NANO TECHNOLOGY

Topics

- Introduction
- Terms and Terminologies
- Fabrication
- Properties and Applications
- Organic Nano Tubes
- Inorganic Nano Tubes
- Applications

Introduction

ORIGIN

The term ‘nanotechnology’ is derived from the Greek word ‘nanos’ or ‘dwarf’.

In fiction

"The Next Tenants" Arthur C. Clarke (1957)

- describes tiny machines that operate on a microscale(millionth of a meter)

In the short story **"How It Was when the Past Went Away" (Robert Silverberg's**1969)

- describes nanotechnology being used in the construction of stereo loudspeakers, with a thousand speakers per inch

In Literature

- Excerpt from Letter of Benjamin Franklin to William Brownrigg (*Nov. 7, 1773)*

- *...At length being at Clapham, where there is, on the Common, a large Pond ... I fetched out a Cruet of Oil, and dropt a little of it on the Water. I saw it spread itself with surprising Swiftness upon the Surface ... the Oil tho' not more than a Tea Spoonful ... which spread amazingly, and extended itself gradually till it reached the Lee Side, making all that Quarter of the Pond, perhaps half an Acre, as smooth as a Looking Glass....*

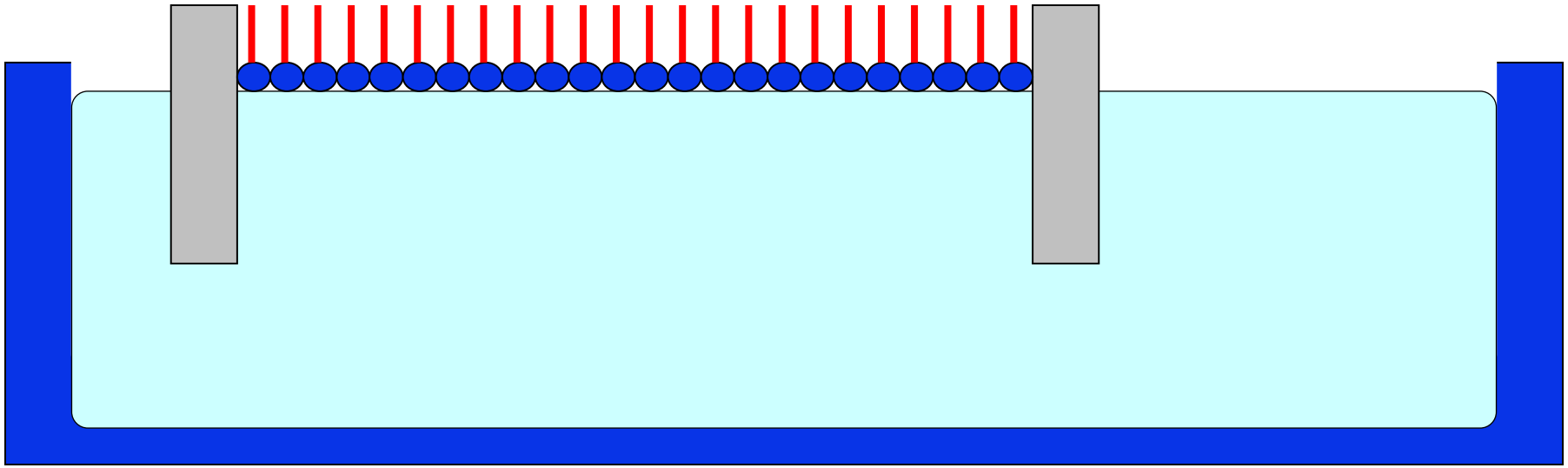
How thick was the film of oil?

Volume = (Area)(Thickness)

$V = A\,t$

thickness is around 1 nanometer

Langmuir monolayer Adsorption



~1 nm thick

Common Nano Terms and Terminologies

- **Nano scale** - at the 1-100 nm scale
- **Nanostructure** - an object that has nano scale features
- **Nano science** - the behavior and properties of nanostructures
- **Nanotechnology** - the techniques for making and characterizing nanostructures and putting them to use
- **Nano manufacturing** - methods for producing nanostructures in reliable and commercially viable ways

Importance of Nano Technology

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Nano Scale

- One nanometer (nm) is one billionth of a meter ie 10^{-9} m

- 1 µm = one millionth of a meter

1 nm = one billionth of a meter

≈ 1/50,000 thickness of a hair!

(ie human hair is 50,000 nm thick)

≈ a string of 3 atoms

- To put that scale in another context, the comparative size of a meter to nano meter is same as that of earth to a glass marble

Why Nano Scale is important???

Reasons

- Matter behaves differently at micro scale and nano scale. Hence any change in nano scale influences the property at micro scale too (i.e. brings about a corresponding change at micro scale)

- In human body dysfunction (such as Alzheimer's disease) is caused due to the malfunctioning of tiny cells (nano scale)
- As the size of the particle decreases,

The surface area increases. This has tremendous effect on chemical reactivity

This explains that in any system , may it be living / non living , nano scale has tremendous effect on the properties and functions

How Do We See nano particles????

Can light microscope be used???????

Helpful, but cannot resolve below 1000 nm

How about electron microscope?????

Has a long history of usefulness at the nanoscale

A scanning probe microscope will be the best choice (SEM and TEM)

Nano Structure

- Nano-sized particles (means zero dimension particles) exhibit drastically different or superior properties
- Nano Structures are fabricated with nano particles for example nano batteries are 200 nm in diameter and can store sufficient energy

Nano Science

- The study of nano materials is called nano science
- It gives an idea about the characteristics of nano materials . They are
  - Smaller
  - Lighter
  - Stronger
  - Faster
  - More Durable

Do properties Change at nano level? Why?

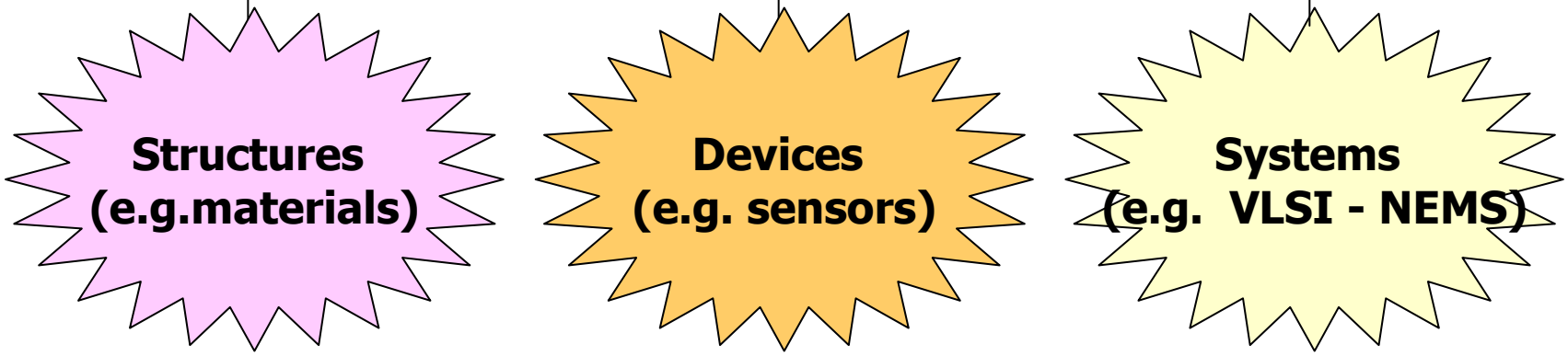
Definitely Yes

For example Gold is **red** in colour at nano scale and **yellow** in colour at micro and macro scale

