm
  - Outer diameter: 2.5 – 30 nm
  - ~50 layers
  - containing more structure defects



Properties of Nanotubes

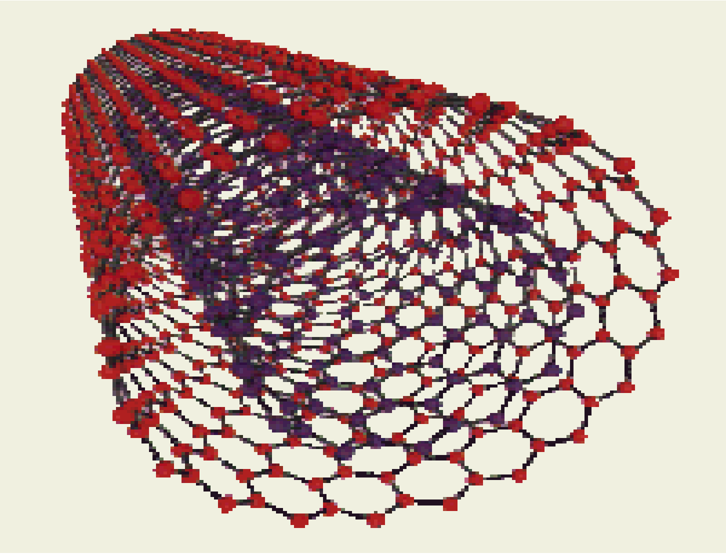
- **Mechanical:**
  - –Young's Modulus**: ~ 1TPa (SWNT), 1.25 TPa (MWNT)**
    (Steel: 230 GPa)
  - –Density ~ 1.3 g/cm^3 (SWNT: Wall-thickness; 0.34 nm,
    Diameter; 1.36 nm)
- **Thermal:**
  - –Conductivity: 2000W/m.K (copper: 400W/m.K)
- **High Aspect Ratio**: Length ~1µm, Diameter ~ 1nm to 50nm

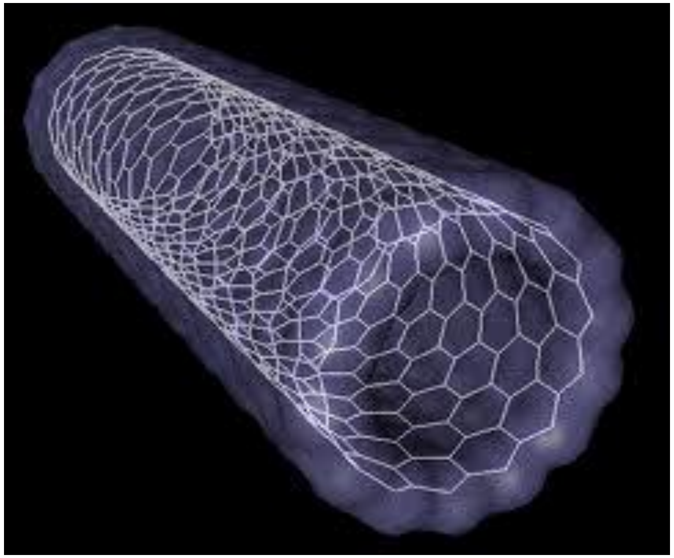
Electrical Properties: Conductivity

- **Nanotubes are long, thin cylinders of carbon:**

Their electrical properties change with diameter, “twist”, and number of walls

They can be either conducting or semi-conducting their electrical behavior.





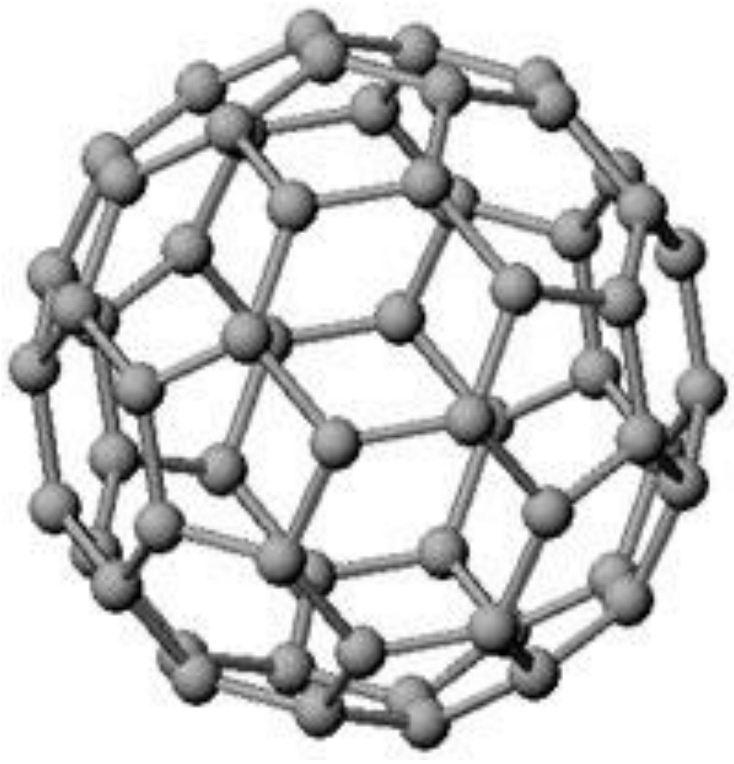
The Histroy of Nanotubes

When	Who	Events
1970s	Harry Kroto & Dave Walton	Try to synthesize long carbon chains
Late 1980s	Scientists around the world	Buckyball was synthesized and confirmed as C60
1991	Japanese Scientist, Sumio Ijima	Discovery of multi wall carbon nanotubes
1993	S, Iijima and T, Ichihashi	Synthesis of single wall carbon nanotubes
1996	Robert F. Curl, Harry Kroto , Richard E. Smalley	Nobel Prize in Chemistry for the discovery of Buckyball
1999	Samsung	Flat Panel display prototype
2001	IBM	The first computer circuit composed of only one single carbon nanotube

Buckyball

- The discovery of nanotubes comes from Buckyball
- The discovery of Buckyball is by accident, from Radio-astronomy
- Around 1970s

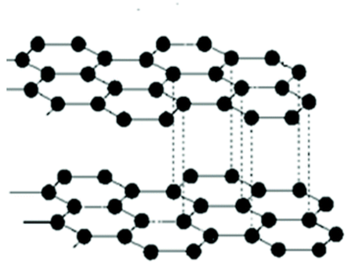
C_{60}



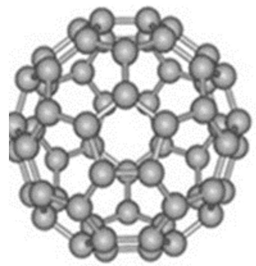
(http://www.slb.com)

