NANOMINERALS, NANOPARTICLES & NANOMATERIALS

e – Learning Material - Unit: 2

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The mineral world includes in present about 4000 valid mineral species of various compositions (from native elements to organic compounds) and size. Some 400 or 500 of the existing mineral species are known only as inclusions in other minerals

Generally, the crystal/grain size of minerals can vary between 10^2m and 10^{-9} m. The

A – Macrominerals 10^5 – 10^{-3} m (mineralogical methods)
B – Microminerals 10^{-4} – 10^{-6} m (optical mineralogy)
C – Inframinerals 10^{-7} – 10^{-8} m (EPMA, NGR, XRD)
D – Nanominerals less than 10^{-8} m (TEM/SAED)

The category A, the macrominerals, includes the majority of the mineral species known worldwide (may be 3000 – 3500 in number).

The microminerals (category B) include a relatively large number of minerals, which can be detected under the microscope and occur mainly as inclusions in other minerals or form only fine to very fine grained aggregates, e.g. clay minerals. Exsolution bodies belong hitherto as well as the daughter minerals in the fluid inclusions.

The inframinerals (category C) cannot be seen or cannot reasonably good be identified under the optical microscope. They occur as ultrafine inclusions and/or as very fine intergrowths, a fact preventing a reliable identification as a result of interfering properties. The main and mostly used methods of identification are EPMA (electron probe microanalysis), NGR (Natural gamma ray measurements) and XRD (X-ray diffraction).

The nanominerals (category D) cannot be depicted by usual Mineralogical / physical methods; even EPMA seems to be useless in many cases. However, their presence can be "seemed"/predicted (NGR) or visualized (TEM transmission electron microscopy) /SAED selected area electron diffraction), HRTEM High-resolution transmission electron microscopy).

Classification:
(Hochella et al. 2008)
Two nanoscale mineral types:
Nanominerals and mineral nanoparticles.
Three nanoscale mineral habits:
nanorods, nanosheets, & nanoparticles. One dimension in nano range

A. Nanominerals:

devoid bulk equivalents
Typical e.g., ferrihydrite - an iron oxyhydroxide, very common in soils & waters (fresh & ocean).
Typically at/or <10 nm in dia., but never > 20 nm. Many nanominerals are yet to be discovered.

B.Mineral nanoparticles
in nanorange & in sizes
exceeding nanorange & reaching
dimensions of minerals.
Great majority of minerals exist
as mineral nanoparticles & as
bulk minerals.

Where are Nanominerals & mineral nanoparticles?
Noticed widely & commonly in atmosphere, oceans, ground & surface waters & soils.
Also in/on most living organisms & even within proteins like ferritin- iron storing protein in body tissue.

Classification of Nanomaterials

Nanomaterials can be classified based on

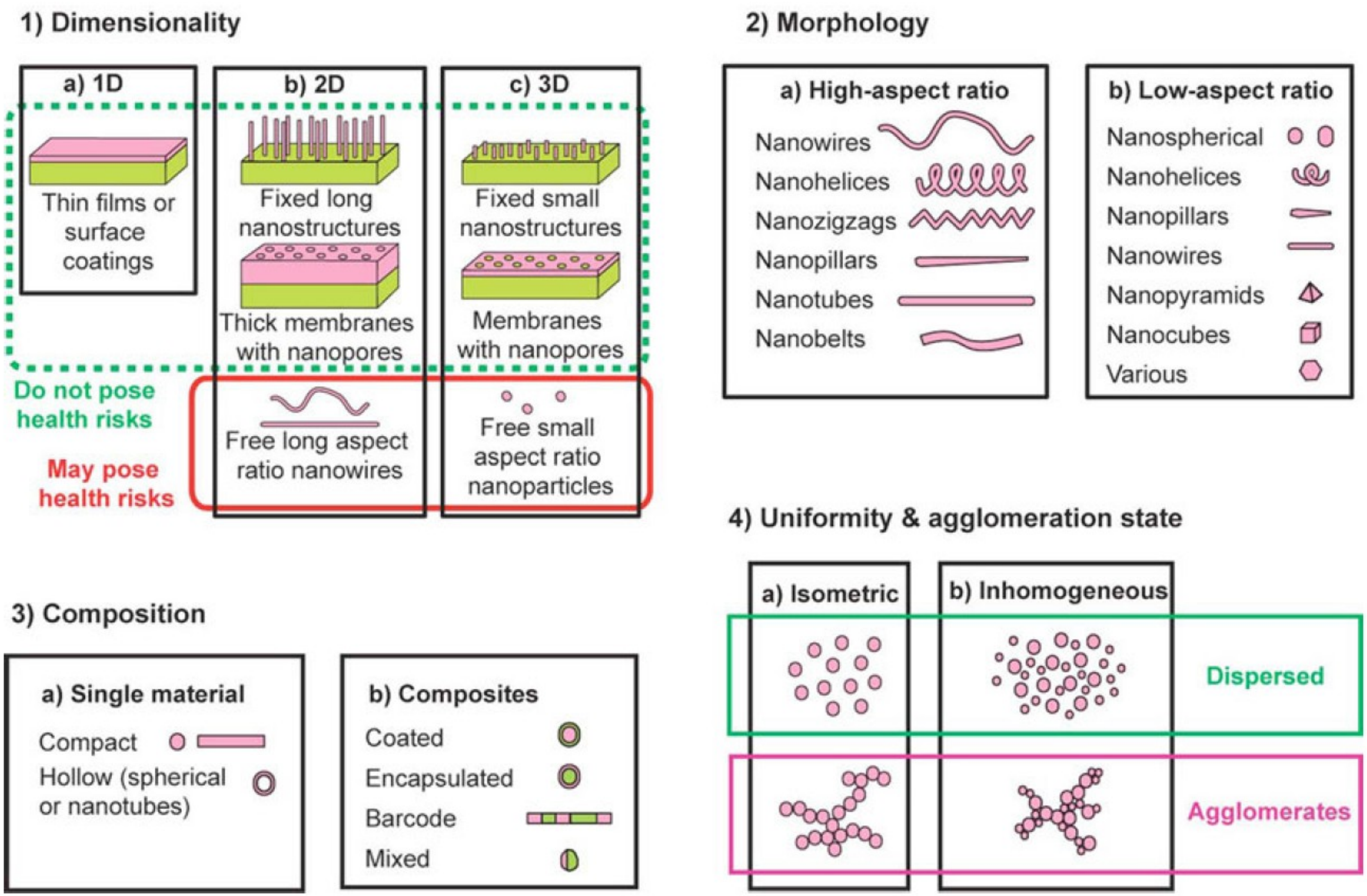
(1) Their origin
(2) Based on phase composition
(3) Based on dimensions

Based on their origin, nanomaterials are broadly classified as

(a) Natural nanomaterials and
(b) Artificial nanomaterials

Natural nanomaterials are those which are obtained naturally.
Examples:- Carbon-nanotubes and fiber s

Artificial nanomaterials are those which are synthesized in laboratories
Examples:- Au/Ag np system and Gold nanoparticles, Polymeric nanocomposites



8. Classification of nanostructured materials from the point of view of nanostructure dimensions, morphology, composition, uniformity and agglomeration
e.

According to Siegel, Nanostructured materials are classified as Zero dimensional one dimensional, two dimensional, three dimensional nanostructures.

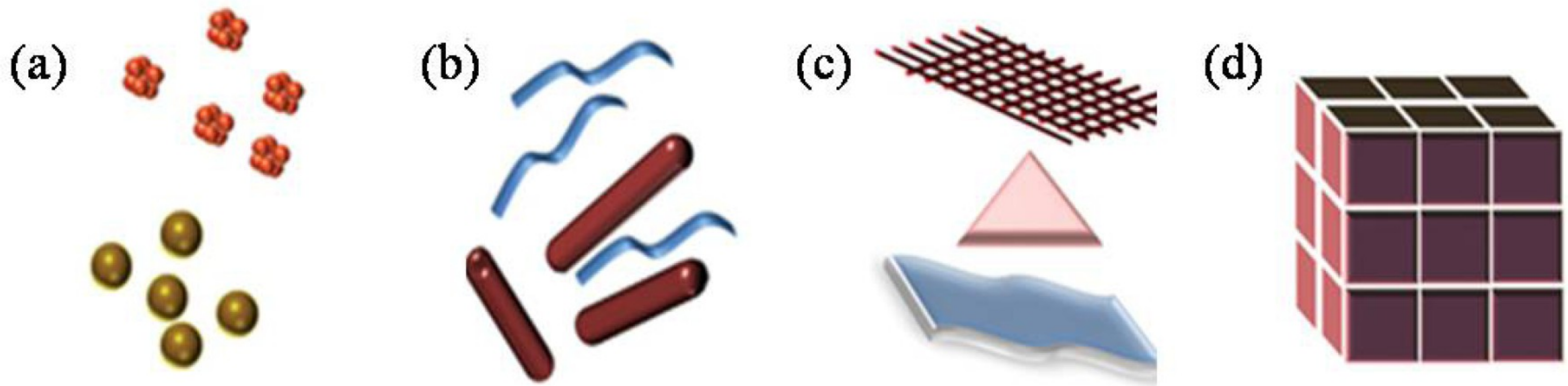
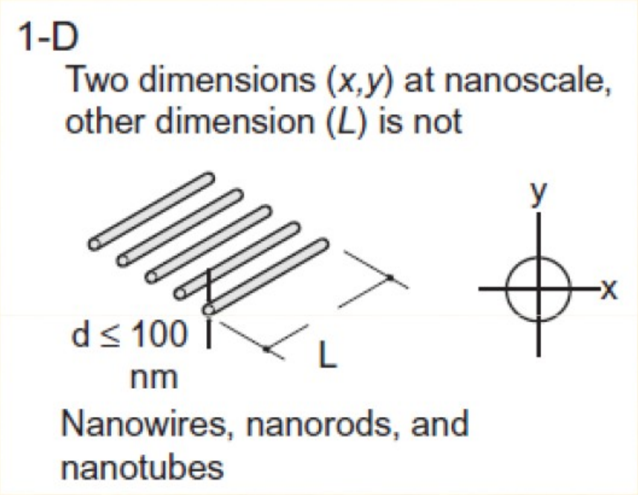
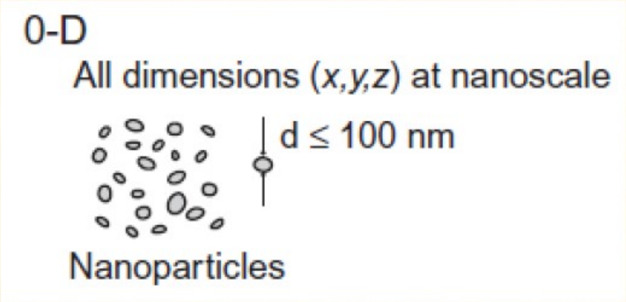


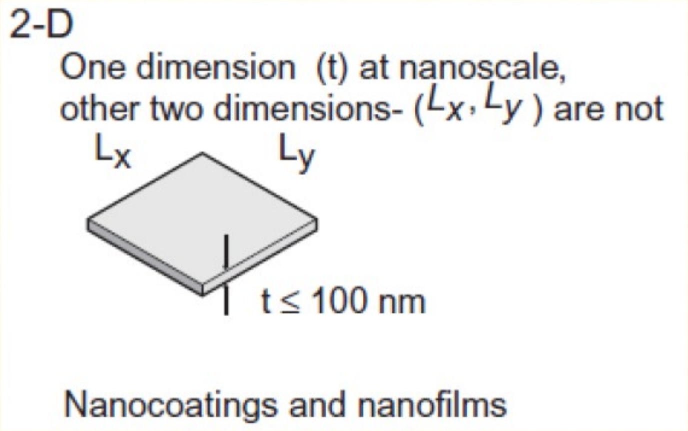
Fig. 3. Classification of Nanomaterials (a) 0D spheres and clusters, (b) 1D nanofibers, wires, and rods, (c) 2D films, plates, and networks, (d) 3D nanomaterials.

Classification

- Classification is based on the number of dimensions, which are not confined to the nanoscale range (<100 nm).
- (1) zero-dimensional (0-D),
- (2) one-dimensional (1-D),
- (3) two-dimensional (2-D), and
- (4) three-dimensional (3-D).