Different **thicknesses** of materials reflect and absorb light differently

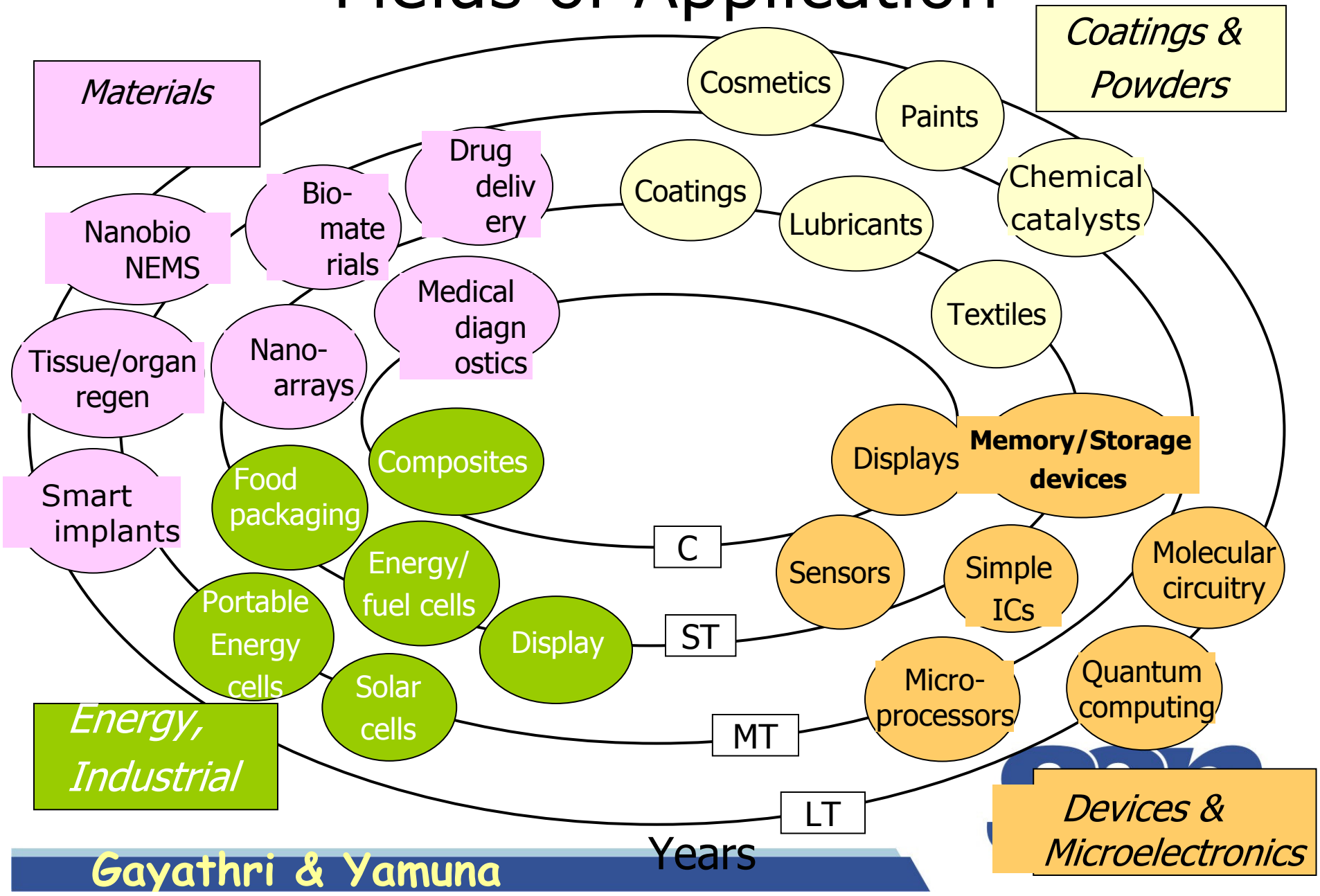
What Is Nano Technology

Nanotechnology is the manipulation of matter at the nanometer scale to create novel structures, devices and systems.



VLSI- Very Large Scale Integration
NEMS- Nano Electro Mechanical System

Fields of Application

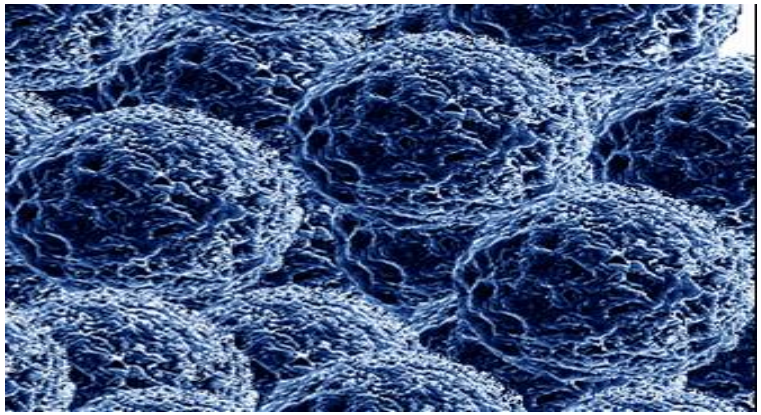


Types Of Nano Materials

- **Nano particles**

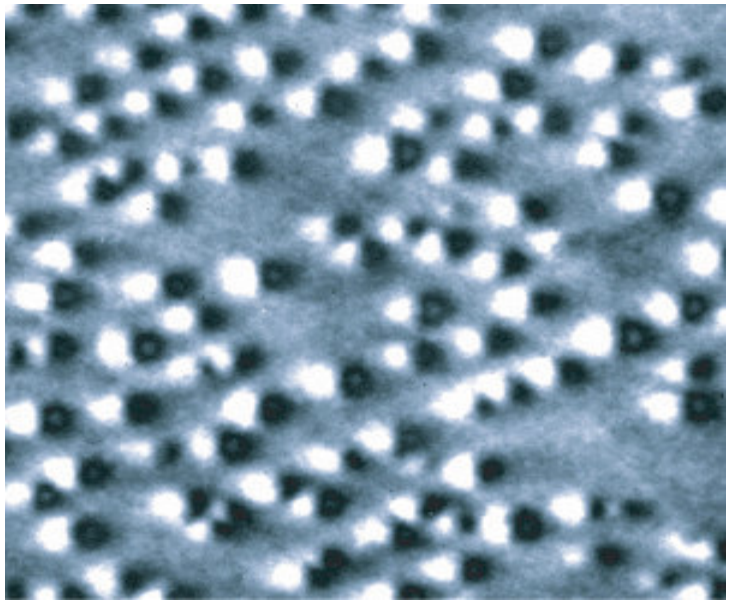
Tiny particles consisting of a single element / compound

Contain properties different from bulk material from which they were derived



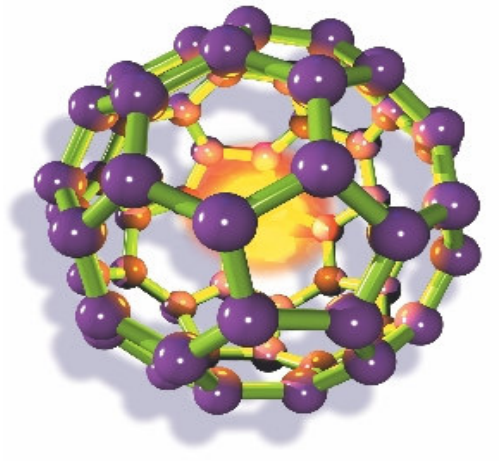
SEM picture of Ag Nano particles

- **Quantum Dots**
  - Nano sized crystals
  - Emit light after light is incident on them

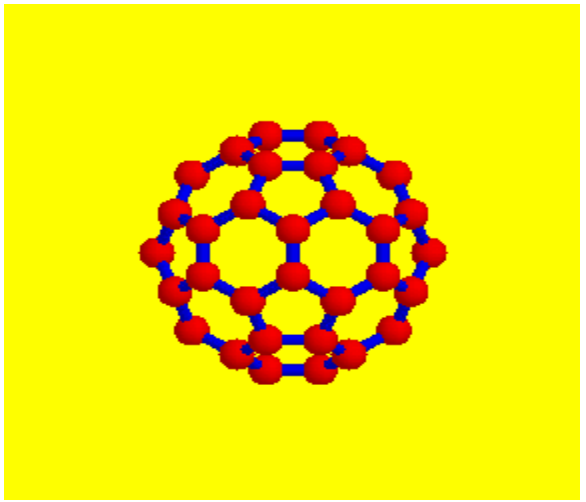


Micrograph of pyramid-shaped quantum dots grown from indium, gallium, and arsenic.
Each dot is about 20 nanometers wide and 8 nanometers in height

- **Buckyballs (Buckminster Fullerenes)**
  - Molecules containing carbon atoms bound together in a hollow sphere
  - Can enter cells as they pass easily through the blood stream