Allotropes of Carbon

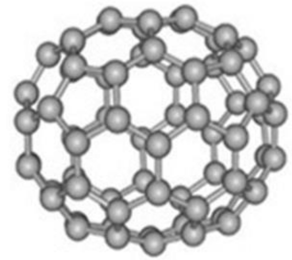
Diamond



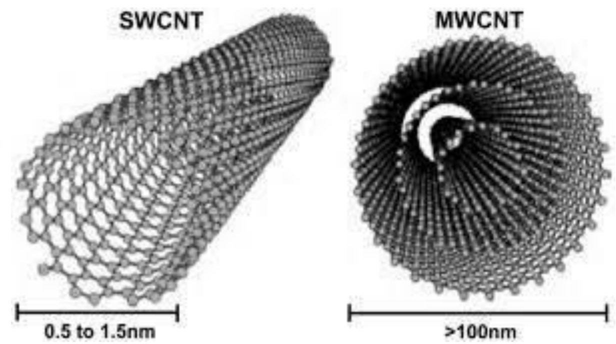
Graphite

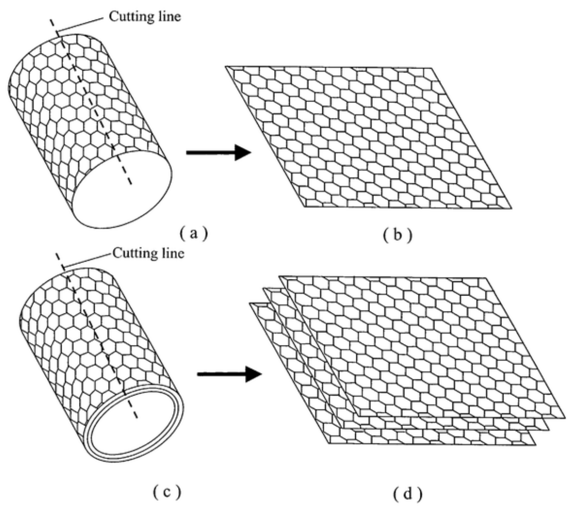


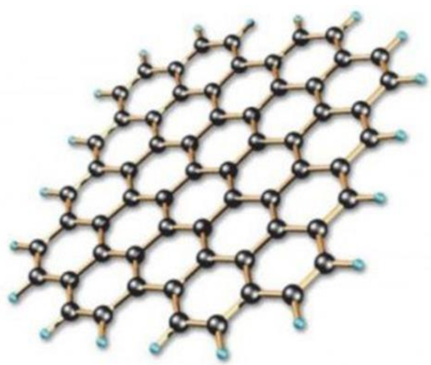
C60

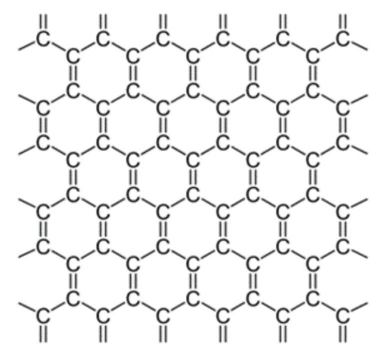


C70





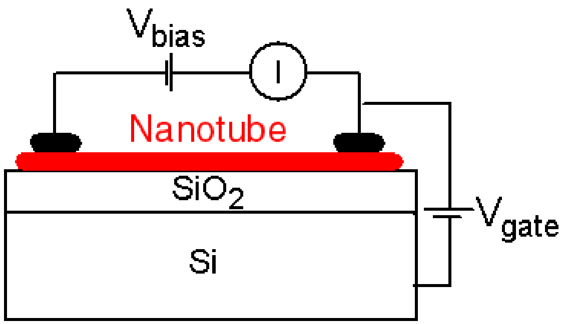


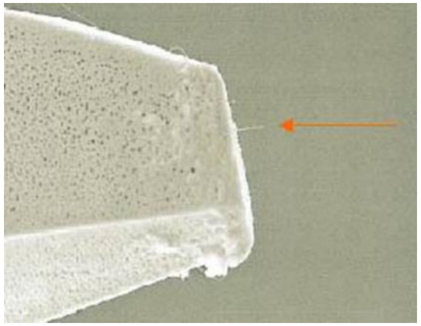


graphene

Applications with CNTs

- **Transistor**
  - Field Effect transistor
  - Single electron transistor
- **SPM Tips**
- **Field Emission Display Device**
- More Possible Applications





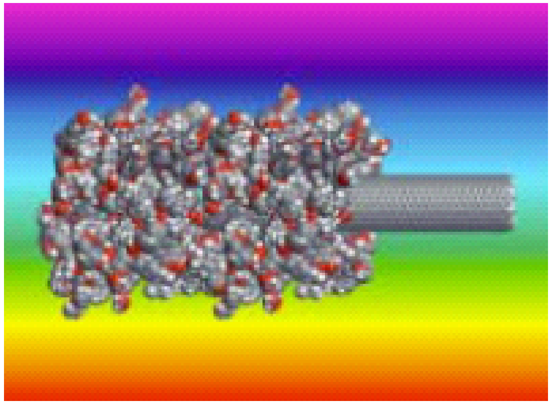
More Possible Applications with CNTs

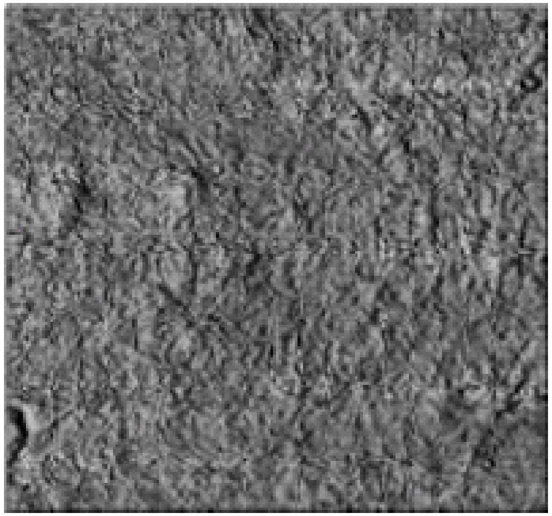
- Nanotube sensors:
  - The electrical conductivities of SWNT change dramatically when they expose to gaseous molecules
- Hydrogen storage:
  - 5~10 wt% hydrogen storage density at room temperature for SWNT
- Light Elements:
  - Electrons from nanotube bombard a phosphor-coated surface to produce light
  - 2 times brighter, 8000h lifetime, can be used for giant outdoors displays
- Memory device:

  Capable to store single electronic charge
  - High mobility

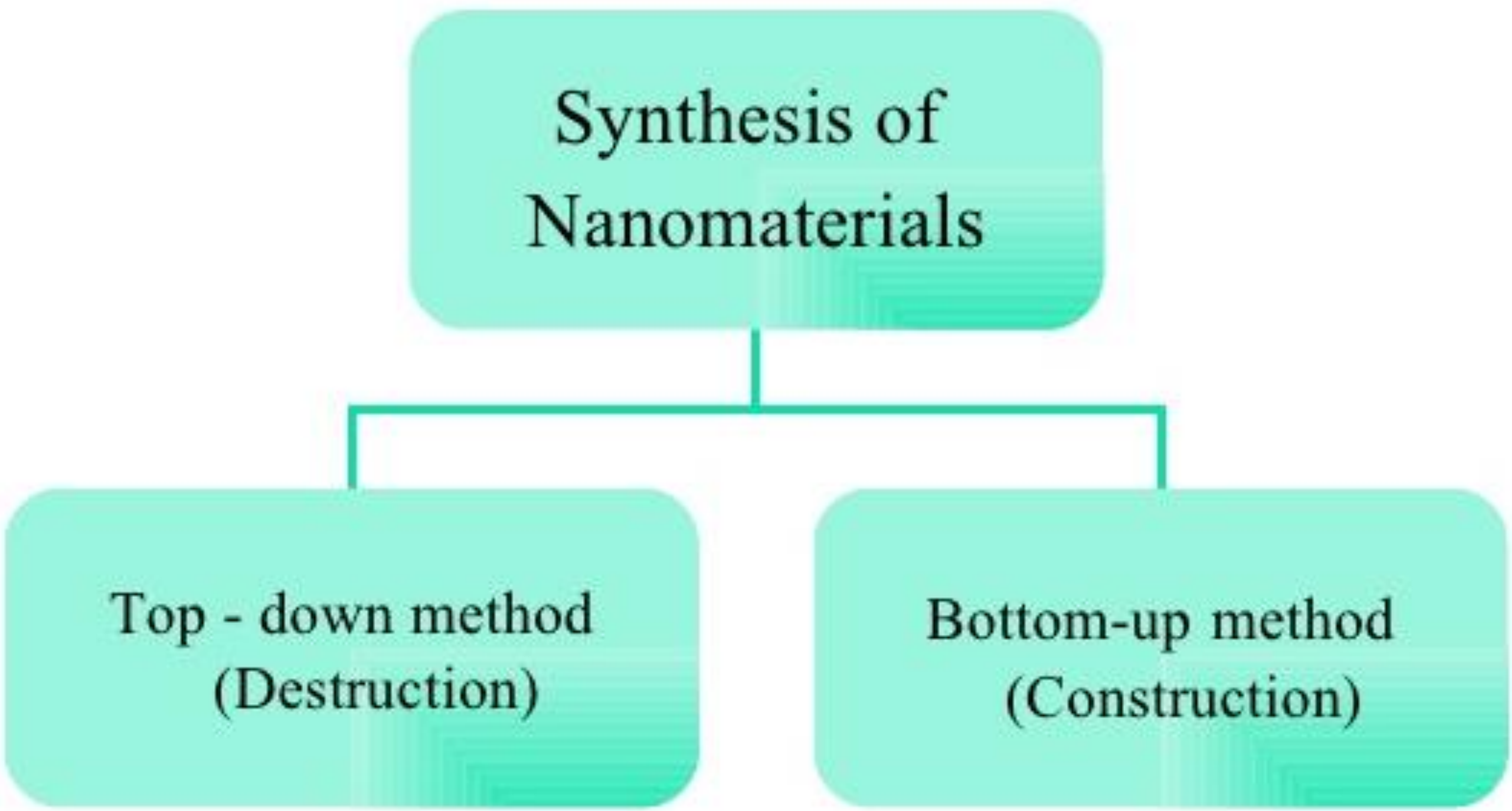
Composite Materials: Carbon Nanotubes

- Reinforced materials
- Lighter materials
- Conductive polymers
- Radar absorbing materials