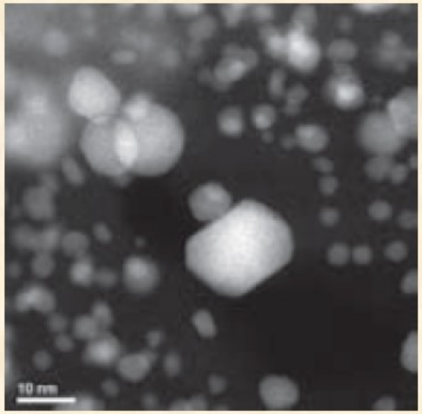






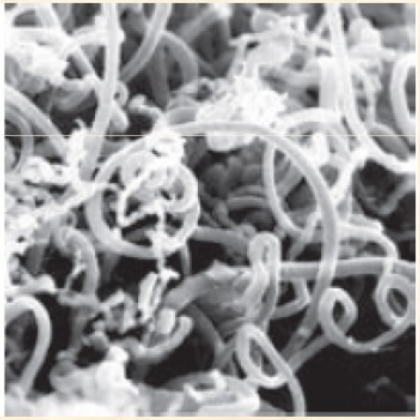
Zero-dimensional nanomaterials

- Materials wherein all the dimensions are measured within the nanoscale (no dimensions, or 0-D, are larger than 100 nm).
- The most common representation of zero-dimensional nanomaterials are **nanoparticles.**
    - **Nanoparticles** can:
- Be amorphous or crystalline
- Be single crystalline or polycrystalline
- Be composed of single or multi-chemical elements
- Exhibit various shapes and forms
- Exist individually or incorporated in a matrix
- Be metallic, ceramic, or polymeric



One-dimensional nanomaterials

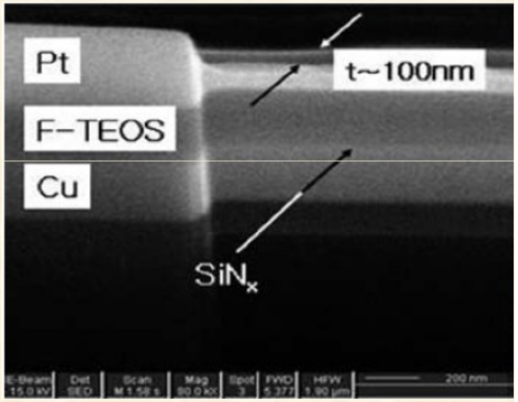
- One dimension that is outside the nanoscale.
- This leads to needle like-shaped nanomaterials.
- 1-D materials include **nanotubes, nanorods, and nanowires**.
    - **1-D nanomaterials** can be



- Amorphous or crystalline
- Single crystalline or polycrystalline
- Chemically pure or impure
- Standalone materials or embedded in within another medium
- Metallic, ceramic, or polymeric

Two-dimensional nanomaterials

- Two of the dimensions are not confined to the nanoscale.
- 2-D nanomaterials exhibit plate-like shapes.
- Two-dimensional nanomaterials include **nanofilms, nanolayers, and nanocoatings.**



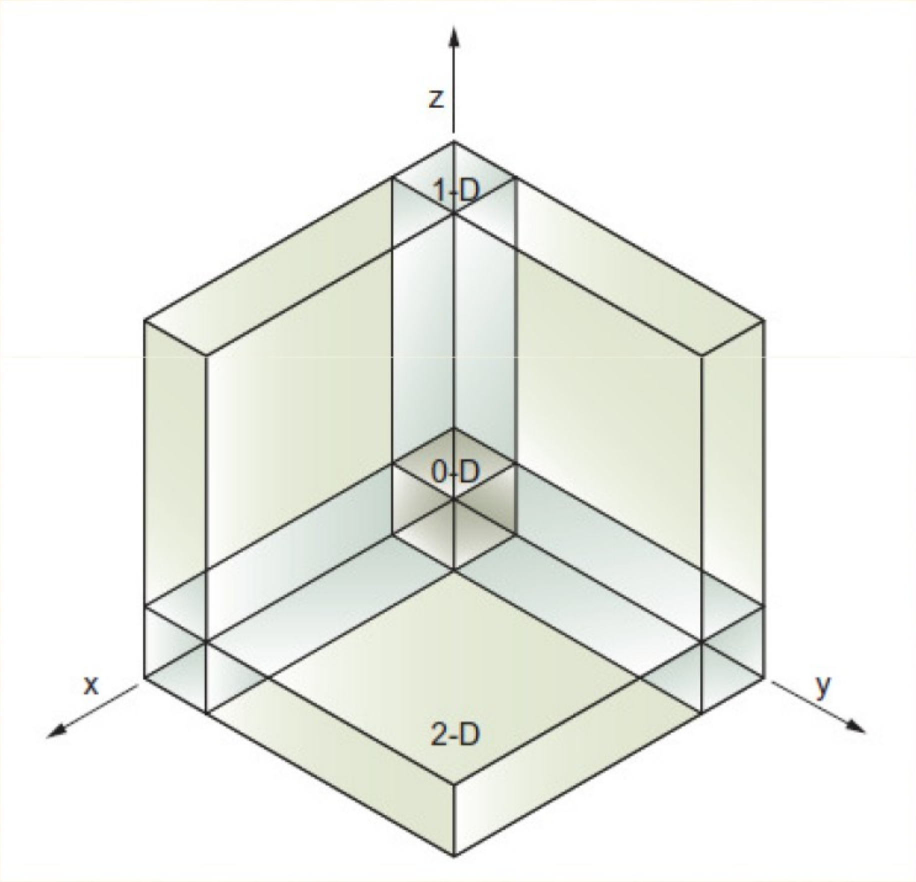
- **2-D nanomaterials** can be:

- Amorphous or crystalline
- Made up of various chemical compositions
- Used as a single layer or as multilayer structures
- Deposited on a substrate
- Integrated in a surrounding matrix material
- Metallic, ceramic, or polymeric

Three-dimensional nanomaterials

- **Bulk** nanomaterials are materials that are not confined to the nanoscale in any dimension. These materials are thus characterized by having three arbitrarily dimensions above 100 nm.
- Materials possess a nanocrystalline structure or involve the presence of features at the nanoscale.
- In terms of nanocrystalline structure, bulk nanomaterials can be composed of a multiple **arrangement of nanosize crystals**, most typically in different orientations.
- With respect to the presence of features at the nanoscale, **3-D nanomaterials** can contain dispersions of nanoparticles, bundles of nanowires, and nanotubes as well as multinanolayers.

Three-dimensional space showing the relationships among 0-D, 1-D, 2-D, and 3-D nanomaterials.



0-D:	All dimensions at the nanoscale
1-D:	Two dimensions at the nanoscale, one dimension at the macroscale
2-D:	One dimension at the nanoscale, two dimensions at the macroscale
3-D:	No dimensions at the nanoscale, all dimensions at the macroscale

Classification Based on Phase composition

Single- Phase solids - Crystalline, amorphous particles and layers, etc.

Multi-phase solids - Matrix composites, coated particles, etc.

Multi-phase system - Colloids, aerogels, ferrofluids, etc.

CuS amorphous nanoparticles are example for single-phase solids, and its inhibit the proliferation of cancer cells rather than normal cells

Multi-phase solids: A method for coating magnetic nanoparticles with a very thin layer of gold. Because many biological markers and linkers have been adapted to attach to gold surfaces, a functional coating of gold allows nanoparticles of other materials to be used with the established markers and linkers. Magnetic nanoparticles are of particular interest for in vivo imaging and treatment operations.

1) Image enhancement in magnetic based diagnostics (such as MRI or other proprietary techniques). (2) Cancer imaging and treatment.

Advantages:-

(1) Avoids direct contact between biological tissue and the core nanoparticle material

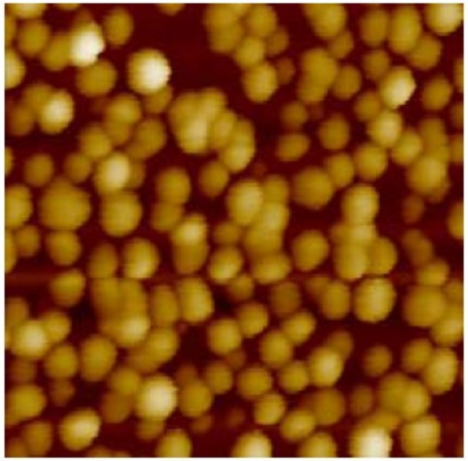
(2) Permits a wide range of magnetic materials to be used in biological tissue

(3) Simple, rapid, and relatively inexpensive chemical process

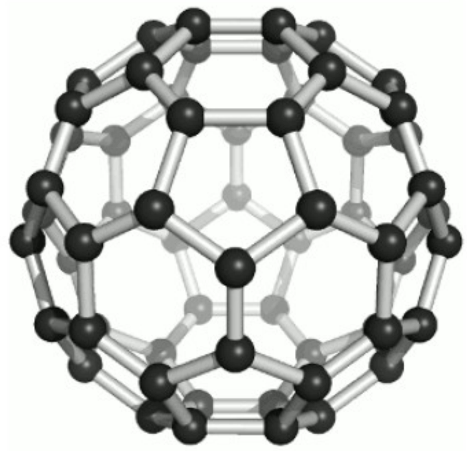
Multi-phase system

Aerogel is a manufactured material with the lowest bulk density of any known porous solid.
It is derived from a gel in which the liquid component of the gel has been replaced with a gas. The result is an extremely low-density solid with several remarkable properties, most notably its effectiveness as a thermal insulator.
It is nicknamed frozen smoke, solid smoke, solid air or blue smoke due to its translucent nature and the way light scatter s in the material
Eq:- Carbon aerogels are composed of particles with sizes in the nanometer range, covalently bonded together. They have high porosity over 50%, with pore diameter under 100 nm and surface areas ranging between 400-1000 sq.km/g.

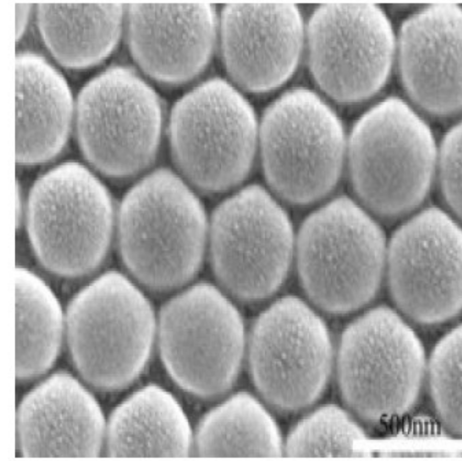
Nanomaterials (gold, carbon, metals, meta oxides and alloys) with variety of morphologies (shapes) are depicted