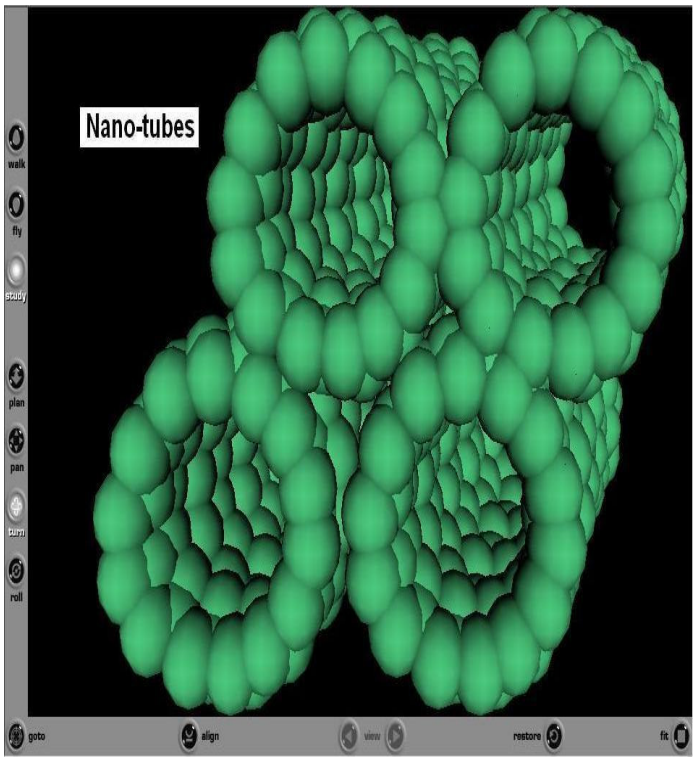


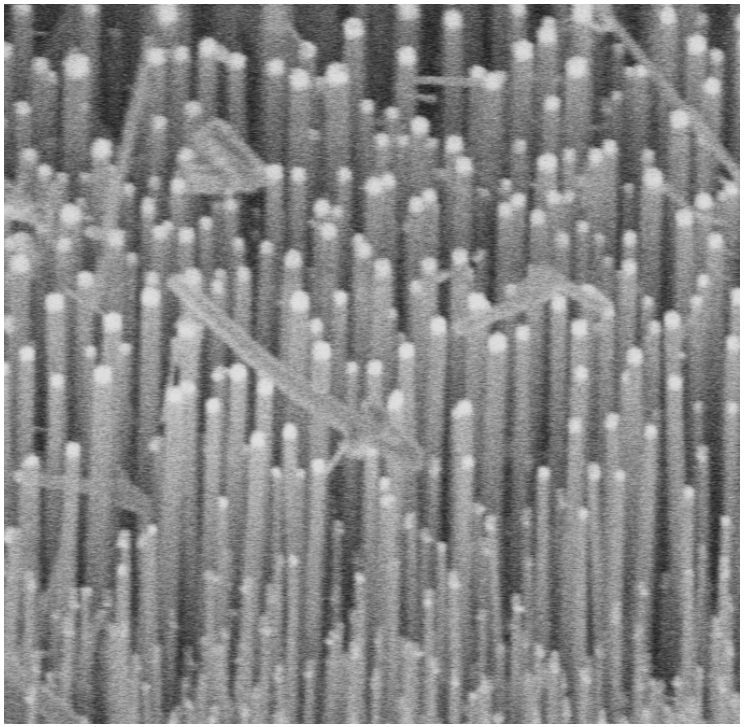
C60



C70

Nano Tubes


Nano-tubes
walk
fly
study
plan
pan
roll
goto
align
view
restore
fit



Nano Fabrication / Manufacturing

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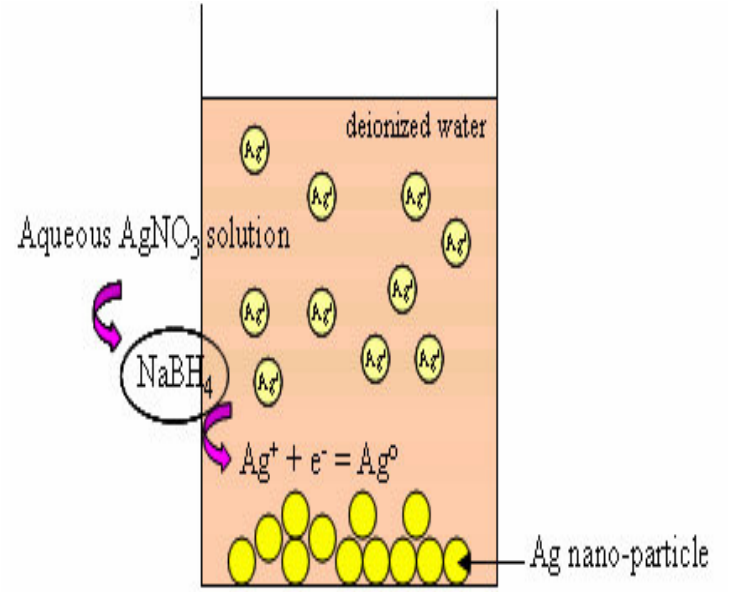
Nanofabrication can generally be divided into two categories based on the approach

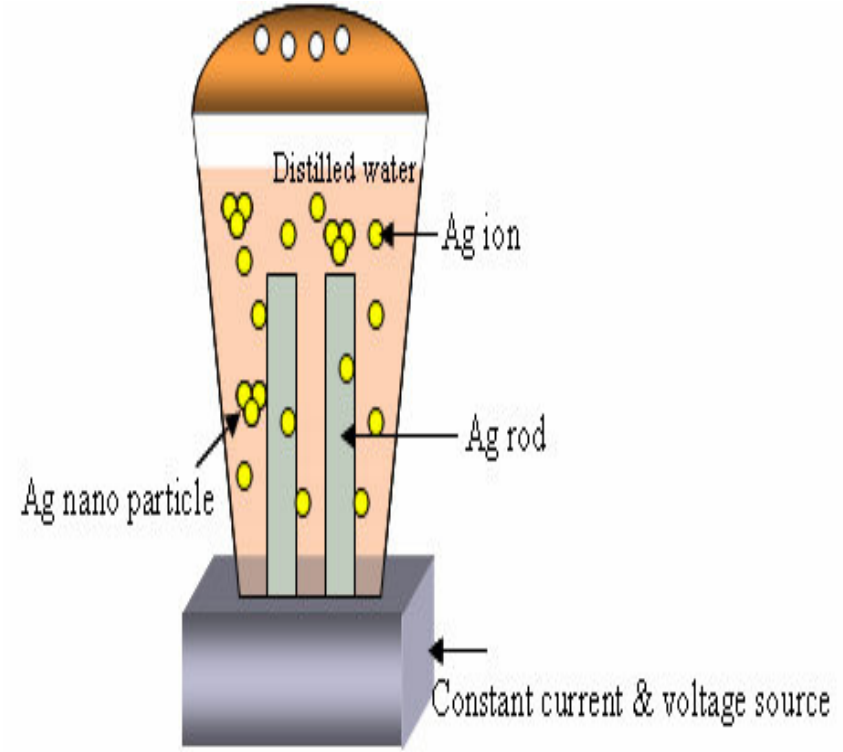
- Bottom up approach seek to arrange smaller components into more complex assemblies
- Use of manufacturing processes such as milling or grinding to produce nano sized particles

- Top down approach seek to create smaller devices by using larger ones to direct their assembly
- During this approach matter is manipulated deliberately by certain chemical and/or physical processes to create materials with specific properties that are not displayed in their larger forms
- This is effected by certain chemical and/or physical processes (PVD, CVD, Etching etc.,)

Manufacture of nano powder

Ag powder by Top Down approach





Organic Nano tubes

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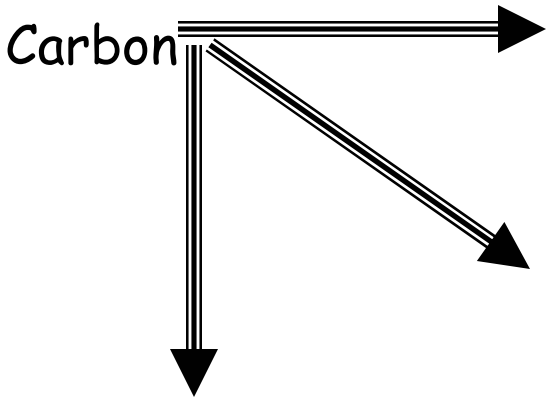
Allotropes of carbon



Graphite (Ambient conditions)
sp^2 hybridization: planar

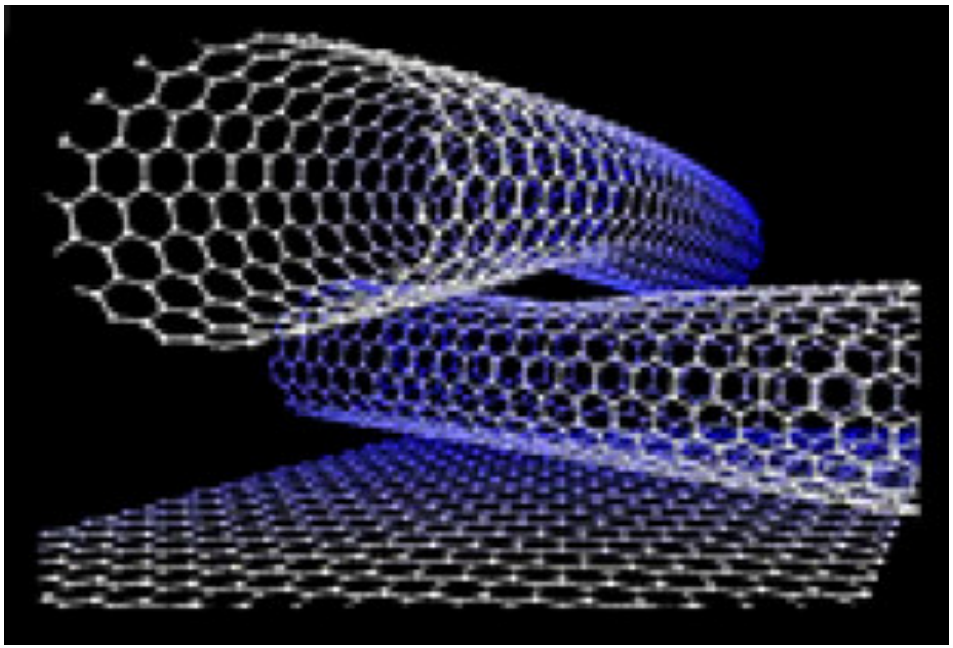
Diamond (High temperature and pressure)
sp^3 hybridization: cubic

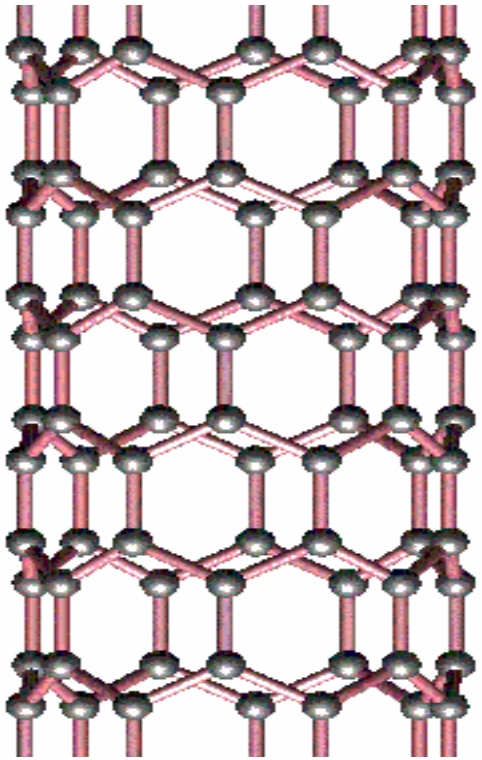
Nanotube/Fullerene (certain growth conditions)
sp^2 + sp^3 character: cylindrical

Finite size of graphene layer has dangling bonds. These dangling bonds correspond to high energy states.