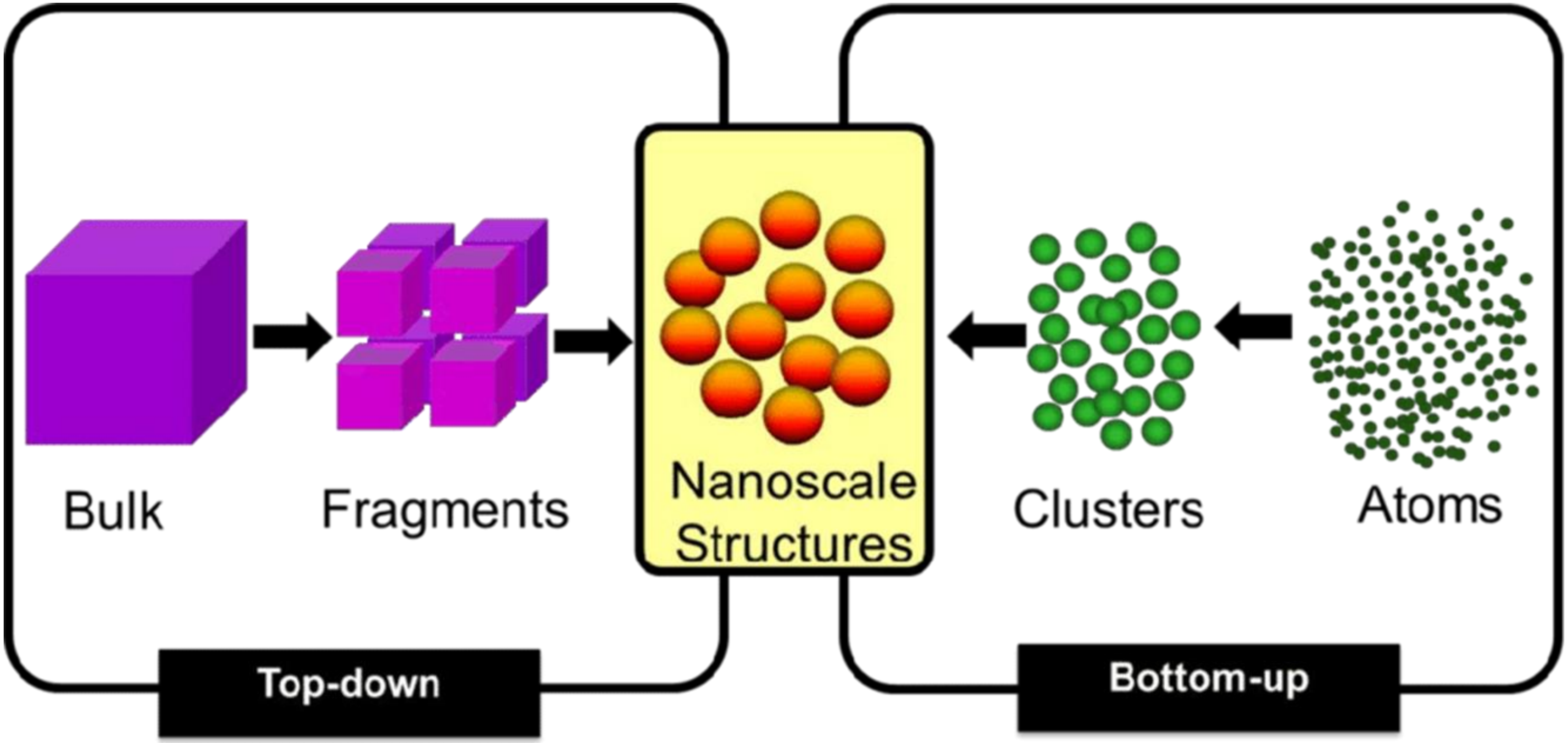




Synthesis of Nanomaterials



Top-Down vs. Bottom-Up

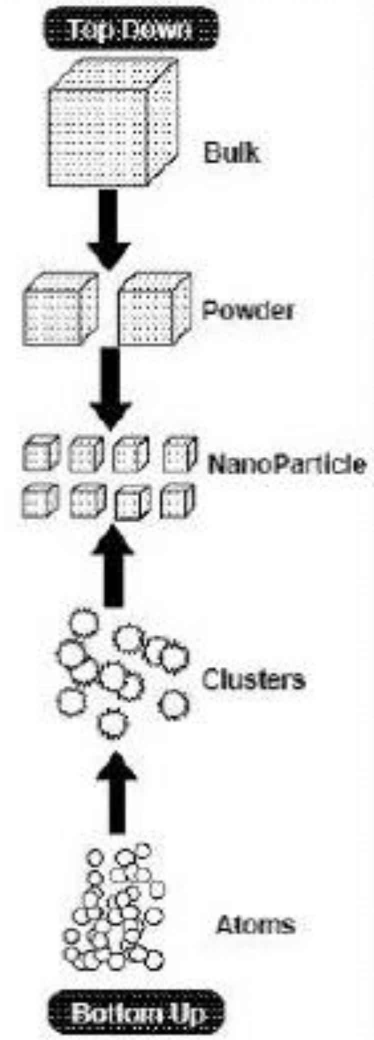


Top-Down Approaches

Top down approach refers to slicing or cutting of a bulk material to get nano sized material. This is similar to making a stone statue. You take a bulk piece of material and modify it by carving or cutting stone, until you have made the shape you want.

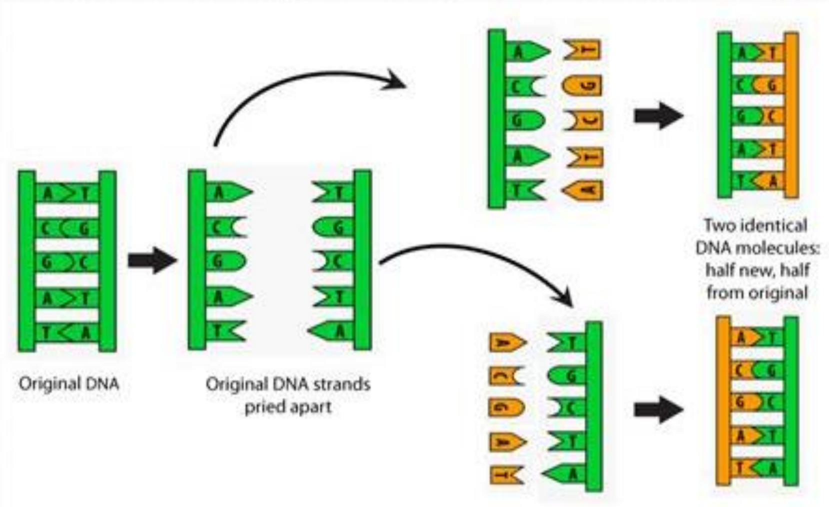
The process involves material wastage and is limited by the resolution of the tools you can use, Cause significant crystallographic damage to the processed patterns.

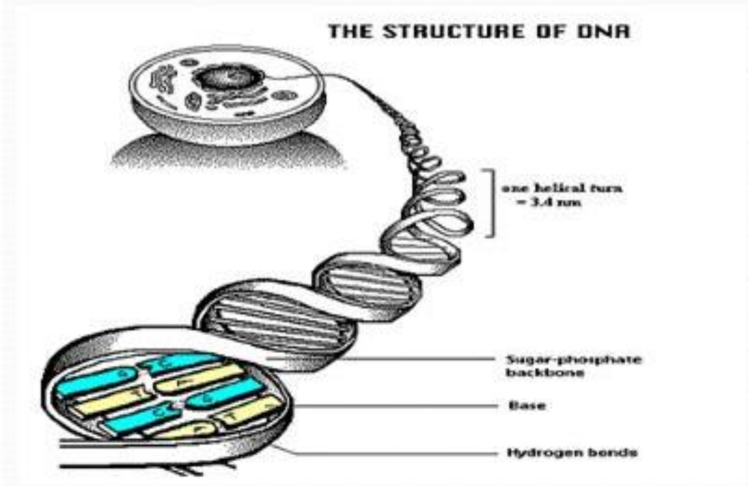
Examples of this kind of approach include the various types of lithographic techniques