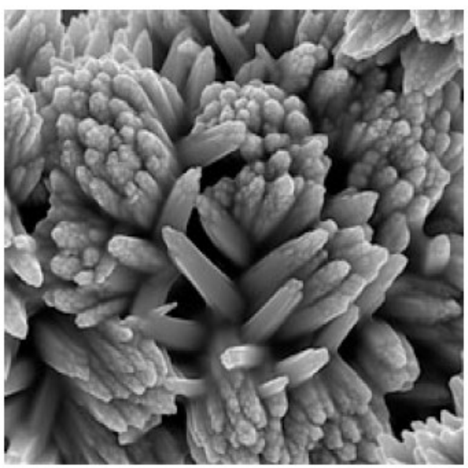
Au nanoparticle



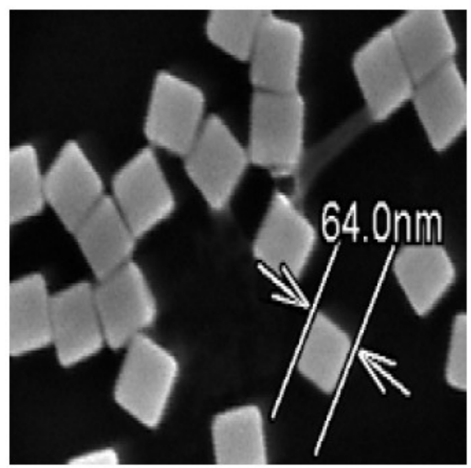
Buckminsterfullerene



FePt nanosphere

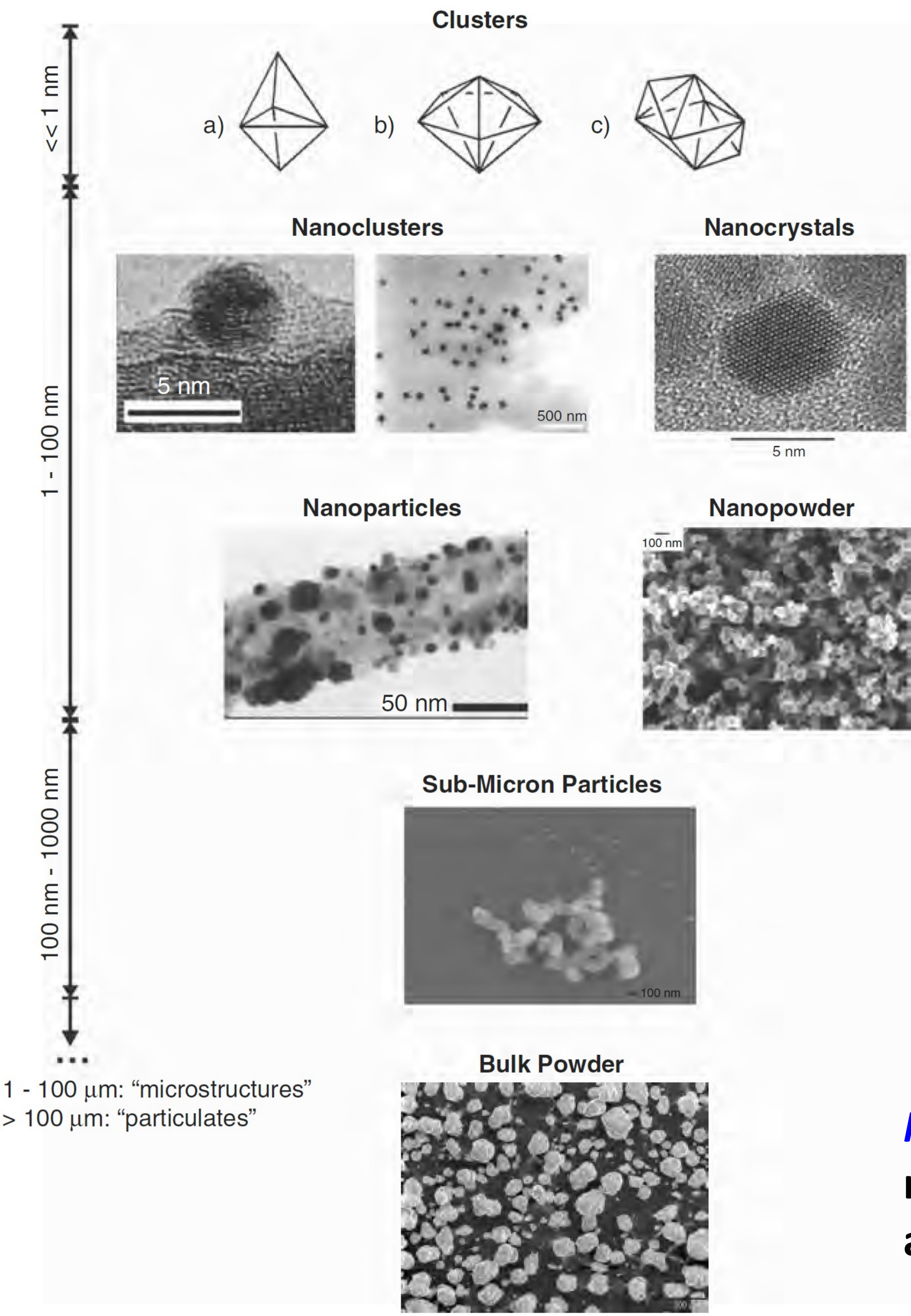


Titanium nanoflower



Silver nanocubes

SnO2 nanoflower



The term nanoparticle is generally used to encompass all 0D nanosized building blocks (regardless of size and morphology), or those that are amorphous and possess a relatively irregular shape.

Nanoclusters should be used to describe 0D nanostructures of a homogeneous size distribution

Any nanomaterial that is crystalline should be referred to as a nanocrystal. Nanocrystals are characterized by the presence of an ordered lattice array of the constituent subunits, as illustrated by a single nanocrystal of CdSe

A special case of nanocrystal that is comprised of a semiconductor is known as a quantum dot. Quantum dots currently find applications
as sensors, lasers, and LEDs.

Nanopowder is shown that consists of microscopic grains, each comprised of nanoscale amorphous units

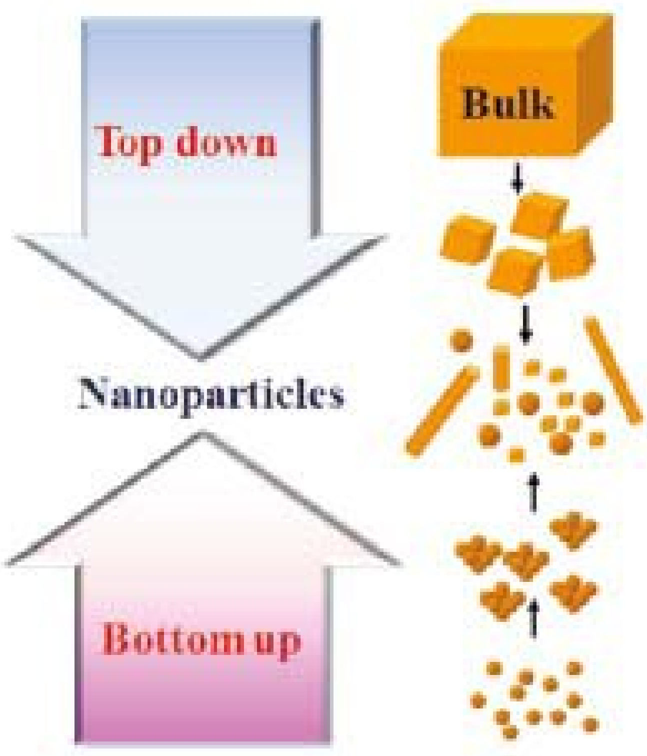
Significance of Nanomaterial's

These materials have created a high interest in recent years by virtue of their unusual mechanical, electrical, optical and magnetic properties.

- Nanophase ceramics are of particular interest because they are more ductile at elevated temperatures as compared to the coarse-grained ceramics.
- Nanostructured semiconductors are known to show various non-linear optical properties. Nanostructured semiconductors are used as window layers in solar cells
- Nanosized metallic powders have been used for the production of gas tight materials, dense parts and porous coatings. Cold welding properties combined with the ductility make them suitable for metal-metal bonding especially in the electronic industry.
- Single nanosized magnetic particles are having special properties in addition to the superparamagnetism behaviour
- Nanostructured metal clusters and colloids of mono- or plurimetallic composition have a special impact in catalytic applications.
- Nanostructured metal-oxide thin films are receiving a growing attention for the realization of gas sensors (NOx, CO, CO2, CH4 and aromatic hydrocarbons) with enhanced sensitivity and selectivity
- Nanostructured metal-oxide (MnO2) finds application for rechargeable batteries for cars or consumer goods. Nanocrystalline silicon films for highly transparent contacts in thin film solar cell

Nanomaterial - synthesis and processing

Nanomaterials deal with very fine structures: a nanometer is a billionth of a meter. This indeed allows us to think in both the 'bottom up' or the 'top down' approaches to synthesize nanomaterials, i.e. either to assemble atoms together or to dis-assemble (break, or dissociate) bulk solids into finer pieces until they are constituted of only a few atoms



Schematic illustration of the preparative methods of nanoparticles

Methods for creating nanostructures

There are many different ways of creating nanostructures: of course, macromolecules or nanoparticles or buckyballs or nanotubes and so on can be synthesized artificially for certain specific materials.

They can also be arranged by methods based on equilibrium or near-equilibrium thermodynamics such as methods of self-organization and self-assembly (sometimes also called bio-mimetic processes).

Using these methods, synthesized materials can be arranged into useful shapes so that finally the material can be applied to a certain application.

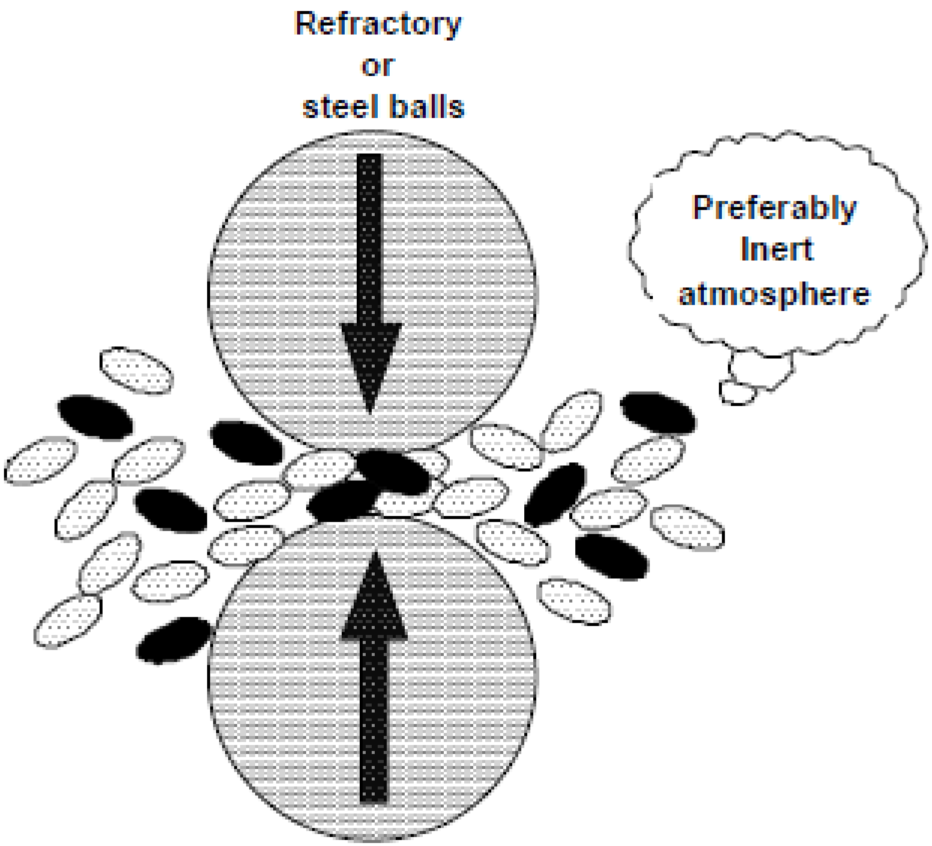
Mechanical grinding

Mechanical attrition is a typical example of 'top down' method of synthesis of nanomaterials, where the material is prepared not by cluster assembly but by the structural decomposition of coarser-grained structures as the result of severe plastic deformation.

This has become a popular method to make nanocrystalline materials because of its simplicity and the relatively inexpensive equipment needed. Similarly, the serious problems that are usually cited are

1. contamination from milling media and/or atmosphere, and

2. to consolidate the powder product without coarsening the nanocrystalline microstructure.



Schematic representation of the principle of mechanical milling

Schematic representation of the principle of mechanical milling The energy transferred to the powder from refractory or steel balls depends on the rotational (vibrational) speed, size and number of the balls, ratio of the ball to powder mass, the time of milling and the milling atmosphere. Nanoparticles are produced by the shear action during grinding.

Wet Chemical Synthesis of Nanomaterials

In principle we can classify the wet chemical synthesis of nanomaterials into two broad groups:

1. The top down method: where single crystals are etched in an aqueous solution for producing nanomaterials, For example, the synthesis of porous silicon by electrochemical etching.

2. The bottom up method: consisting of sol-gel method, precipitation etc. where materials containing the desired precursors are mixed in a controlled fashion to form a colloidal solution.

Sol-gel process

The sol-gel process, involves the evolution of inorganic networks through the formation of a colloidal suspension (sol) and gelation of the sol to form a network in a continuous liquid phase (gel).

The precursors for synthesizing these colloids consist usually of a metal or metalloid element surrounded by various reactive ligands.

The starting material is processed to form a dispersible oxide and forms a sol in contact with water or dilute acid.