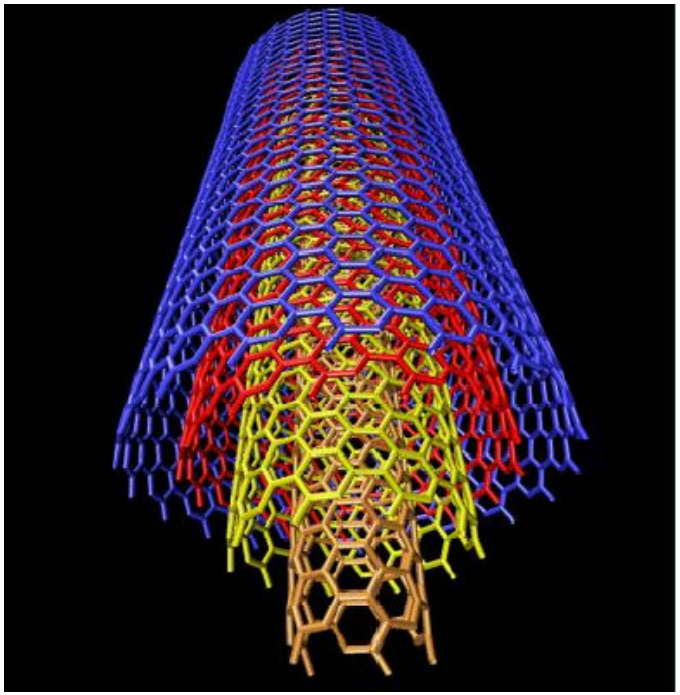
Nanotube formation ⇄ Eliminates dangling bonds + Increases Strain Energy → Total Energy ↓

Carbon Nano Tubes (CNT)





SWNT composed of a single cylinder of carbon



MWNT consisting of concentric tubes or cylinders of carbon (effectively straws within straws).

Nanotubes, minuscule cylinders of carbon atoms just a few nanometers across, are lightweight and stronger than steel, and they can conduct electricity. Sheets of nanotubes can now be easily manufactured.

Manufacture of CNTs

Carbon nanotubes can be manufactured using a variety of methods:

1. **Laser ablation** (furnace) uses a high-power laser to vaporise a graphite (sublimation point above 3,500°C) source loaded with a metal catalyst.

The carbon in the graphite reforms as predominantly single-wall nanotubes on the metal catalyst particles.

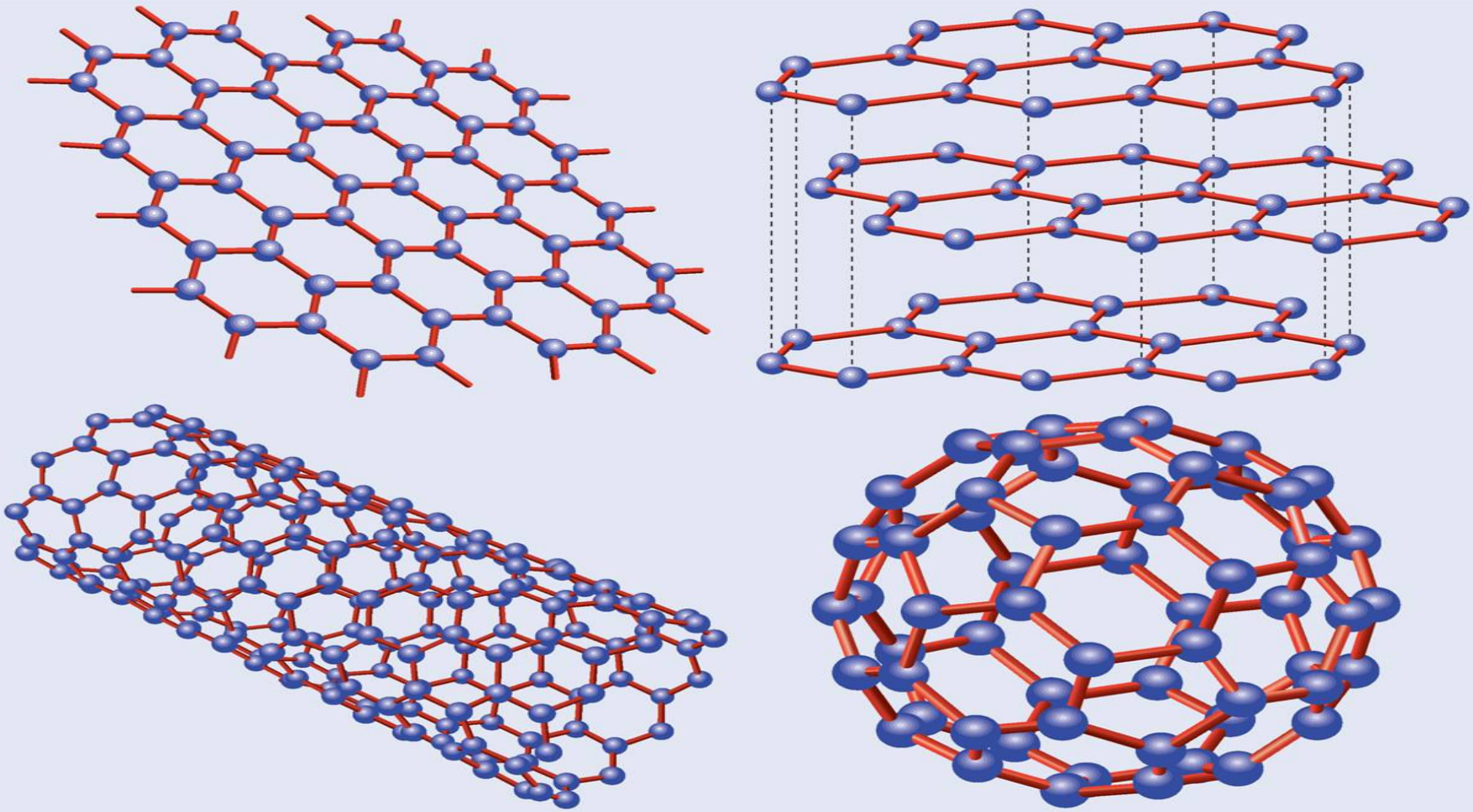
2. Arc discharge method involves an electrical discharge from a carbon-based electrode in a suitable atmosphere to produce both single and multi-wall tubes of high quality but in low quantities

3. Chemical vapour deposition (CVD) is where a hydrocarbon feedstock is reacted with a suitable metal-based catalyst in a hot furnace to 'grow' nanotubes which are subsequently removed from the substrate and catalyst by a simple acid wash.