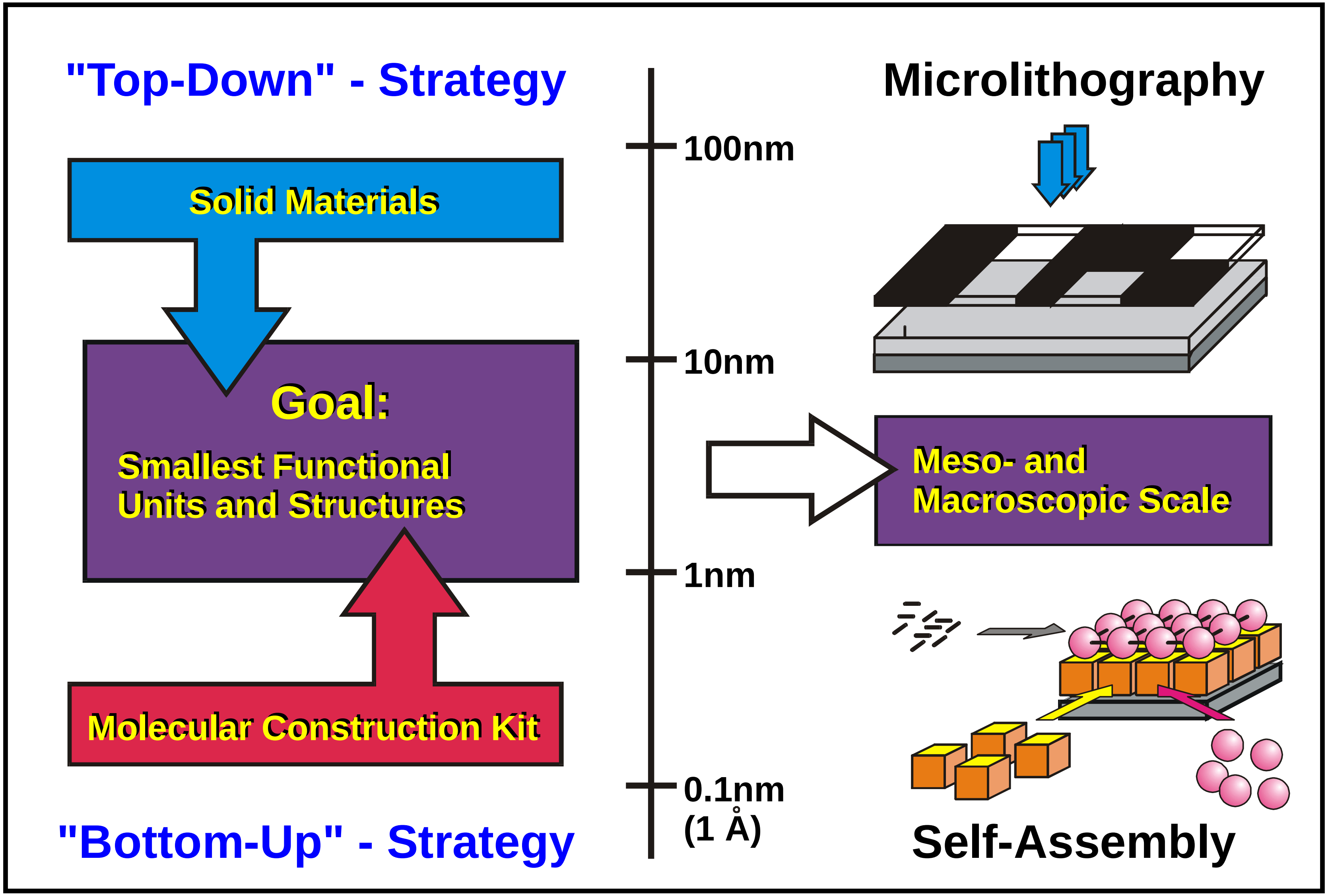
Bottom-Up Approaches

- Assembling nano materials atom – by – atom or molecule – by – molecule (self assembling).
- This approach is much cheaper.
- Things become much larger.
- Examples of molecule self assembly are Watson–Crick basepairing and nano-lithoghraphy.





Top-Down vs. Bottom-Up



Self Assembly

The **spontaneous association of molecules** under equilibrium conditions into stable, structurally well-defined aggregates.

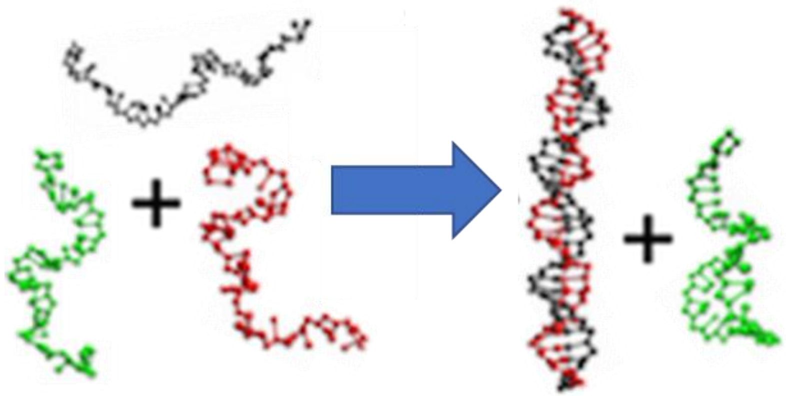
As opposed to the "**Top Down**" methods of the semiconductor industry, Self assembly exploits the naturally existing effects of Brownian Motion, Intermolecular Forces, and the 2nd Law of Thermodynamics to produce structures in a "**Bottom Up**" fashion.

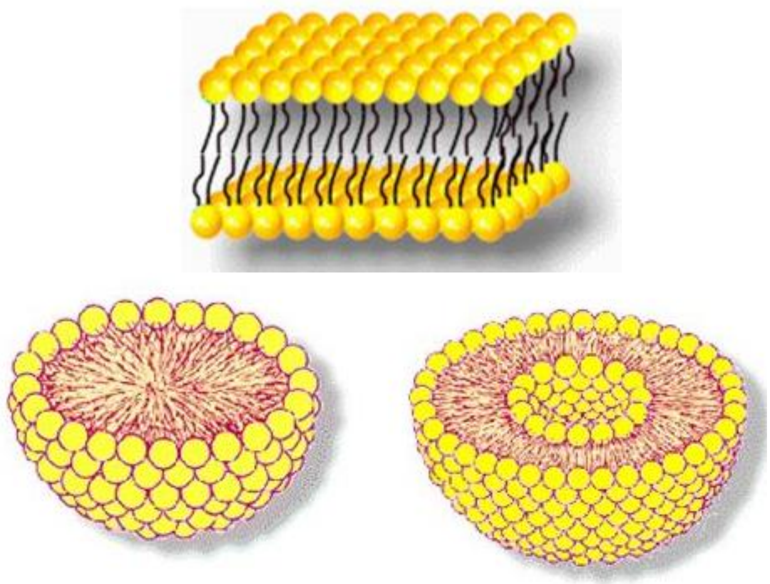
- Biology uses a "bottom-up" assembled strategy
- The unique properties of the DNA and protein building blocks
- Introduction to molecular recognition and self-assembly

Self Assembly

Spontaneous change in a system from a more disordered state to an ordered or structured state

e.g. DNA - complementary strands





e.g. amphiphilic lipids when placed in water will form bilayers, vesicles or micelles. - cell membranes

Self Assembly of Magnetic Nanoparticles

Techniques have been developed that use iron nano particles that self assemble into 3D arrays .