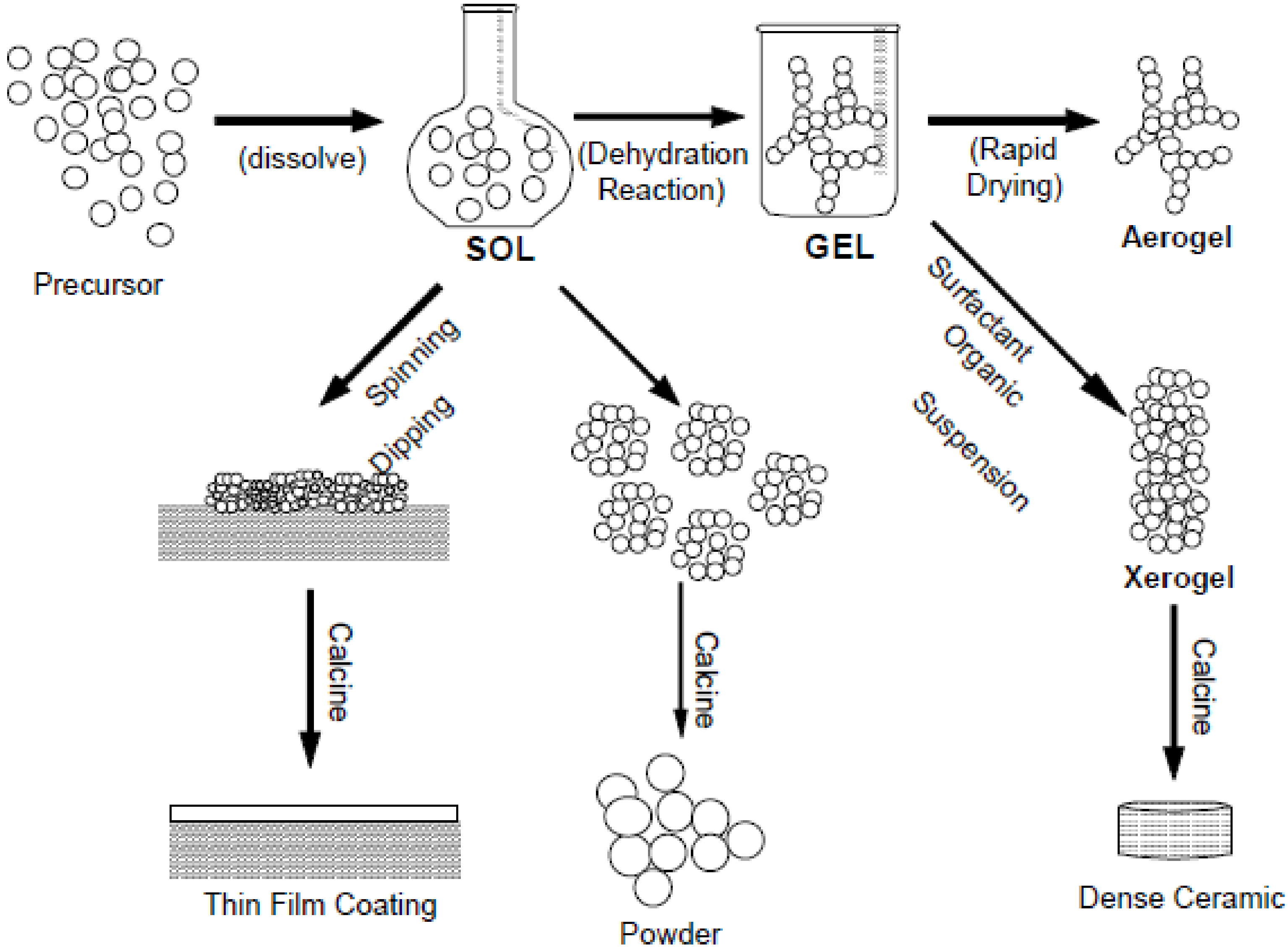
Removal of the liquid from the sol yields the gel, and the sol/gel transition controls the particle size and shape. Calcination of the gel produces the oxide.

Sol-gel processing refers to the hydrolysis and condensation of alkoxide-based precursors such as $Si(OEt)_4$ (tetraethyl orthosilicate, or TEOS). The reactions involved in the sol-gel chemistry based on the hydrolysis and condensation of metal alkoxides M(OR)**z** can be described as follows:

$$MOR + H_2O \rightarrow MOH + ROH \text{ (hydrolysis)}$$

$$MOH + ROM \rightarrow M\text{-}O\text{-}M + ROH \text{ (condensation)}$$

Sol-gel method of synthesizing nanomaterials is very popular amongst chemists and is widely employed to prepare oxide materials. The sol-gel process can be characterized by a series of distinct steps.



Schematic representation of sol-gel process of synthesis of nanomaterials

1. Formation of different stable solutions of the alkoxide or solvated metal precursor.

2. Gelation resulting from the formation of an oxide- or alcohol- bridged network (the gel) by a polycondensation reaction that results in a dramatic increase in the viscocity of the solution.

3. Aging of the gel (Syneresis), during which the polycondensation reactions continue until the gel transforms into a solid mass, accompanied by contraction of the gel network and expulsion of solvent from gel pores. Ostwald ripening (also referred to as coarsening, is the phenomenon by which smaller particles are consumed by larger particles during the growth process) and phase transformations may occur concurrently with syneresis. The aging process of gels can exceed 7 days and is critical to the prevention of cracks in gels that have beencast.

4. Drying of the gel, when water and other volatile liquids are removed from the gel network. This process is complicated due to fundamental changes in the structure of the gel.

The drying process has itself been broken into four distinct steps: (i) the constant rate period, (ii) the critical point, (iii) the falling rate period, (iv) the second falling rate period. If isolated by thermal evaporation, the resulting monolith is termed a xerogel. If the solvent (such as water) is extracted under supercritical or near super critical conditions, the product is an aerogel.

5. Dehydration, during which surface- bound M-OH groups are removed, there by stabilizing the gel against rehydration. This is normally achieved by calcining the monolith at temperatures up to 8000C.

6. Densification and decomposition of the gels at high temperatures (T>8000C). The pores of the gel network are collapsed, and remaining organic species are volatilized. The typical steps that are involved in sol-gel processing are shown in the schematic diagram below.

Gas Phase synthesis of nanomaterials

The gas-phase synthesis methods are of increasing interest because they allow elegant way to control process parameters in order to be able to produce size, shape and chemical composition controlled nanostructures

In conventional chemical vapour deposition (CVD) synthesis, gaseous products either are allowed to react homogeneously or heterogeneously depending on a particular application

Gas phase processes have inherent advantages, some of which are noted here:

An excellent control of size, shape, crystallinity and chemical composition

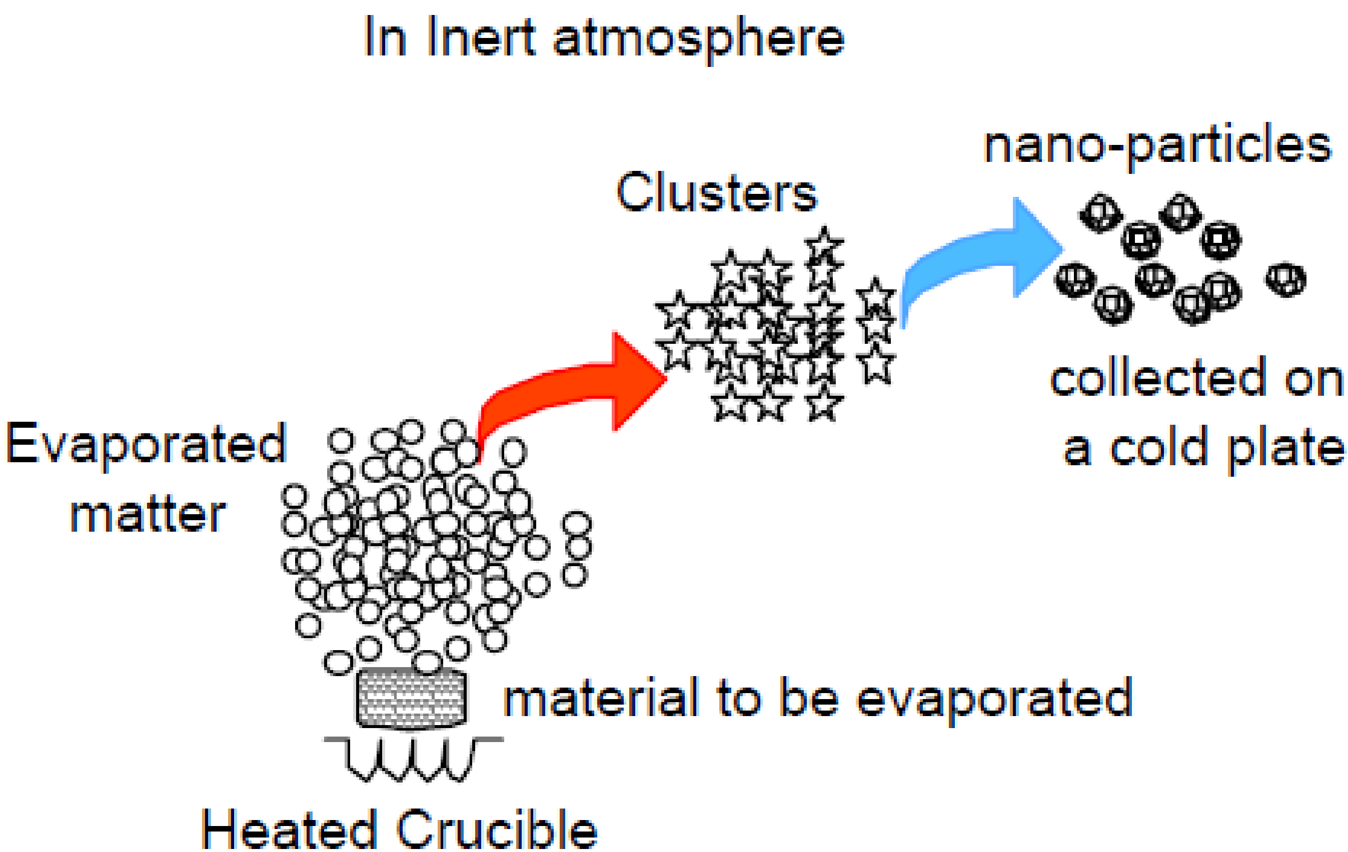
Highly pure materials can be obtained

Multicomonent systems are relatively easy to form

Easy control of the reaction mechanisms

Furnace

The simplest fashion to produce nanoparticles is by heating the desired material in a heat resistant crucible containing the desired material. This method is appropriate only for materials that have a high vapour pressure at the heated temperatures up to 2000°C



Disadvantages of Nanomaterials

(i) **Instability of the particles** - Retaining the active metal nanoparticles is highly challenging, as the kinetics associated with nanomaterials is rapid. In order to retain nanosize of particles, they are encapsulated in some other matrix.

(ii) Nanomaterials are thermodynamically metastable and lie in the region of high-energy local-minima. Hence they are prone to attack and undergo transformation. These include poor corrosion resistance, high solubility, and phase change of nanomaterials. This leads to deterioration in properties and retaining the structure becomes challenging.

(iii) Fine metal particles act as strong explosives owing to their high surface area coming in direct contact with oxygen. Their exothermic combustion can easily cause explosion.

(iv) **Impurity** - Because nanoparticles are highly reactive, they inherently interact with impurities as well.

(v) **Biologically harmful** - Nanomaterials are usually considered harmful as they become transparent to the cell-dermis.

(vi) **Difficulty in synthesis, isolation and application** - It is extremely hard to retain the size of nanoparticles once they are synthesized in a solution.