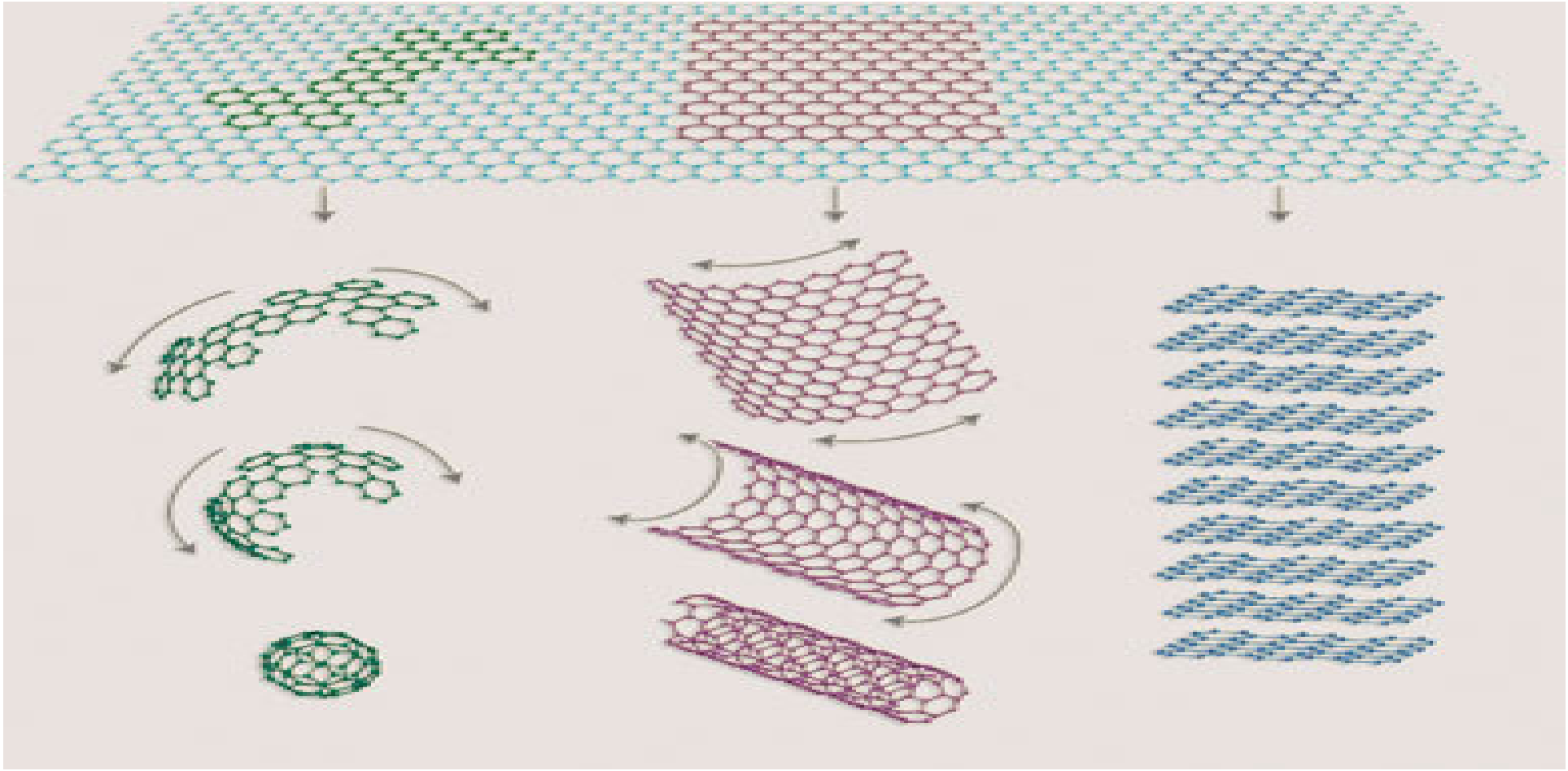
Steps involved in CNT fabrication

- Graphite sublimes and during condensation graphene is formed
- Graphene sheets spirals to a "Bucky ball" (1 nm)
- Graphene Rolls forming SWCNTs and /or MWNT
- SWNT – three different types
- MWNT – Two different types

2 Graphene: mother of them all



Graphene (top left) consists of a 2D hexagonal lattice of carbon atoms. Each atom is covalently bonded to three others; but since carbon has four valence electrons, one is left free – allowing graphene to conduct electricity. Other well-known forms of carbon all derive from graphene: graphite is a stack of graphene layers (top right); carbon nanotubes are rolled-up cylinders of graphene (bottom left); and a buckminsterfullerene (C_{60}) molecule consists of graphene balled into a sphere by introducing some pentagons as well as hexagons into the lattice (bottom right).

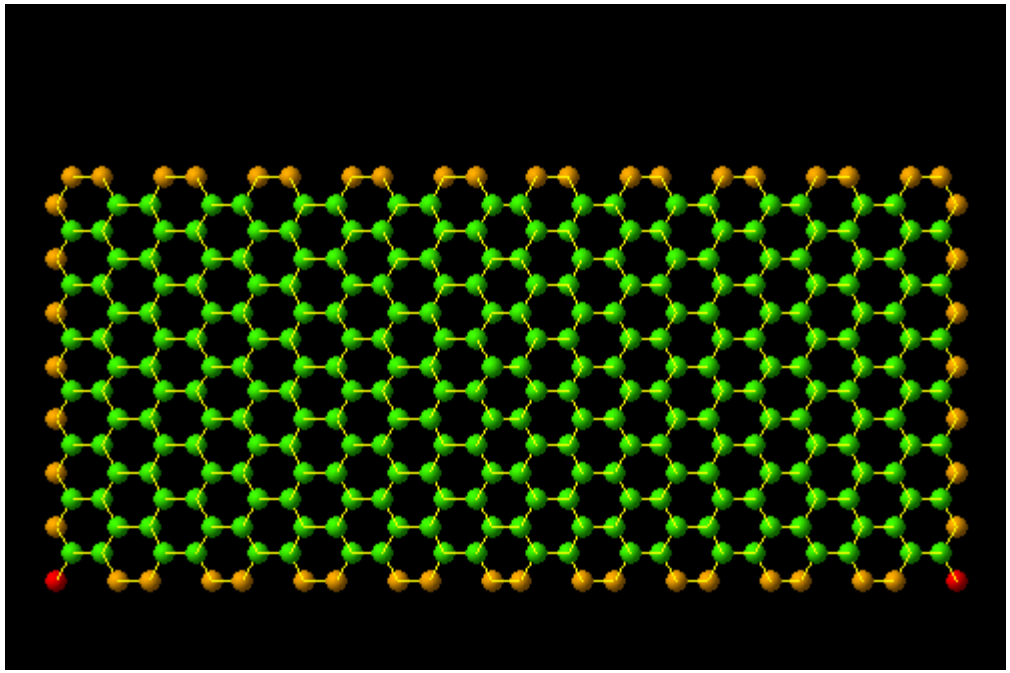


Bucky ball

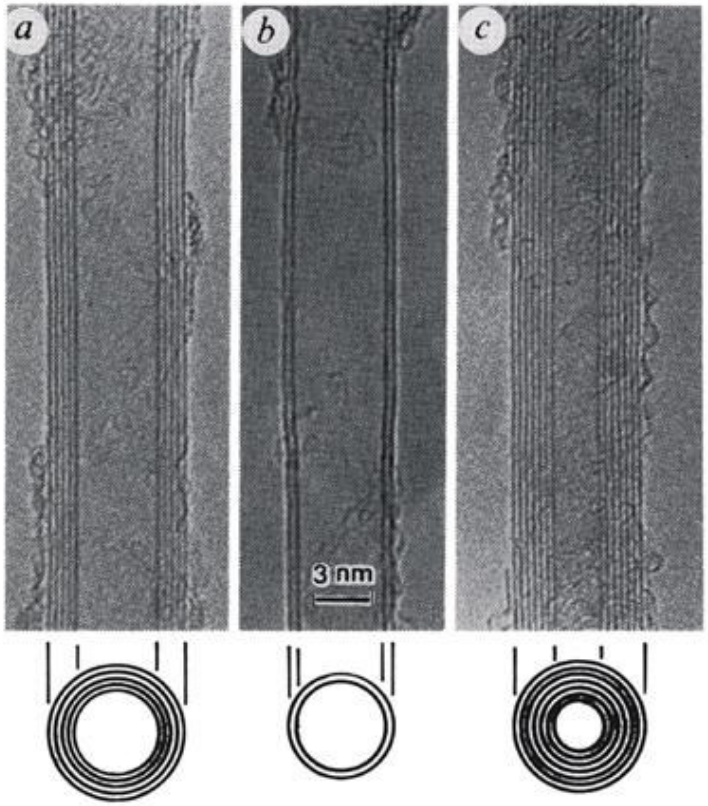
Formation of SWNT

MWNT

Two types of Carbon Nanotubes

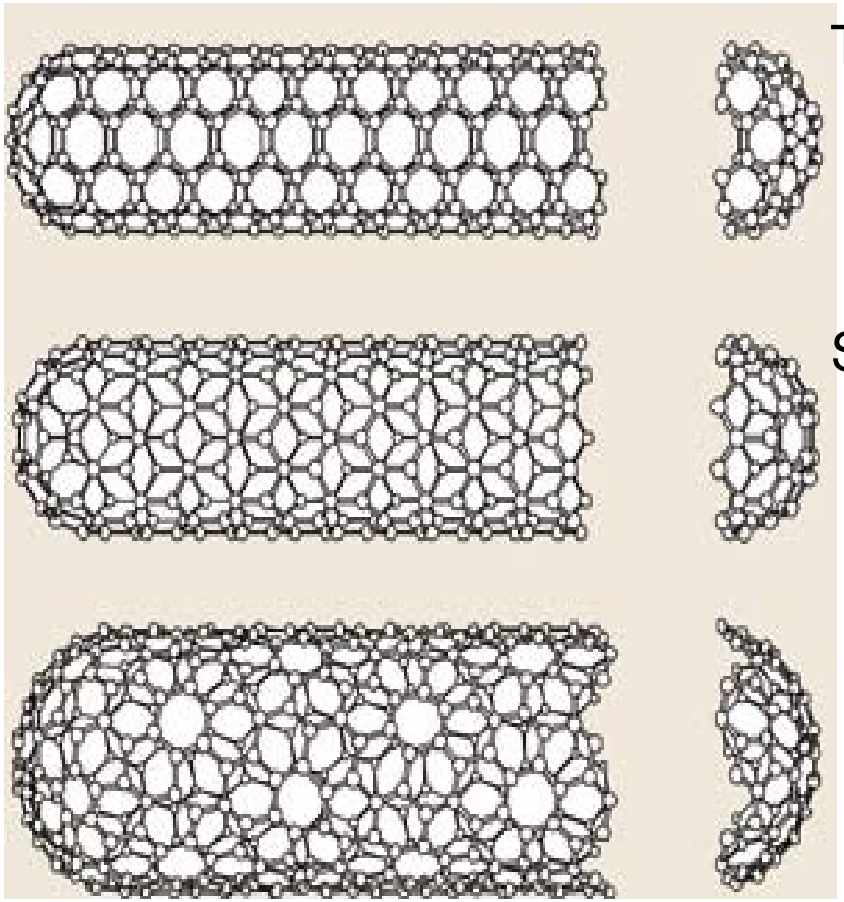


Animation shows formation of different conformations of Single-Walled CNT



Multi-Walled CNT

Conformations of SWNTs



Top To Bottom → Arm Chair

Side To Side → ZigZag

Corner To Corner → Chiral (spiral)