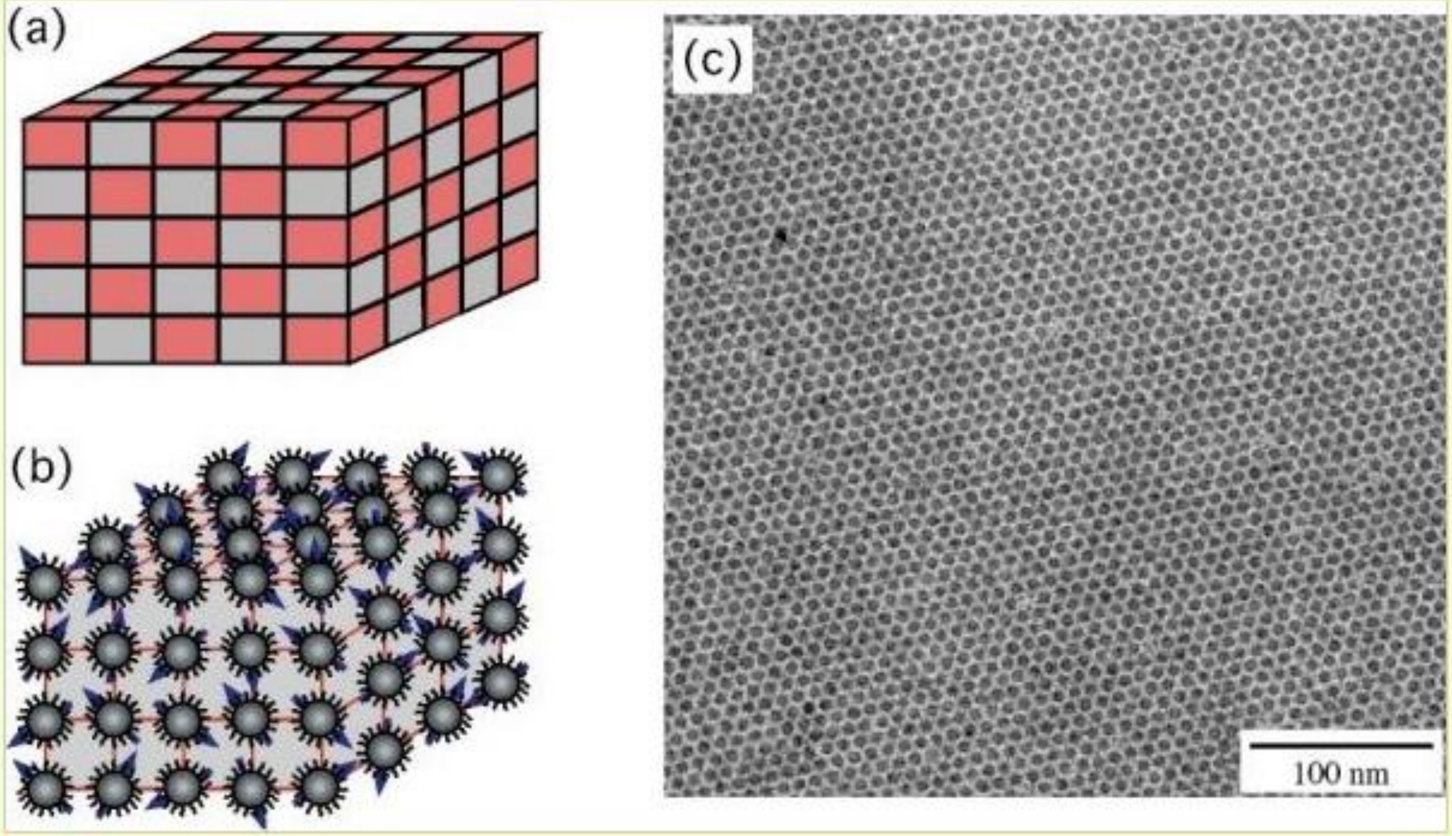


Fig. 1 Large Image

Schematics of (a) a three-dimensional superlattice crystal, (b) a magnetic superlattice of a nanoparticle self-assembly, and (c) a TEM image of a two-dimensional iron nanoparticle array.

Nanotechnology Applications in Medicine

- Because of their small size, nanoscale devices can readily **interact with biomolecules** on both the surface of cells and inside of cells.
- By gaining access to so many areas of the body, they have the potential to **detect disease** and **deliver treatment**.
- Nanoparticles can **deliver drugs directly** to diseased cells in your body.
- **Nanomedicine** is the medical use of molecular-sized particles to deliver drugs, heat, light or other substances to specific cells in the human body.

Nanotechnology in Healthcare

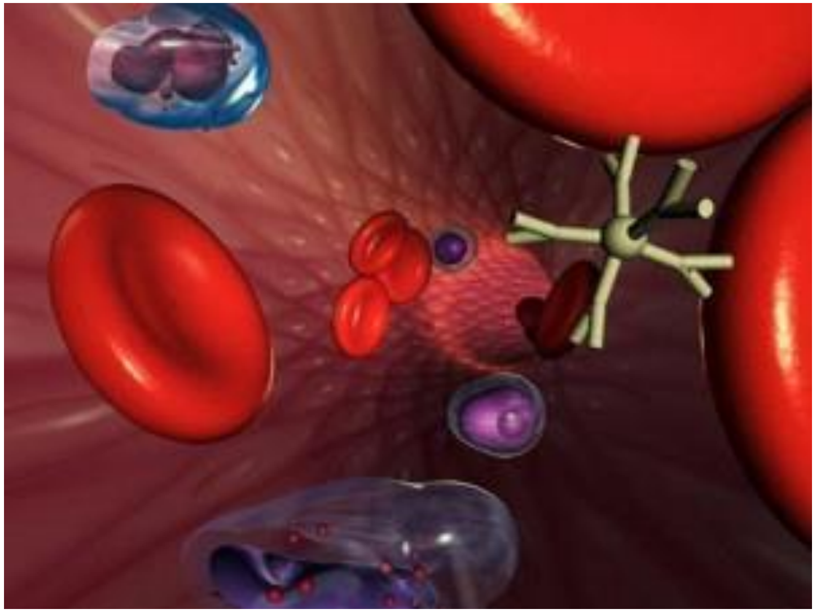
- Greatly improved “directed therapies” for treating cancer using new nano- drug/gene delivery systems
- Tiny implantable devices to monitor health.
- New point-of-care and home healthcare devices.
- Tiny implantable devices with nanobiosensors to treat chronic diseases (diabetes, cardiovascular, arthritis, Parkinson’s disease, Alzheimer’s disease,…) with fewer side-effects.

Voyage of the Nano-Surgeons

NASA-funded scientists are crafting microscopic vessels that can venture into the human body and repair problems – one cell at a time.

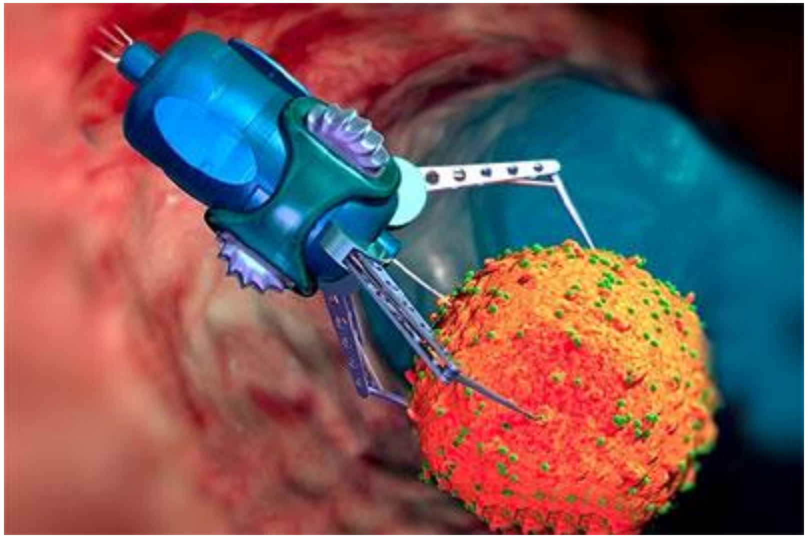
January 15, 2002: It's like a scene from the movie "Fantastic Voyage." A tiny vessel -- far smaller than a human cell -- tumbles through a patient's bloodstream, hunting down diseased cells and penetrating their membranes to deliver precise doses of medicines.

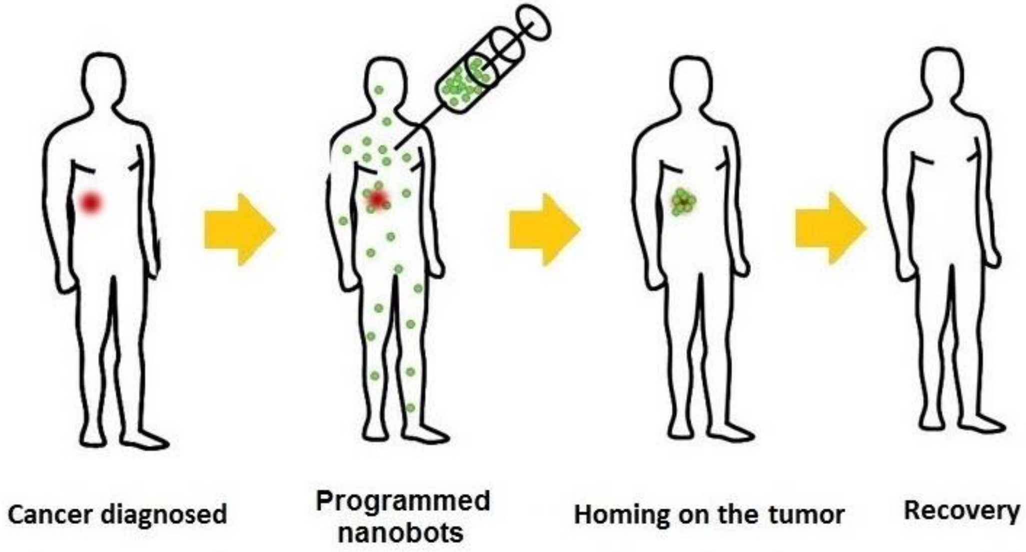
Only this isn't Hollywood. This is real science.