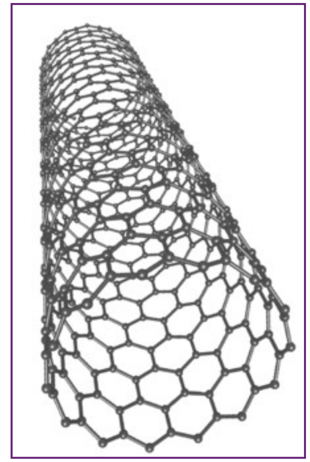
Carbon and Forms of Carbon

- Sixth element in the periodic table
- Atomic weight 12.011
- Three isotopes:
  - C^{12} (99% of the naturally occurring carbon -reference for relative atomic mass of 12),
  - C^{13} (has magnetic moment, spin=1/2 – used as a probe in NMR),
  - and C^{14} (radioactive isotope, half life 5730 years –used in dating of artefacts and 'label' organic reaction mechanisms)
- Electronic ground state: $1s^2 2s^2 2p^2$
- C exhibits "catenation" = bonding to itself – limitless number of chains, rings and networks

Objects that are Made From Carbon

Diamond

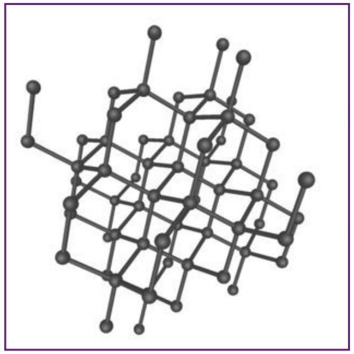
Graphite

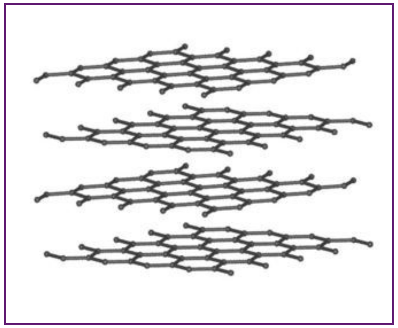


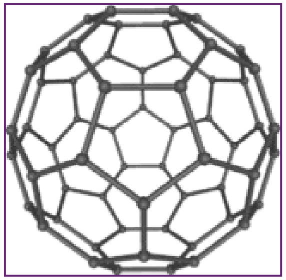
Nanotube

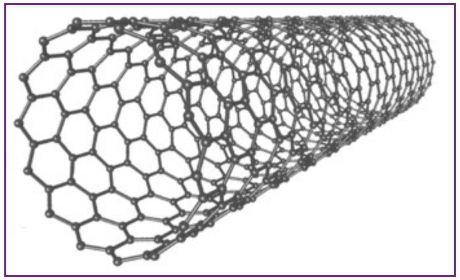
Coal

Allotropes of carbon have different covalent bonding arrangements.





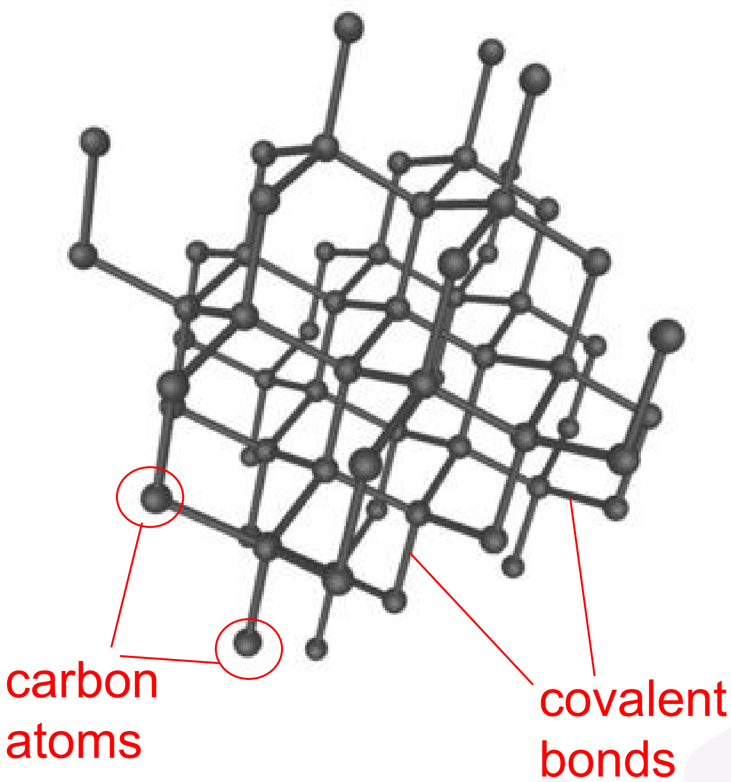




diamond **graphite** **buckyball** **nanotube**

- Carbon atoms form covalent bonds by sharing outer shell electrons with each other
- Diamond, graphite, buckyballs and carbon nanotubes all have different covalent arrangements of carbon atoms
- The differing covalent arrangements of carbon atoms lead to the different properties of carbon allotropes.

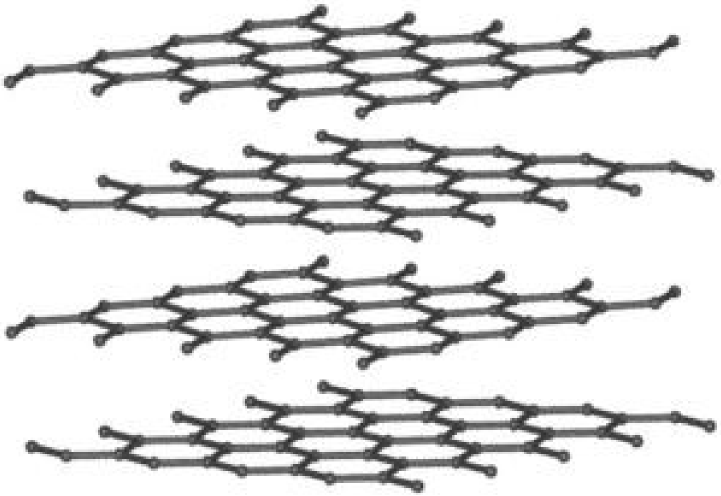
Covalent Bonds In Diamond



- Diamond is formed by a 3D box-like network of carbon atoms
- The continuous nature of the covalent arrangements forms

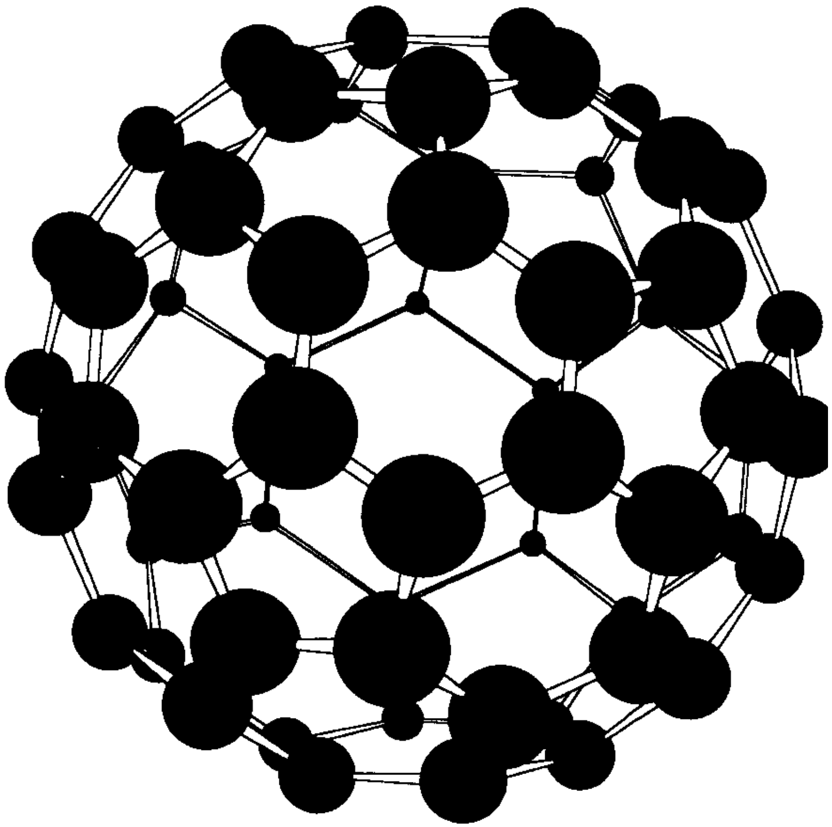
  a giant molecule
- Electrons are fixed.

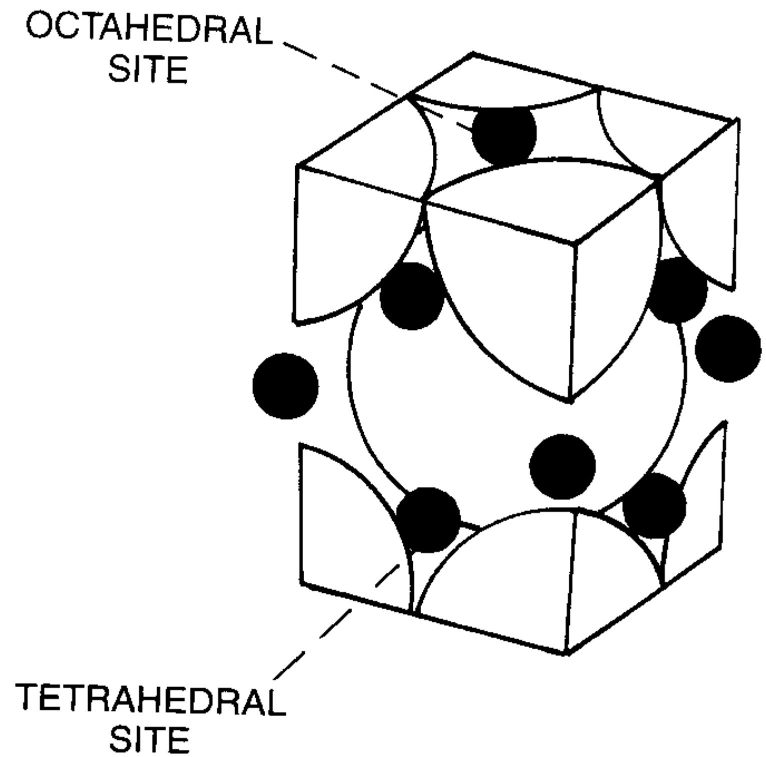
Covalent Bonds In Graphite



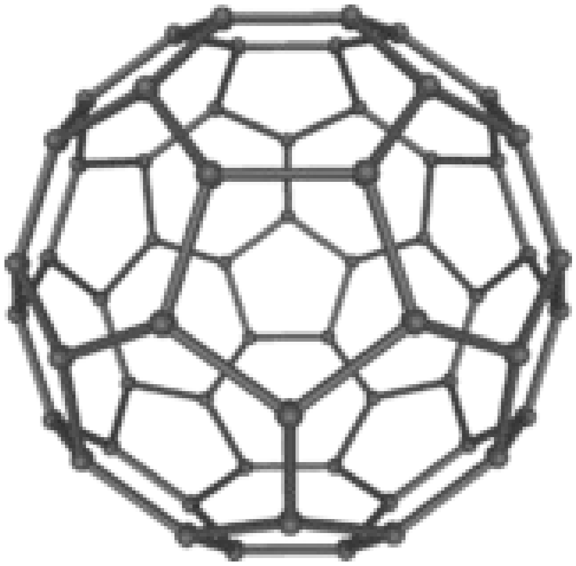
- Graphite is formed by hexagonally-arranged carbon molecules forming 2D layers of sheets
- Electrons are free to move between each carbon sheet.

Types of Carbon





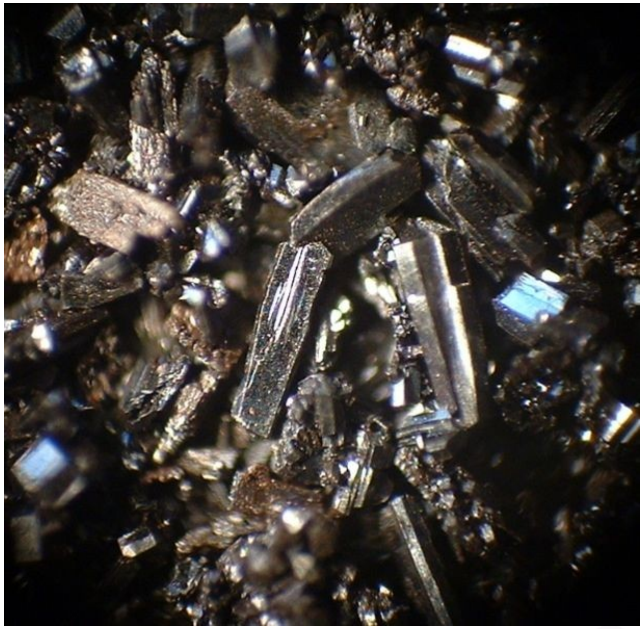
Covalent Bonds In Buckyballs



- Carbon atoms in buckyballs are arranged in a soccer ball shape
- C60 Buckyballs have 20 regular hexagon faces and 12 regular pentagon faces - these faces come together at 60 carbon atom vertices
- Electrons are localised internally due to the curvature of the structure.

Image: Mstroeck @ Wikipedia

A Bit More About Buckyballs



Buckyballs in crystalline form

- Buckyballs are also called fullerenes (after architect Richard Buckminster Fuller)
- Buckyballs were discovered in 1985 by Robert Curl, Harold Kroto and Richard Smalley
  - these scientists won the 1996 Nobel Prize in Chemistry for discovering this new allotrope of carbon.