- Practically every manufacturer currently uses catalytic chemical vapour deposition (CVD) to make their tubes

- This involves growing the CNTs by passing a carbon-based gas, such as methane or ethylene, over Fe/ Ni / Co catalyst at 550 – 750 ^{o}C (adsorption principle)

- The CNTs are recovered by washing with dilute mineral acid

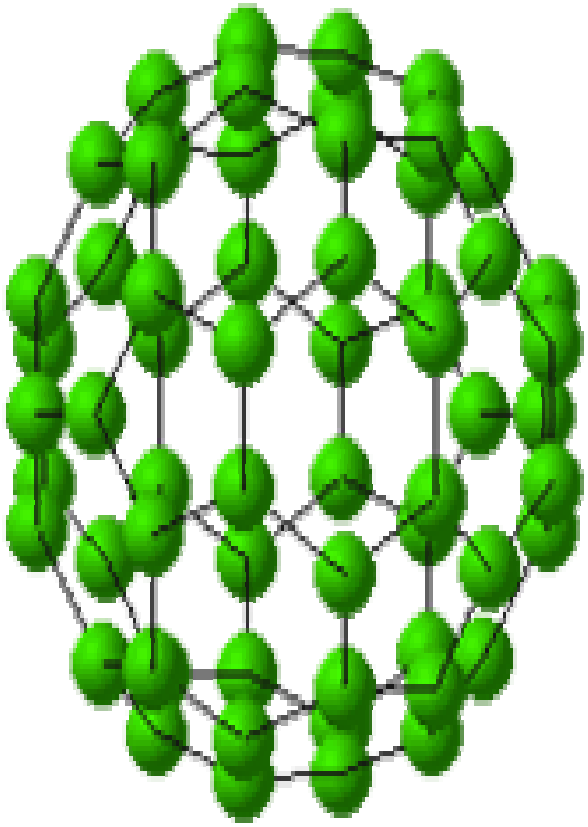
- MWNT are easily produced by this method

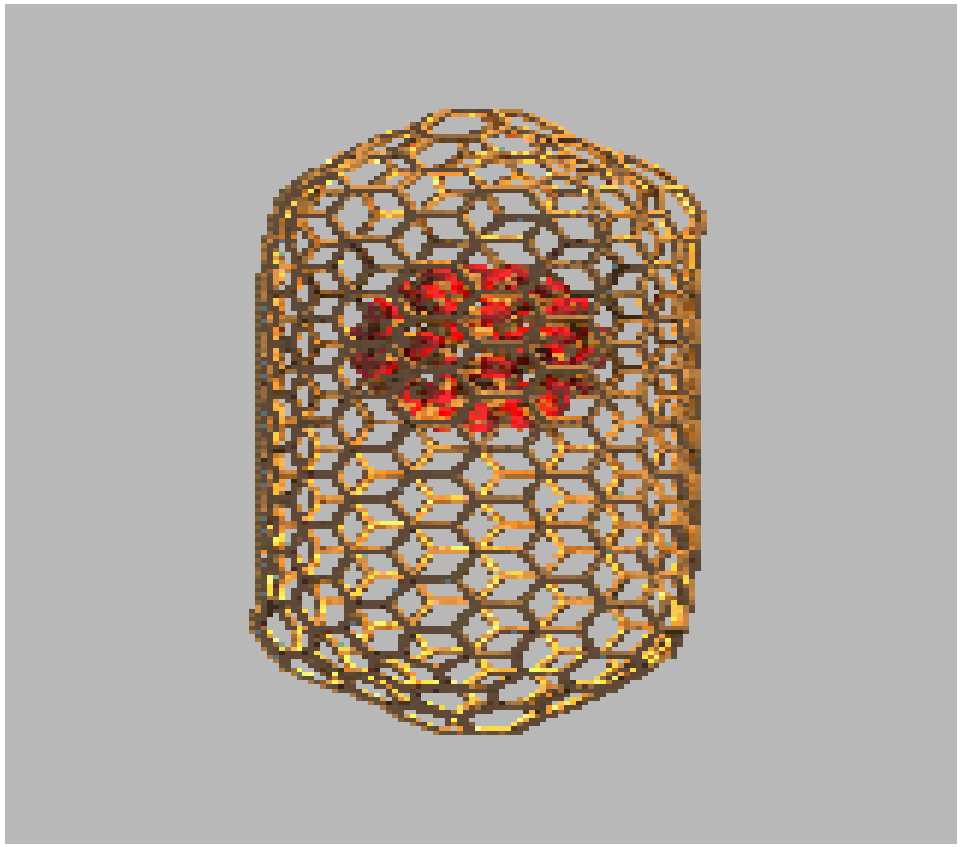
SWNT

- Most single-walled nanotubes (SWNT) have a diameter of close to 1 nanometer, with a tube length that can be many thousands of times longer

- The structure of a SWNT can be visualised by wrapping a one graphene into a seamless cylinder

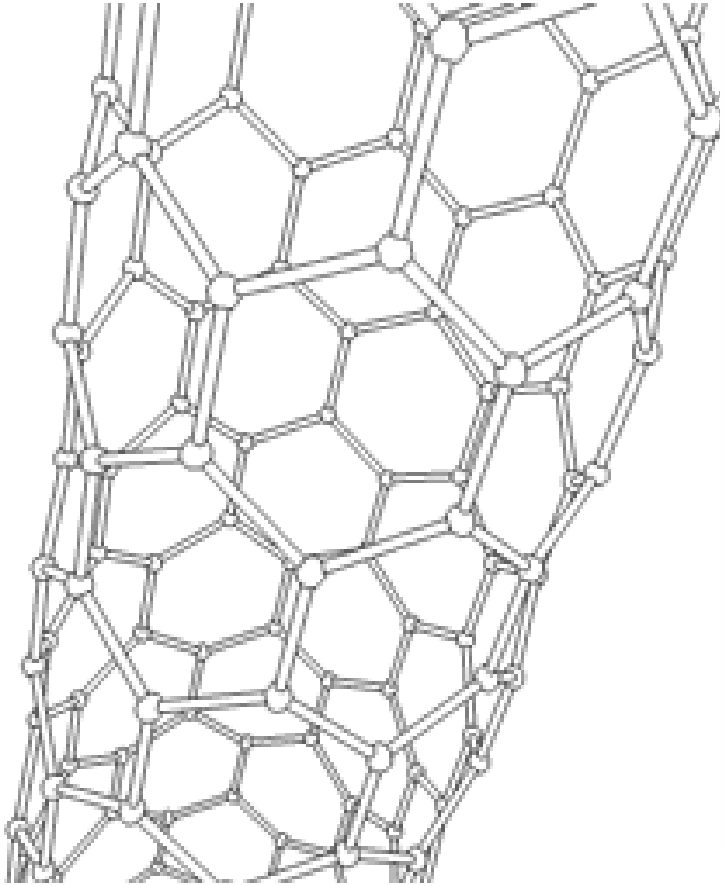
SWNT – from bucky ball

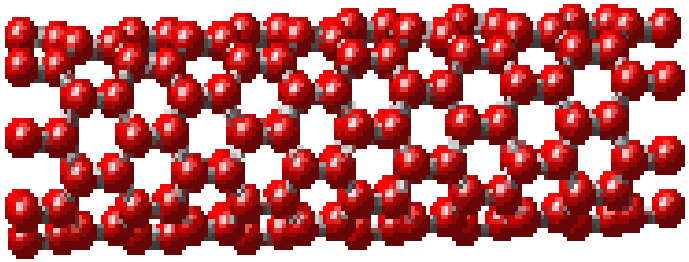




Animation shows formation of CNTvia bucky ball

This animation of a rotating SWNT shows its 3D structure and the channel in the SWNT





Single-walled nanotubes are a very important variety of carbon nanotube because they exhibit important electric properties due to their various conformations, that are not shared by the multi-walled carbon nanotube (MWNT)

In other words SWNT are superior to MWNTs

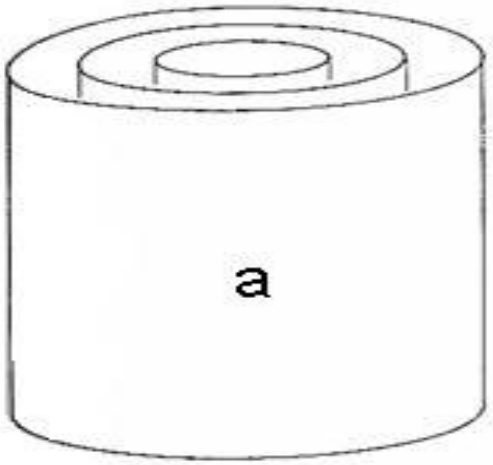
MWNT

- Multi-walled nanotubes (MWNT) consist of multiple layers of graphene rolled in on themselves to form a tube shape