Right: Tiny capsules much smaller than these blood cells may someday be injected into people's bloodstreams to treat conditions ranging from cancer to radiation damage. Copyright 1999, Daniel Higgins, University of Illinois at Chicago.

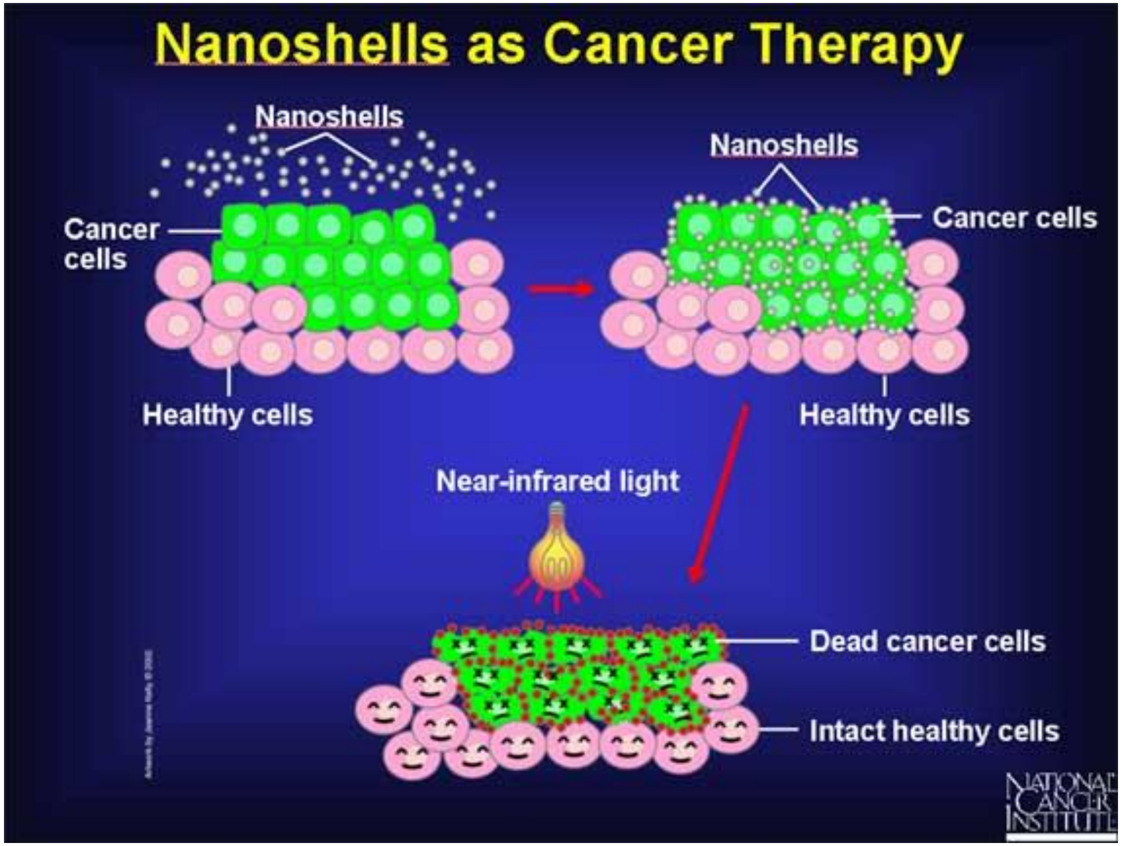
Voyage of the Nano-Surgeons





Nanoshells as Cancer Therapy

Nanoshells are injected into cancer area and they recognize cancer cells. Then by applying near-infrared light, the heat generated by the ***light-absorbing Nanoshells*** has successfully killed tumor cells while leaving neighboring cells intact.

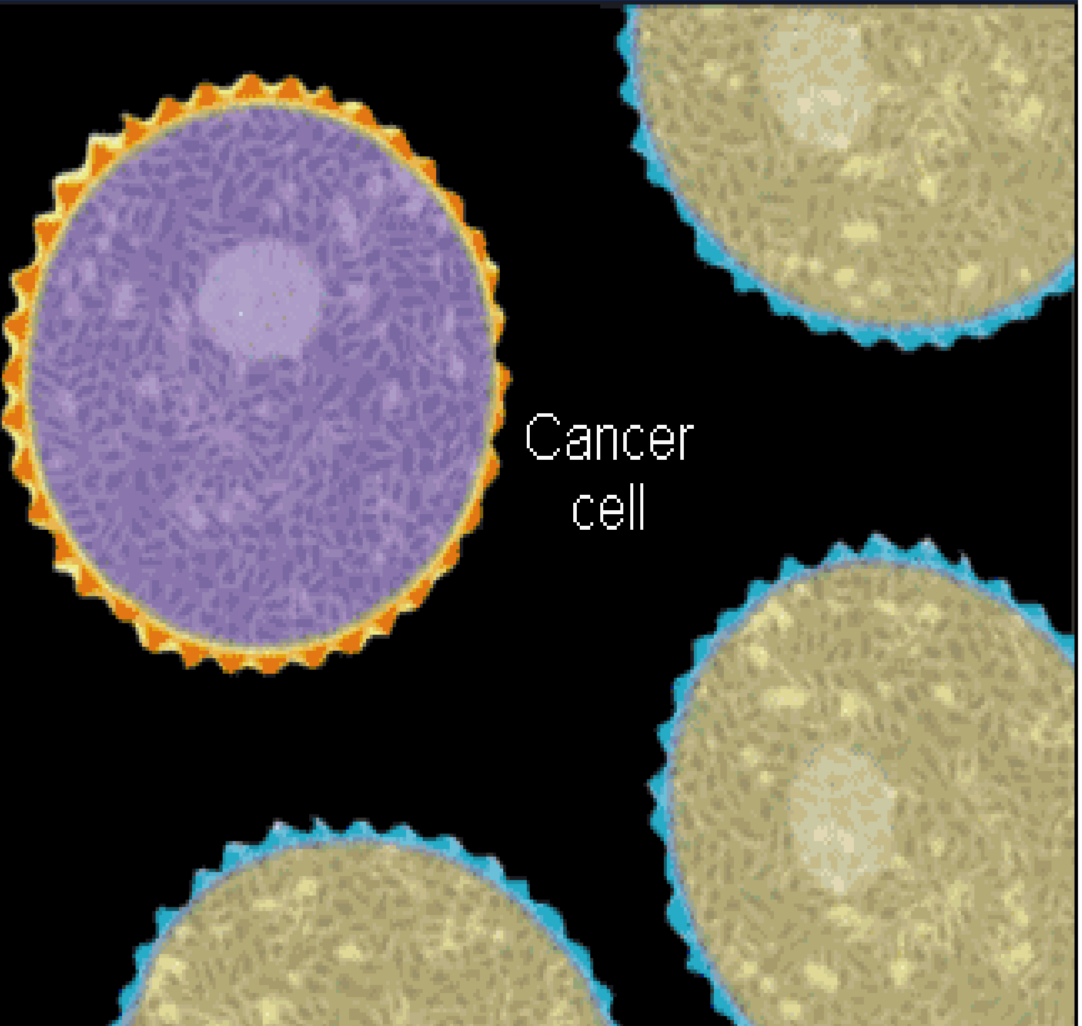


Nanoshells

Nanoshells kill tumor cells selectively

Nanoparticles

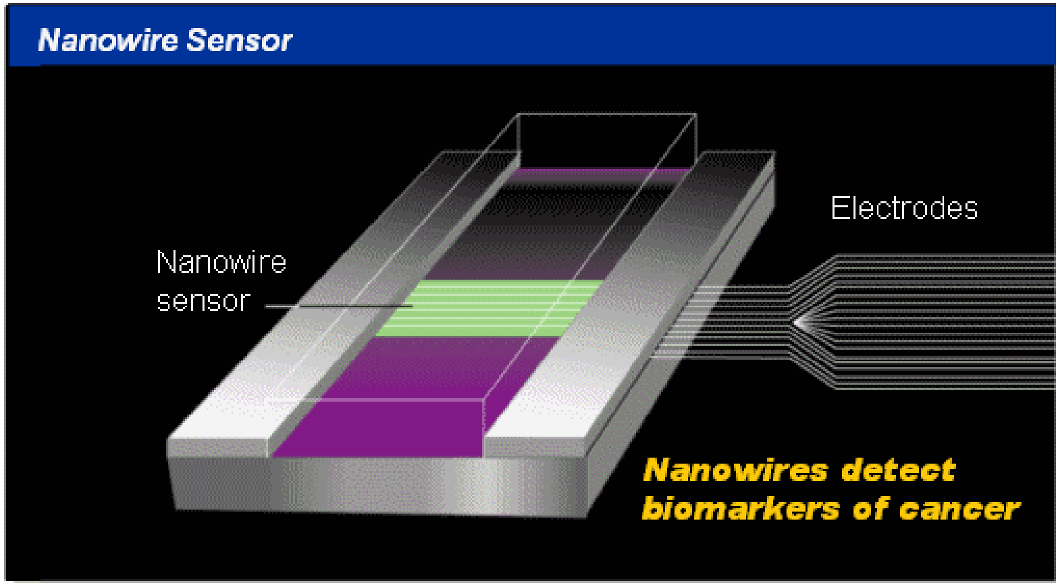
Nanoparticles used for molecular imaging of malignant lesions



Nanowires as Medical Sensors

- **Nanosized sensing wires** are laid down across a micro-fluidic channel. As particles flow through the micro-fluidic channel, the Nanowire sensors pick up the molecular identifications of these particles and can immediately relay this information through a connection of electrodes to the outside world.