Image: Wikipedia

Covalent Bonds In Carbon Nanotubes

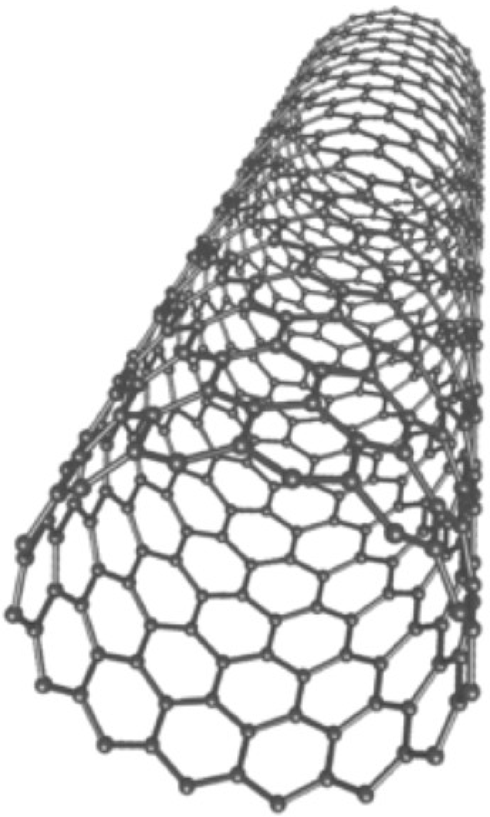


Image: Wikipedia

- Carbon nanotubes are formed by a layer of hexagonally-arranged carbon atoms rolled into a cylinder - usually have half buckyballs on one or both ends
- Electrons are localised internally, and some can move along the length of the tube by ballistic transport
- Carbon nanotube diameter ~ 1nm
- Carbon nanotube length can be a million times greater than its width
- Nanotubes can be
  - single-walled (d = 1-2 nm), or
  - multi-walled (d = 5-80 nm).

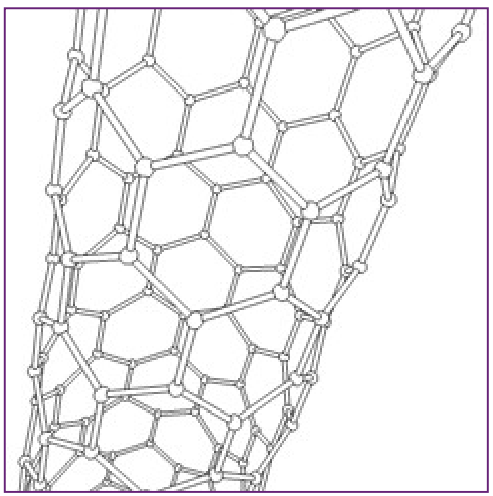
Properties of Carbon Allotropes

Allotrope	Hardness	Tensile strength	Conducts heat	Conducts electricity
Coal	+	+	+	no
Graphite	++	++	+++++	+++++
Diamond	+++++	Not known	+++	no
Buckyballs	+++++	++++	+	+
Carbon Nanotubes	++++++	+++++	+++++	++++++

Carbon Nanotubes

What is it?

- Carbon nanotubes, composed of interlocking carbon atoms, are 1000x thinner than an average human hair – but can be 200x stronger than steel.

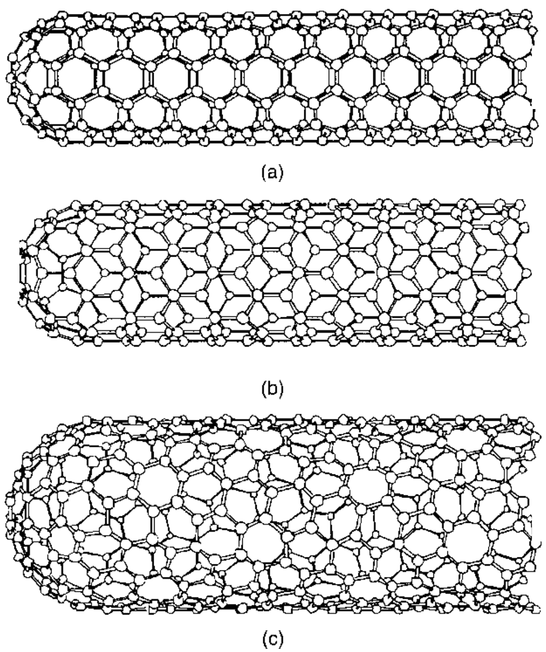


Carbon Nanotubes

What is it?

- Sheet of graphite rolled into a tube
- Single-Walled (SWNT) and Multi-Walled (MWNT)
- Large application potential, metallic, semiconducting

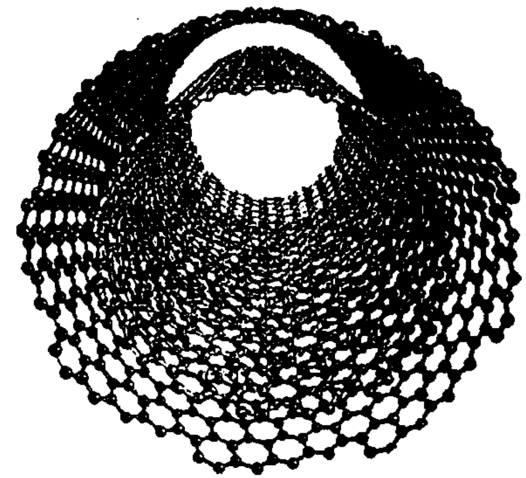
SWNT



armchair

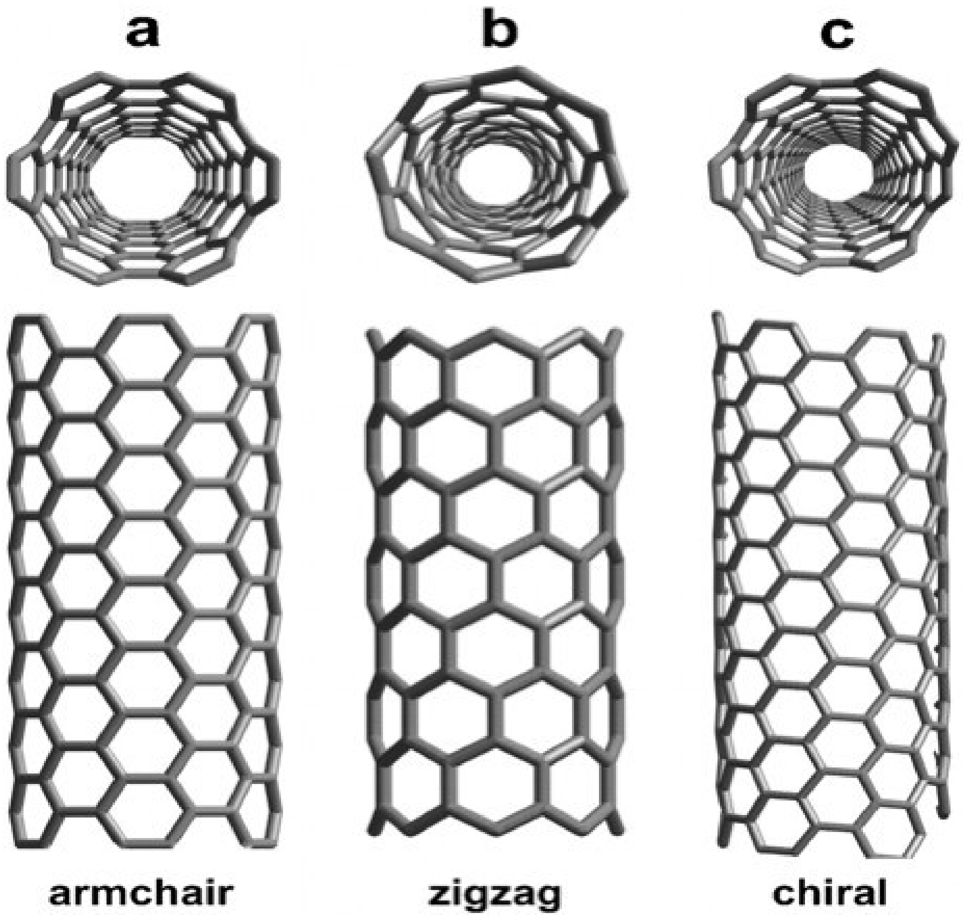
zigzag

chiral



MWNT

Covalent Bonding - Carbon



<u>Single-walled carbon nanotubes:</u>

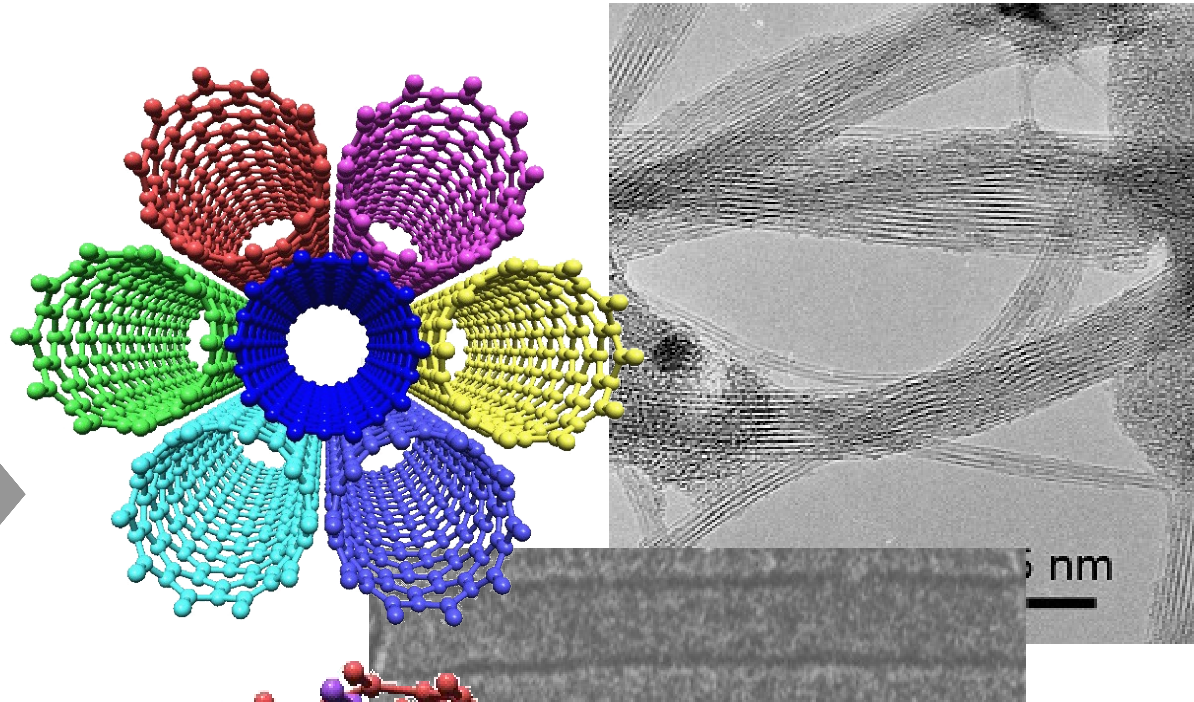
- armchair - metallic
- zigzag - semiconducting
- chiral - semiconducting

- multi-walled - metallic

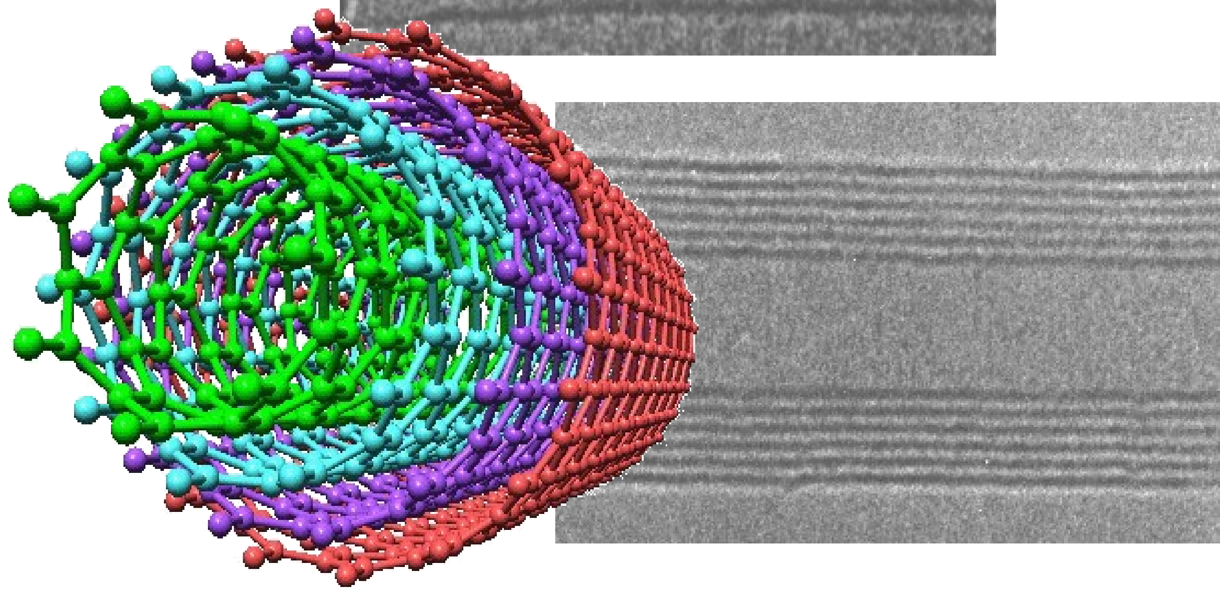
Types of Carbon nanotubes

Two main types of carbon nanotubes:

Single-walled nanotubes (SWNTs) consist of a single graphite sheet seamlessly wrapped into a cylindrical tube.