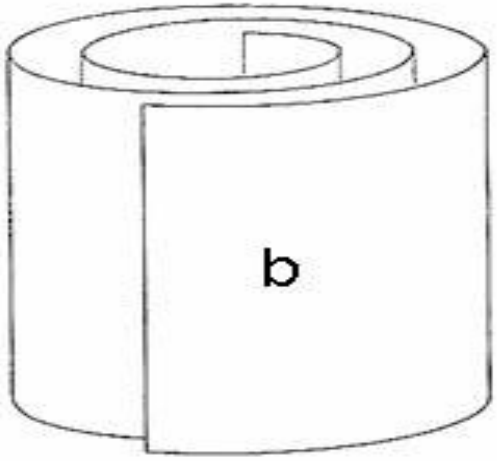
- The interlayer distance in multi-walled nanotubes is close to the distance between graphene layers in graphite, approximately 3.3 Å

- There are two models which can be used to describe the structures of multi-walled nanotubes

Russian doll model

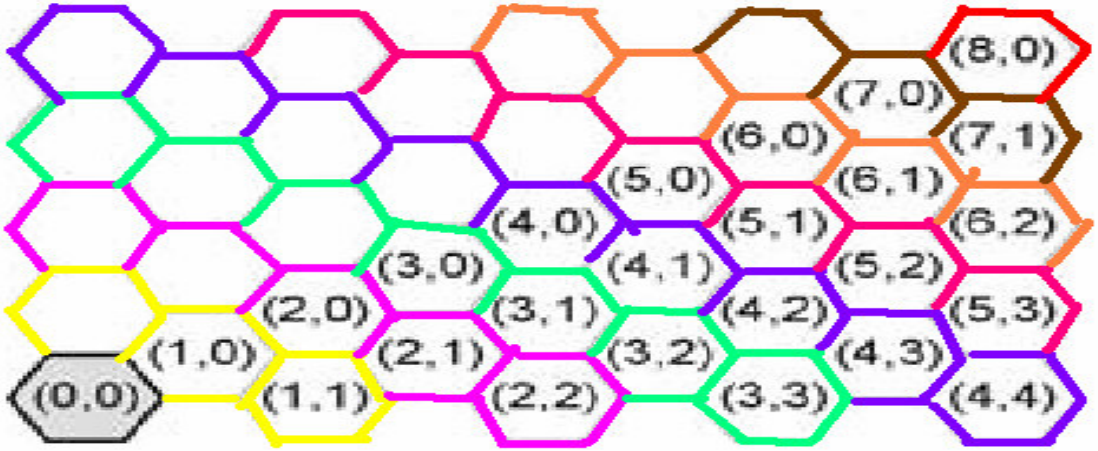


Parchment Or Swiss Roll model



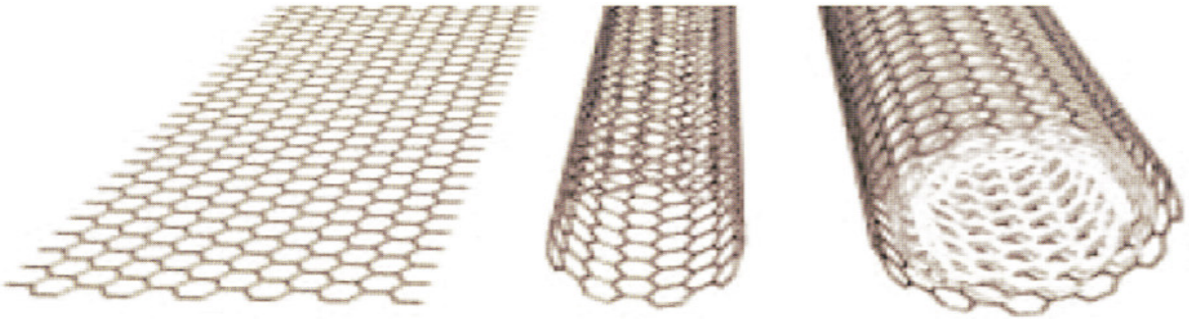
Russian Doll Model of Rolling

In this model , sheets of graphite are arranged in concentric cylinders



Parchment Model

In this model single sheet of graphite is rolled in around itself, resembling a scroll of parchment or a rolled up newspaper



(a) (b) (c)

Source: Kreupl *et al.* (2002)

Properties Of CNTs

- Carbon nano tubes are cylindrical structures usually less than 30 nanometers in diameter and several microns long

- Their aspect ratio (length-to-diameter ratio) is in millions (10,000,000 To 40,000,000)

- **CNTs are hydrophobic**

- The chemical bonding of nanotubes is composed entirely of sp^2 bonds (similar to graphite)

- Nanotubes naturally align themselves into "ropes" held together by Van der Waals forces (this too like graphite)

- No other element in the periodic table bonds to itself in an extended network with the strength of the carbon-carbon bond

Hence they exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat

- Out of the two types of CNTs , SWCNTs are endowed with exceptionally high electrical and thermal conductivity, strength, stiffness, and toughness

- It is interesting to note that various types of CNTs resemble in their thermal property but differ in their electrical properties

Conductivity

- CNTs conductivity has been shown to be a function of their conformation (degree of twist), as well as their diameter
- Their conductivity is six times more and current density is 1000times greater than that of Cu
- Their conductance lies between metallic and semi-conducting materials
- SWNTs are better conductors than MWNTs

Thermal conductivity and Expansion

CNTs may be the best heat-conducting material man has ever known

Ultra-small SWNTs have even been shown to exhibit superconductivity below 20°K

They exhibit almost zero in-plane thermal expansion but large inter-plane expansion

Strength and Elasticity

SWNTs are stiffer than steel (6 folds greater) and are very resistant to damage from physical forces (ie excellent wear resistant)

This property makes CNTs very useful as probe tips for high-resolution scanning probe microscopes

Applications Of CNTs

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CNT in sports and Space

- SWNTs have the highest Young's modulus (about 1 TPa) if normalized to their diameter and, therefore, all types of CNTs have attracted much interest for low weight structural composites
- It is used to manufacture stronger and lighter tennis rackets, bike parts, golf balls, golf clubs, golf shaft and baseball bats

- It is used as space elevator

CNT in Electrical devices

- The high aspect ratio also makes CNTs ideal **f**ield-**e**mission material (FE is the emission of electrons from a solid under an intense electric field)
- Si or W tips were initially used.
- CNTs have an advantage over Si or W tips in that their strong, they are physically inert to sputtering, chemically inert to poisoning, and can carry a huge current density of 10^9 A/cm^2 before electro migration

CNTs in Batteries and Storage devices

- CNTs are used as an alternative to tungsten filaments in incandescent lamps
- The low resistance of CNT compared to activated carbon, greatly increase its power density
- Carbon nano fibers are presently being used to increase the conductivity of porous carbon electrodes and thus improve their power density

- Due to its high Conductivity it finds application as "quantum wires" and as electrode in fuel cell (instead of Pt electrode)

- The large surface area and tubular structure of CNTs suggest that capillarity effects are important. Thus, CNTs is useful for the storage of hydrogen, a key aspect of the clean energy economy

CNT in Electronics

- Films of carbon nanotubes are used to replace indium tin oxide (ITO) in LCDs, touch screens, and photovoltaic devices

- Nanotube films are also used in displays for computers, cell phones, PDAs, and ATMs

CNT in Smart Garments

- CNTs are used in the manufacture of Water proof and Tear resistant clothes

- It also used to manufacture Combat Jackets , worn by special patients for continuous monitoring

CNT as Structural Material

- It is mixed with concrete to increase the tensile strength, and halt crack propagation in huge structures

- Carbon nanotubes are used to replace steel in suspension bridges

- CNTs are used in commercial electric motor brushes

- It is used to fabricate nano gears and nano bearings used in nano machines

CNT in Pollution Abatement

- Nanotube membranes are used for filtering carbon dioxide from power plant emissions
- It is used to remove salts from water (possibly desalination purpose in future)
- It is also used to fill radio active substance before disposing under sea