- They can detect the presence of altered genes associated with cancer and may help researchers pinpoint the exact location of those changes



Medical Implantation

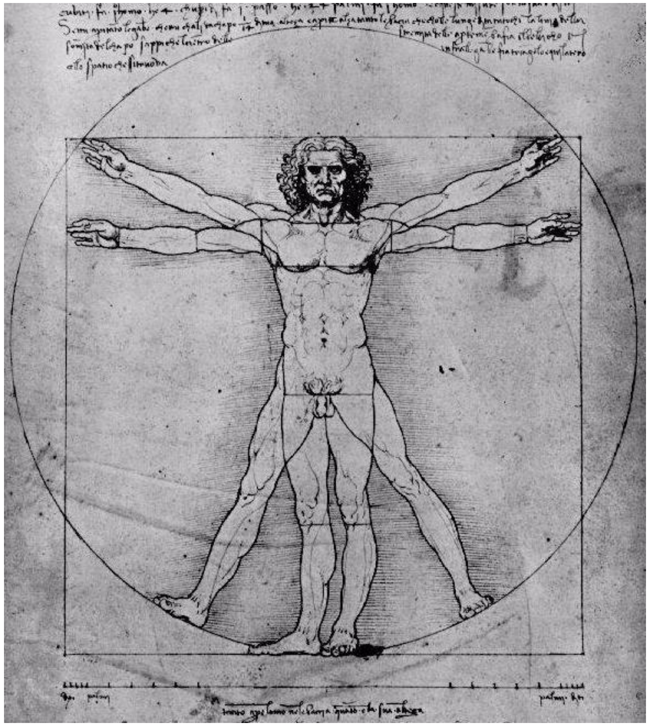
- Unfortunately, in some cases, the biomedical metal alloys may wear out within the lifetime of the patient. But Nanomaterials **increases the life time** of the implant materials.
- Nanocrystalline zirconium oxide (zirconia) is hard, wear resistant, bio-corrosion resistant and bio-compatible.

- It therefore presents an attractive alternative material for implants.
- **Nanocrystalline silicon carbide** is a candidate material for ***artificial heart valves*** primarily because of its low weight, high strength and inertness.

Potential Health Concerns

- Cause for concern:
  - Nanoparticles are similar in size to many biological structures → easily absorbed by the body.
  - Nanoparticles remain suspended in the environment for extended periods of time.
- Health Impacts of nanoparticles are expected to be dependent on composition and structure.
- The potential health concerns of nanomaterials are largely unknown.
- The EPA has started the National Nanotechnology Initiative which is providing funding to further investigate this issue.

We have come a long way…



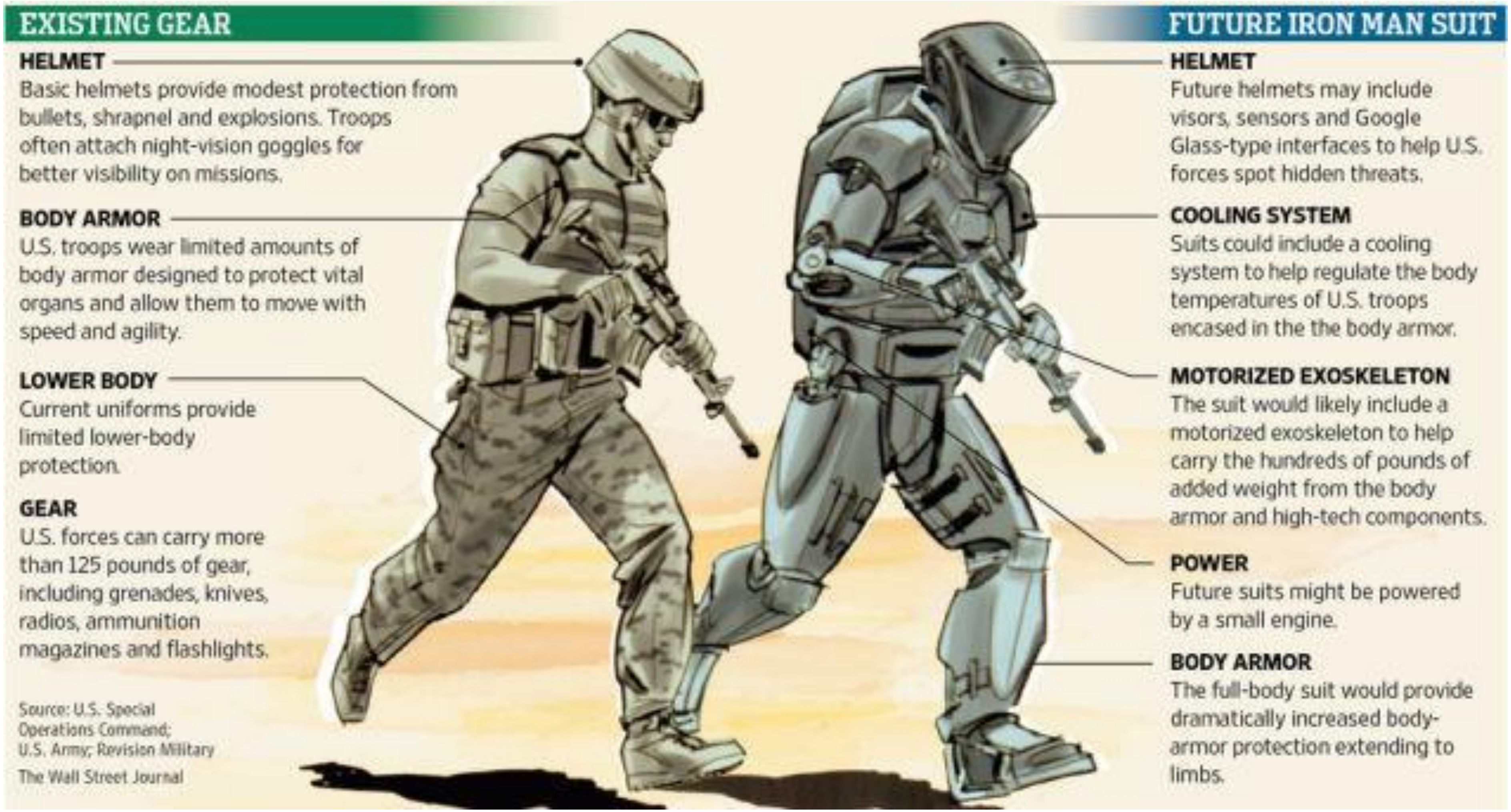
Art: Da Vinci's "Vitruvian Man" 1490

but we still have so far to go!

Military Battle Suits

- Enhanced nanomaterials form the basis of a state-of- the-art ‘**battle suit**’ that is being developed.
- A short-term development is likely to be energy-absorbing materials that will withstand blast waves;
- longer-term are those that incorporate **sensors** to detect or respond to ***chemical and biological weapons*** (for example, responsive nanopores that ‘close’ upon detection of a biological agent).

The Making " Iron Man"



The US Military has launched a program to design a new suit for elite forces

New Protective Military Suit

The U.S. Special Operations Command is asking designers for ideas to produce a suit to protect soldiers of the future.