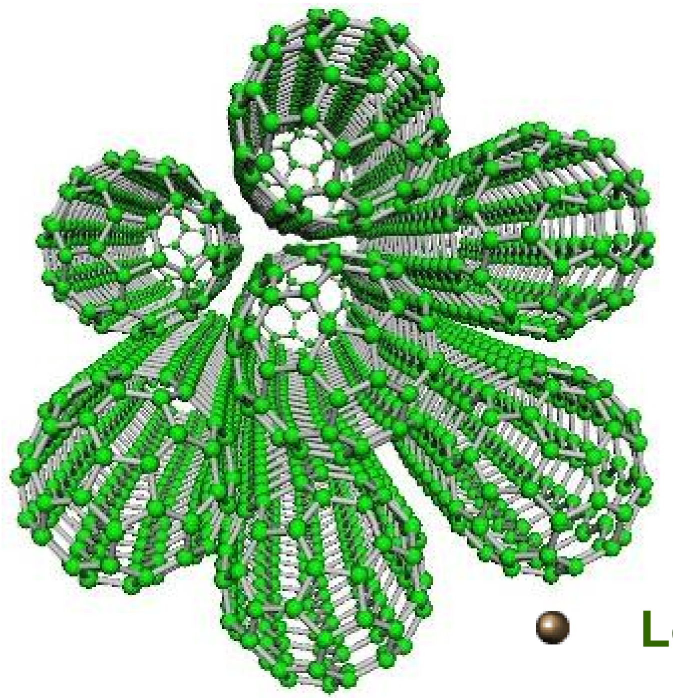
Multiwalled nanotubes (MWNTs) comprise an array of such nanotube (more than one wall) that are concentrically nested with in.



Unique Properties Of Carbon Nanotubes

- 200x stronger than steel of the same diameter
- The first synthetic material to have greater strength than spider silk
- Excellent conductors of electricity and heat
- Have huge potential for product development.

Why Carbon Nanotubes ?

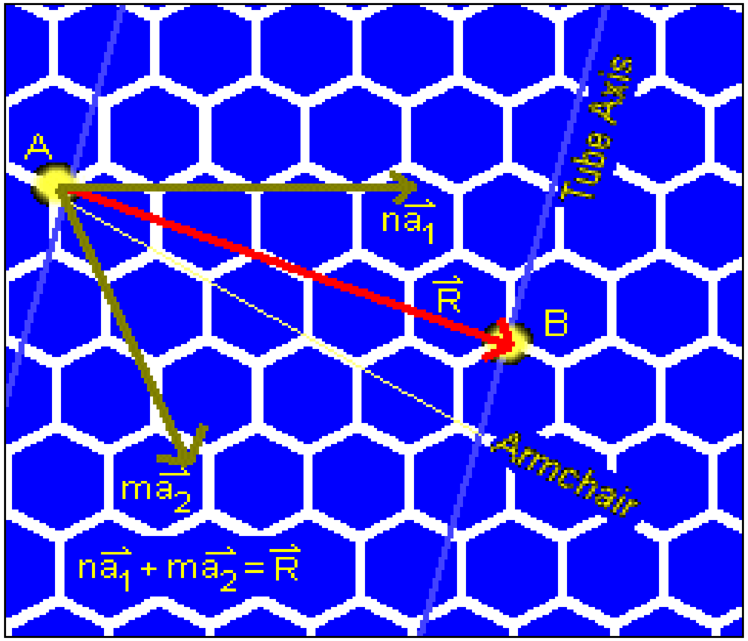


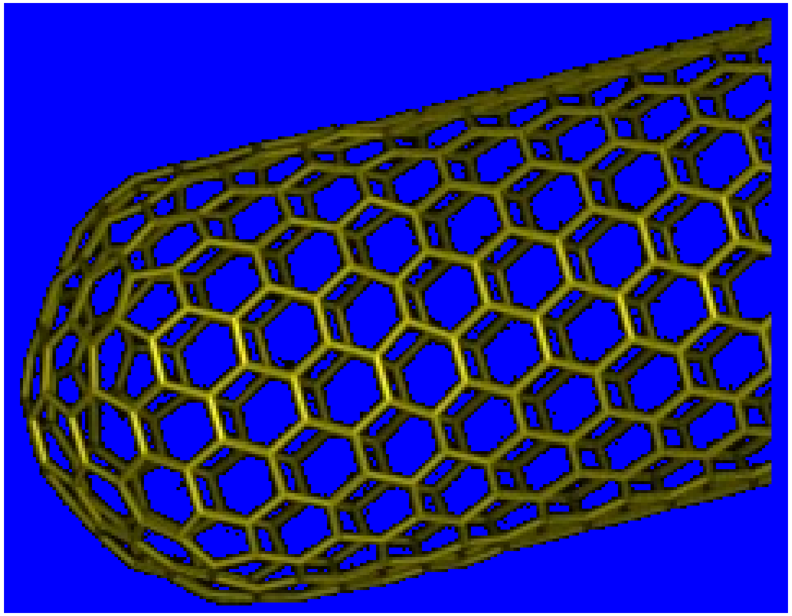
- **Small Dimensions**
- **Chemically Stable**
- **Mechanically Robust**
- **High Thermal Conductivity**
- **High Specific Surface Area (Good Adsorbents)**
- **Low Resistivity (Ballistic Electron Conduction)**

Ideal materials for applications in conductive and high-strength composites; energy storage and energy conversion devices; sensors; field emission displays and radiation sources; hydrogen storage media; and nanometer-sized semiconductor devices, probes, and interconnects.

Structure of Single Walled Carbon Nanotubes

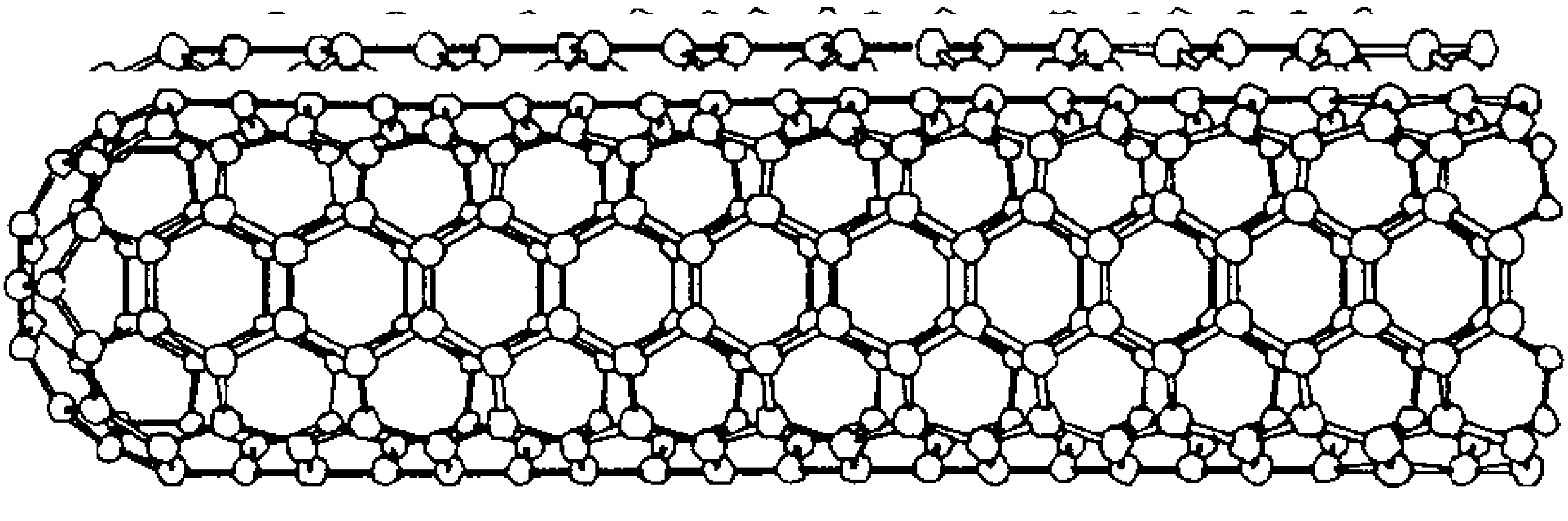
- Structure depends on rolling direction (chirality)
  - Metallic
  - Semi-conducting





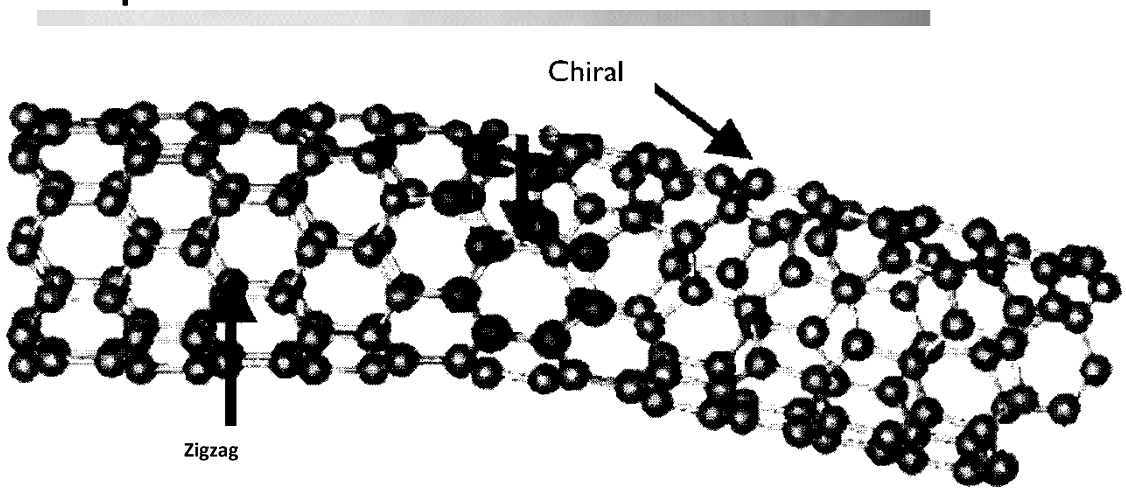
Three Forms of CNTs

- Chiral



Properties of Nanotubes

- Electrical Properties
  - Meta
  - Semi-
    - D
  - Rope
  - Comb
    - B
    - R



- Chirality and diameter of nanotubes are important parameters!!!

Properties of Nanotubes

- Mechanical Properties
  - Young's modulus E = 1.28 – 1.8TPa (steel 0.21TPa)
  - Strength R_m = 45,000 MPa (high strength steel 2,000 MPa)
  - Buckling – no fracture – change in hybridization (from *sp*^{2})

Molecular dynamics simulations of a (10,10) nanotube under axial tension (J. Bernholc, M. Buongiorno Nardelli and B. Yakobson). Plastic flow behavior is shown after 2.5 ns at T = 3,000 K and 3% strain. The blue area indicates the migration path (in the direction of the arrow) of the edge dislocation (green). This sort of behavior might help make composite materials that are really tough (as measured by their ability to absorb energy).