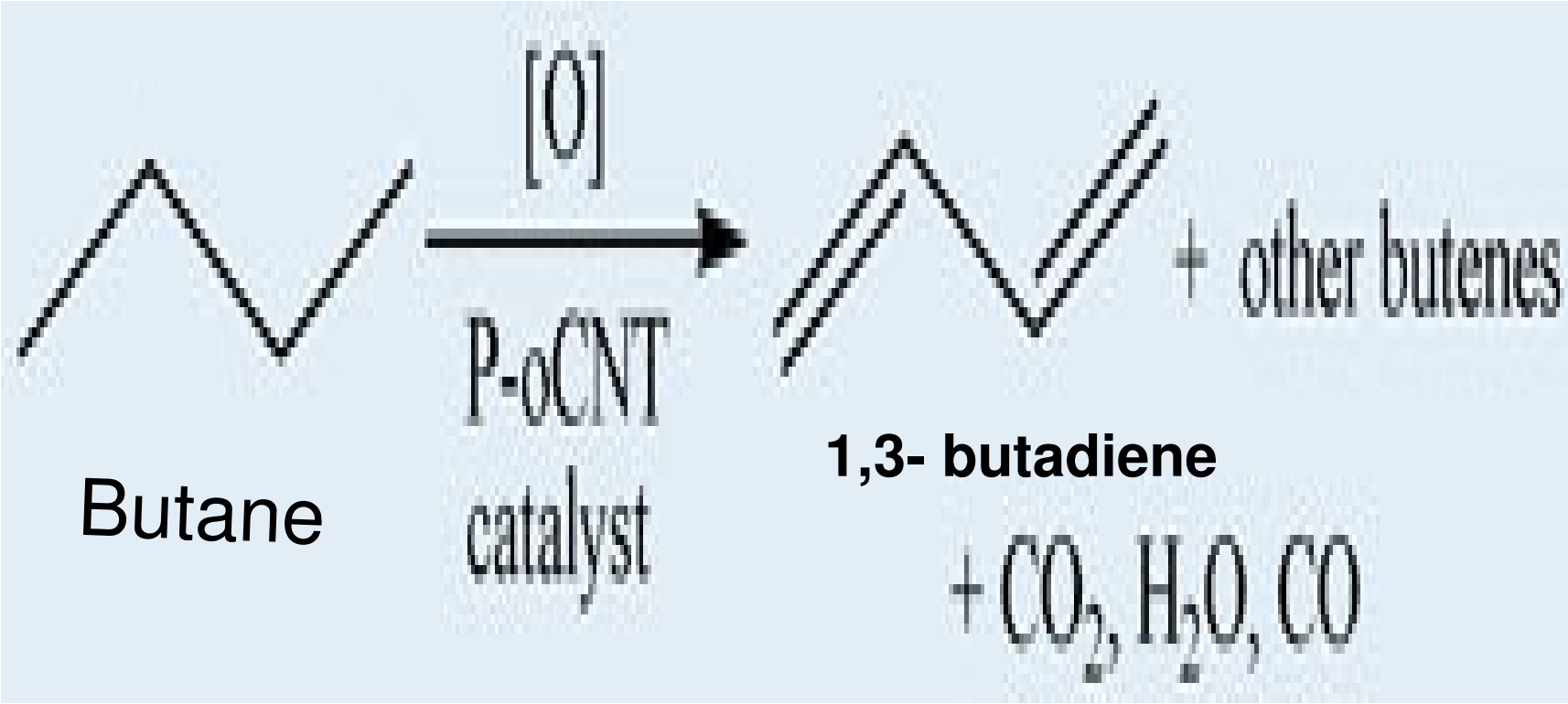
CNTs in Medical Field

- Of late CNTs are used as Biosensors and Biomedical implants due to its biocompatibility
- Soluble nano tubes are used in drug delivery systems
- Functionalized carbon nanotubes have been used to deliver proteins, nucleic acids, drugs, antibodies and other therapeutics

CNTs as catalyst/ CNT in Chemical Industry
Role of CNT in catalysis

- Industry currently uses transition metal oxide catalysts (such as V_2O_5 / MgO) to produce butadiene and other alkenes from butane

- By oxidising the surface of carbon nanotubes and adding a dash of phosphorous, stable catalyst was created that could effectively strip hydrogen from butane gas more selectively, and under milder reaction conditions, than the above method

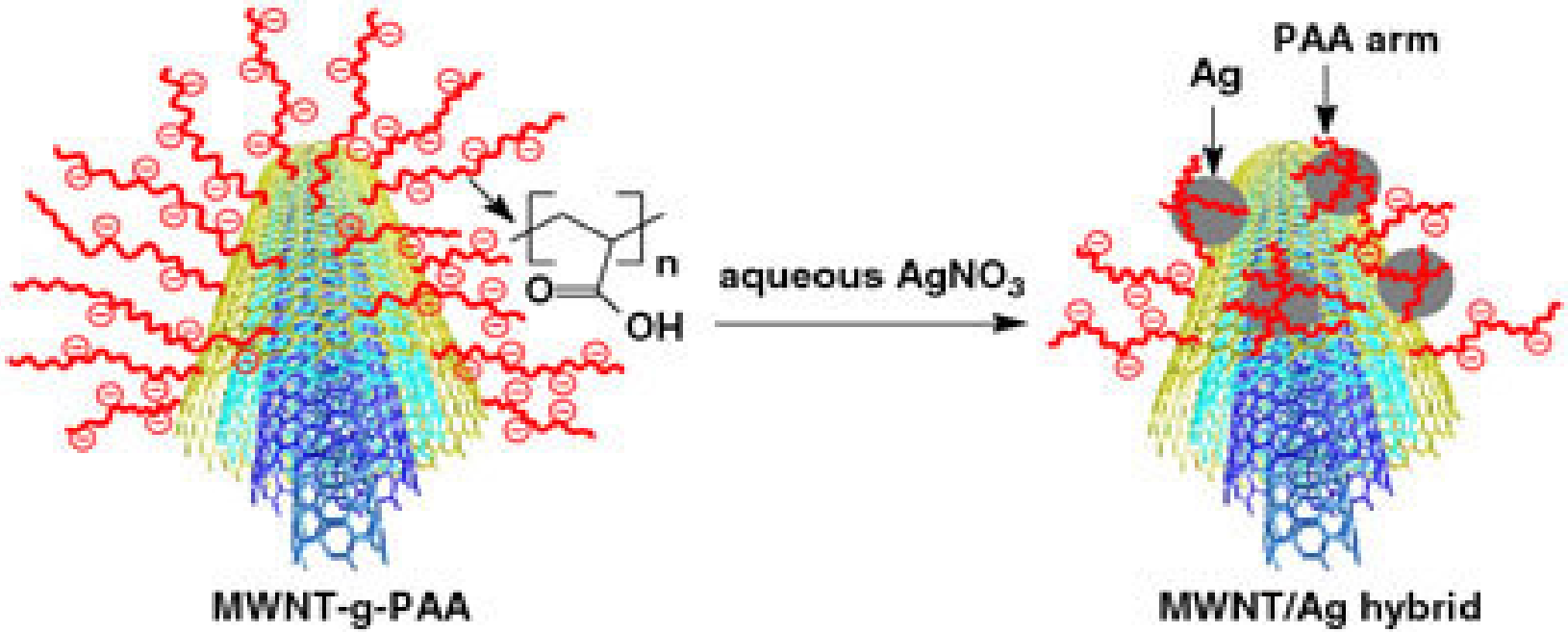


P-oCNT ≡ P+ oxidised CNT

Other applications

- MWNTs coated with magnetite are used as magnets
- Nano tube composites are used as antistatic shielding on airplane wings and fuselages

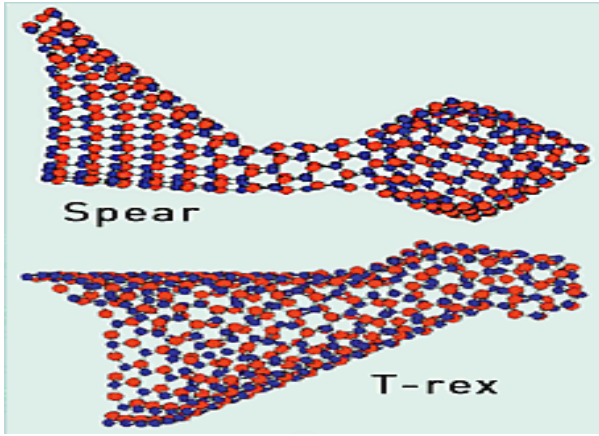
- Polyacrylic acid-grafted MWNTs acts like a resin to recover / reclaim precious metals (Ag and Au) from their aqueous solution (mechanism is similar to deionisation)



Other Nanotubes… (Inorganic Nano tubes)

Boron nitride nanotubes

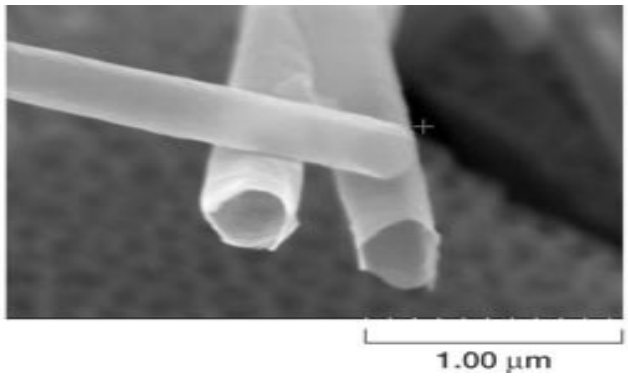
- Resistance to oxidation, suited for high temperatures
- Young's modulus of 1.22 TPa
- Semiconducting
- Predictable electronic properties independent of diameter and # of layers



Boron nitride nanotubes adopt various shapes (red=boron, blue=nitrogen):

SiC nanotubes

- Resistance to oxidation
- Suitable for harsh environments
- Can functionalize surface Si atoms



SiC nanotubes grown at NASA Glenn:

Any Queries?