Government requirements:

DISPLAYS
Give wearer feedback information relevant to the environment from an array of sensors

HEALTH STATUS
Embedded systems monitor the body's vital statistics such as oxygen levels and body heat

LIGHTWEIGHT DESIGN
Minimizes load and maximizes protection

ARMOR
Protects the head and body, especially from explosions, by using advanced materials

POWER
Built-in management systems along with wearable computers, antennas and a programmable radio

MOBILITY
Exoskeleton will be powered to enhance endurance and agility

Screenshot from Army video

SOURCES: U.S. Special Operations Command, Chicago Tribune

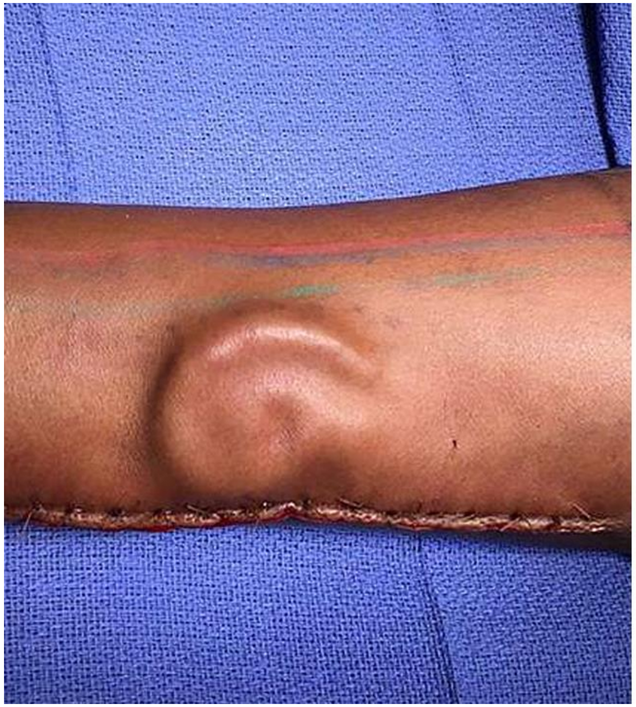
MCCLATCHY NEWSPAPERS

Nanomaterials: Other Applications

- **Sunscreens and Cosmetics**
  - ✓ Nanosized ***titanium dioxide*** and ***zinc oxide*** are currently used in some sunscreens, as they absorb and reflect ultraviolet (UV) rays.
  - ✓ Nanosized ***iron oxide*** is present in some lipsticks as a pigment.
- **Fuel Cells**
- **Displays**
- **Batteries**
- **Catalysts**
- **Magnetic Nanomaterials:**

  Hard Disks with high storage capacity

Artificial Ear: US soldier has new ear grown in her arm



The ear, grown to replace one lost in a car crash, will have functional blood vessels and nerve endings.

https://www.telegraph.co.uk/news/2018/05/10/us-soldier-has-new-ear-grown-arm/

10 MAY 2018 • 8:13PM

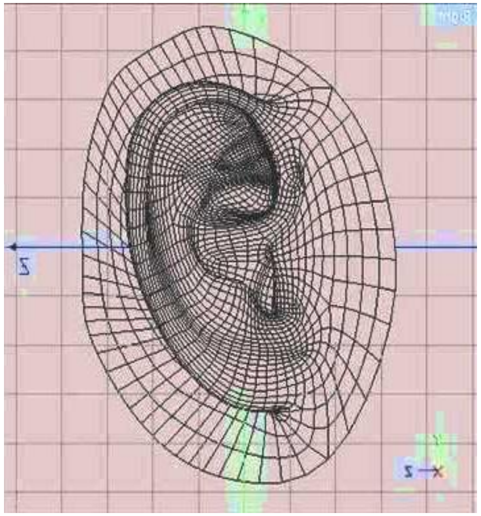
Artificial Organ

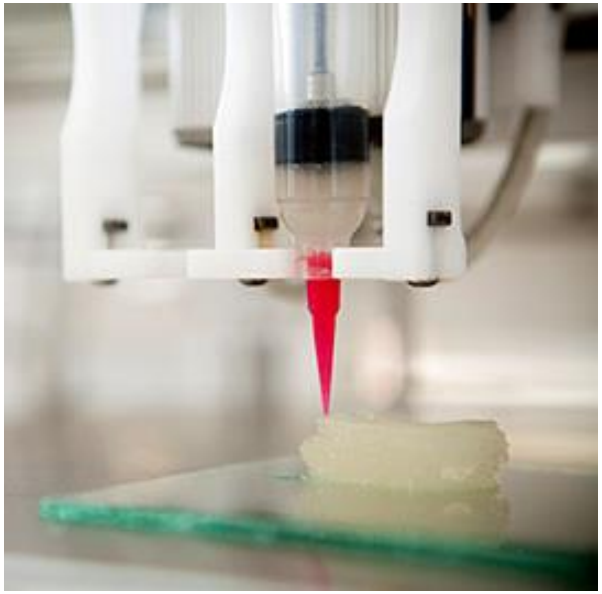
A human ear from cartilage cells the back of a mouse,

Dr. Vacanti, a transplant surgeon
at Massachusetts General Hospital in Boston, USA

BBC News; Thursday, 25 April, 2002, UK

Artificial Ear





Artificial Ear

Artificial Nose

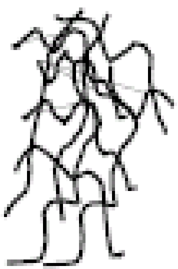
Growing a nose on a forehead is a revolutionary approach to surgical reconstruction.

NATIONAL
GEOGRAPHIC

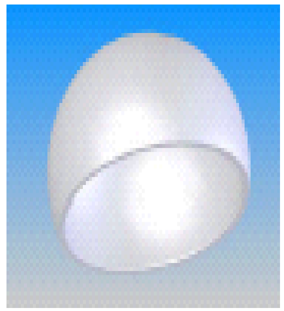
2013, September

A Fully-Implantable Bioartificial Tissue/Organ

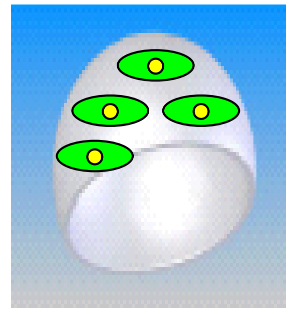
Practical Procedure



Start with
a porous scaffold



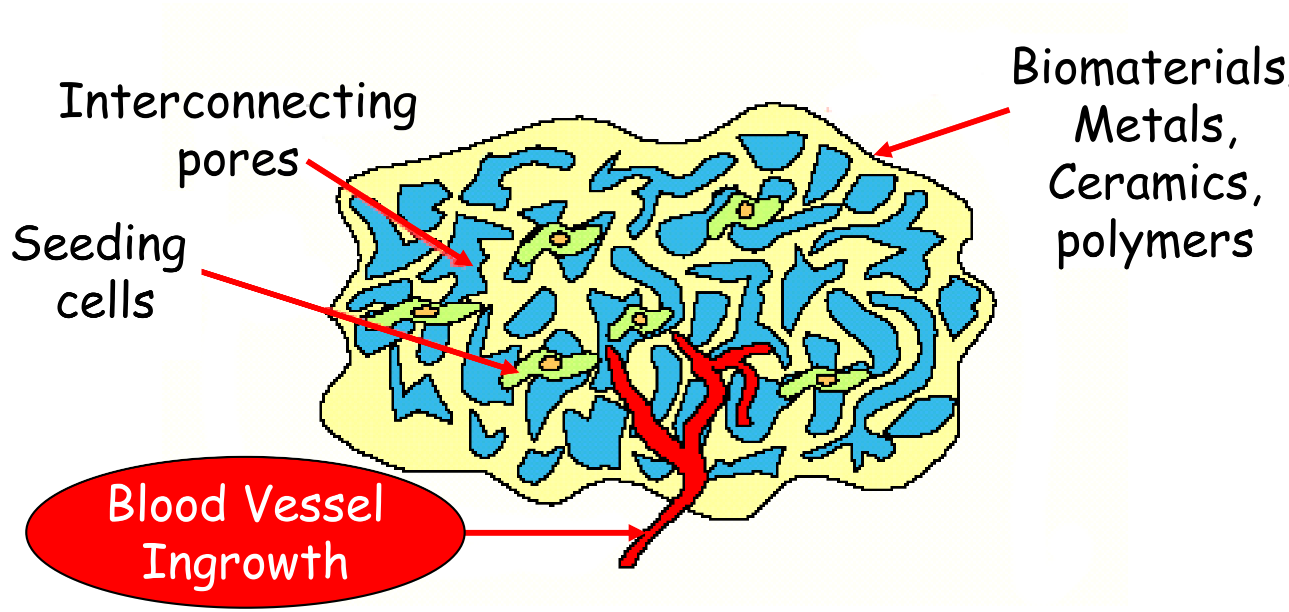
Mold to the shape
of a tissues or organ



Seed with cells
(autologeous or
allogeneic)

Culture the cells and
Grow a tissue or organs

Major Concerns



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