Filling of Nanotubes

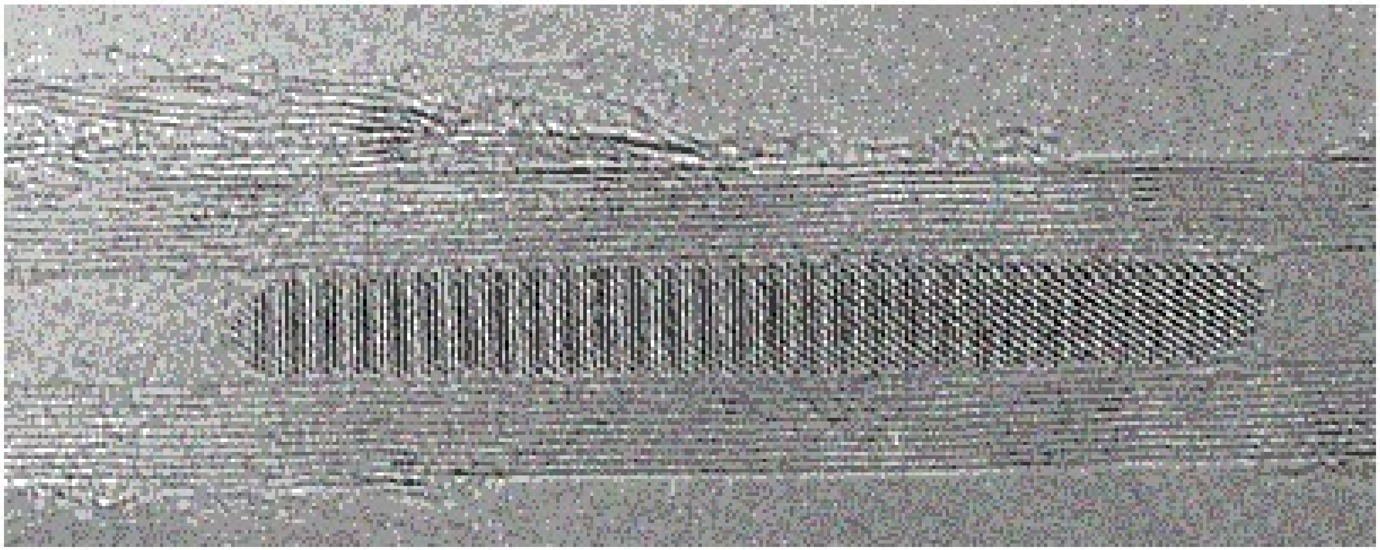
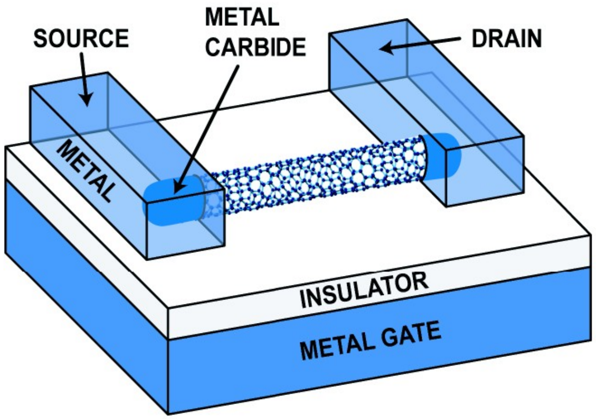


Figure 6.20. Transmission electron micrograph of a MWNT filled with Sm_2O_3. The interlayer separation in the MWNT is c.a. 0.34 nm. Lattice planes in the oxide are clearly seen. (From Ref. 55 by permission of The Royal Society of Chemistry.)

Application of Nanotubes

- Variety of Applications
  - Cost dependent
- Field Emission and Shielding
  - Flat panel displays TV and computer monitors)
  - High electrical conductive armchair SWNTs – shield magnetic fields (protection)
- Computers
  - Based on conductivity change (small V change can change conductivity 10^6 times – switch on of faster than current)
- Fuel Cells
  - Storage of charge carriers (Li, H)
- Chemical Sensors
  - Sensitivity of vibration modes to the presence of other molecules (Raman)
- Catalysts
  - hydrogenation
- Mechanical Reinforcement
  - 5% (vol) increases strength of Al by factor 2

CNTs in Electronic Devices



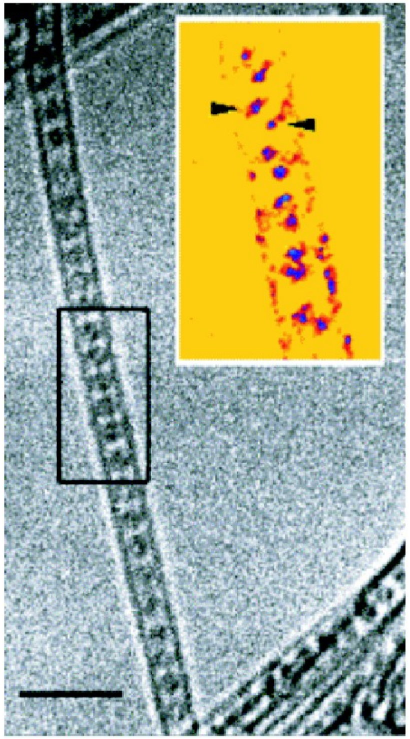
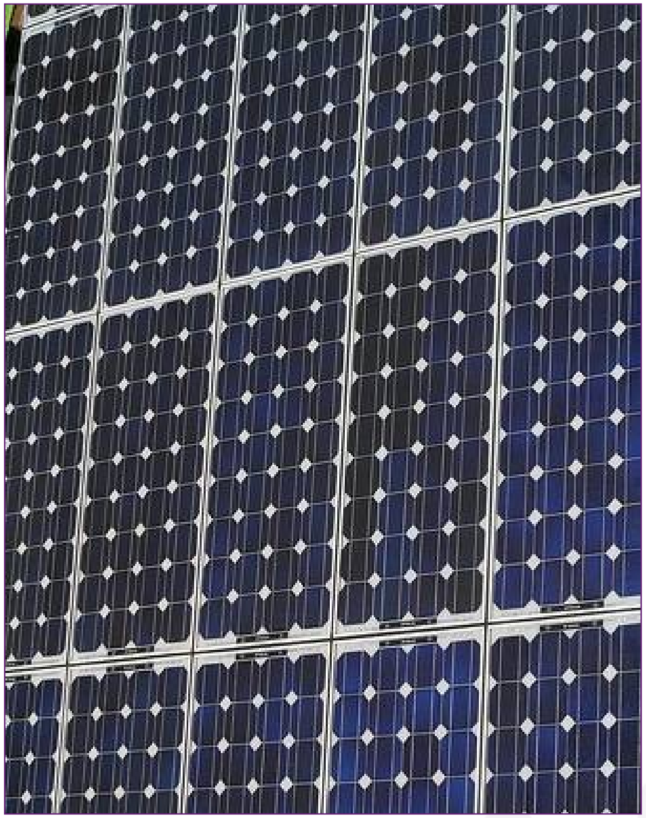


Figure 5.16. Nanoscale electronic device connected with a nanotube (left). (Reproduced with kind permission of Ph. Avouris.) $La_2@C_{80}$ trapped inside a single walled carbon nanotube. a.k.a PEAPODS (right). (Reproduced with kind permission of D. E. Luzzi.)

Nanotubes In Efficient Solar Cells



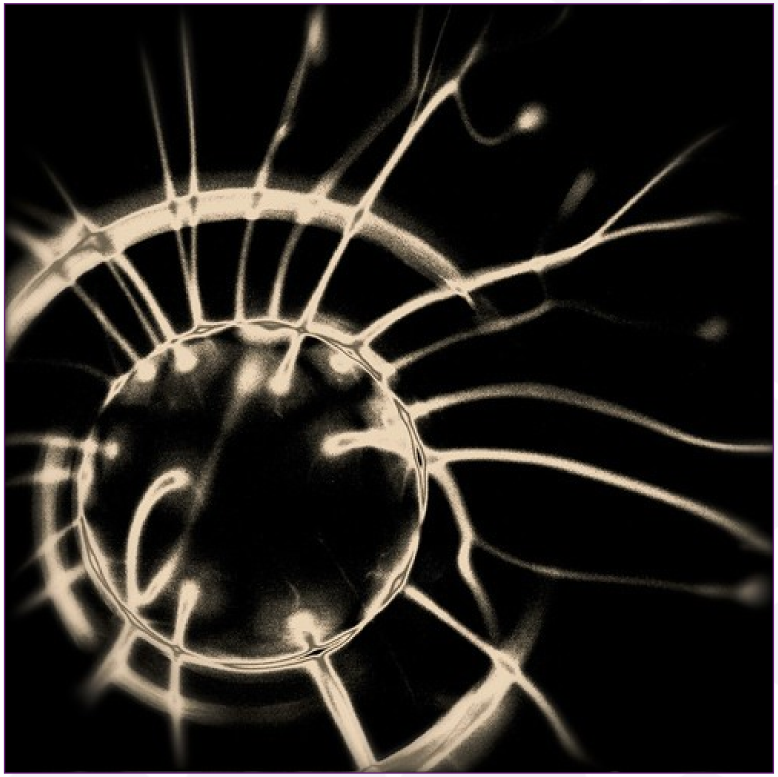
- Scientists have developed the ‘blackest black’ colour using carbon nanotubes
- The carbon nanotubes are arranged like blades of grass in a lawn
  - they absorb nearly all light
- Use of carbon nanotubes in solar cells could vastly improve their efficiency.

Nanotubes In Sporting Equipment

- Badminton racquet manufacturer Yonex incorporates carbon nanotubes into their cup stack carbon nanotubes racquets (www.yonex.com)
- American baseball bat manufacturer Easton Sports has formed an alliance with a nanotechnology company Zyvex to develop baseball bats incorporating carbon nanotubes
- Tennis racquets also incorporate carbon nanotubes (www.babolat.com).

Nanotubes In Miniaturised Electronics

- Branching and switching of signals at electronic junctions is similar to what happens in nerves
- A carbon nanotube 'neural tree' can be trained to perform complex switching and computing functions
- Could be used to detect/respond to electronic, acoustic, chemical or thermal signals.

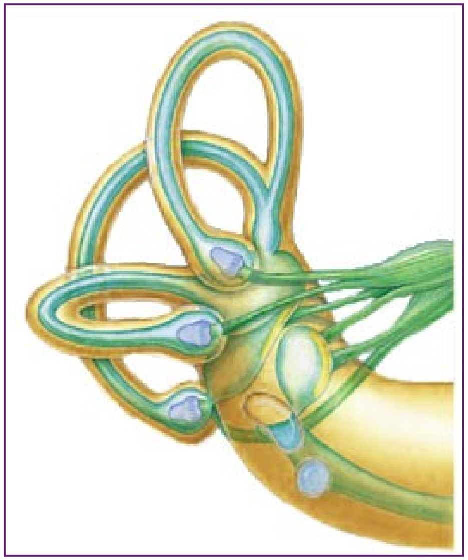


Nanotubes In AV Technology

- Carbon nanotubes are being used to develop flat screen televisions with higher resolution than the human eye can detect
- Your next TV screen could be thin, ultra-light and foldable…

Graphene Sheets

A new form of carbon with many potential uses.



- Professor Gordon Wallace and his team at the University of Wollongong have been studying this new form of carbon just one atom thick

  “The very unusual electronic properties of graphene sheets means they could be used in solar cells or new battery technology,” he says

  “Because of the biological affinity of carbon, they might also be useful as electrodes for a range of medical bionic devices such as cochlear implants”
- Graphene sheets could also be used to create transparent electrodes and coatings that prevent the build up of static electricity.

Manufacturing Carbon Nanotubes

Molecular Engineering

- Carbon nanotubes can be made using molecular engineering
- Molecular templates are created
  - under the right chemical conditions carbon atoms arrange themselves into nanotubes on the template
- This process is also known as **chemical synthesis** or **self-assembly**, and is an example of the **'bottom-up'** approach to molecular engineering.

Molecular Engineering

2 Approaches

- '**Bottom-up**' approach: structures are built atom by atom
  - can use self-assembly or sophisticated tools (eg scanning tunnelling microscope, atomic force microscope) which can pick up, slide or drag atoms or molecules around to build simple nanostructures

- '**Top-down**' approach: traditional engineering techniques such as machining and etching are used at very small scales
  - products tend to be refinements of existing products, such as electronic chips with more and more components crammed onto them.

Image: kikisdad@flickr.com