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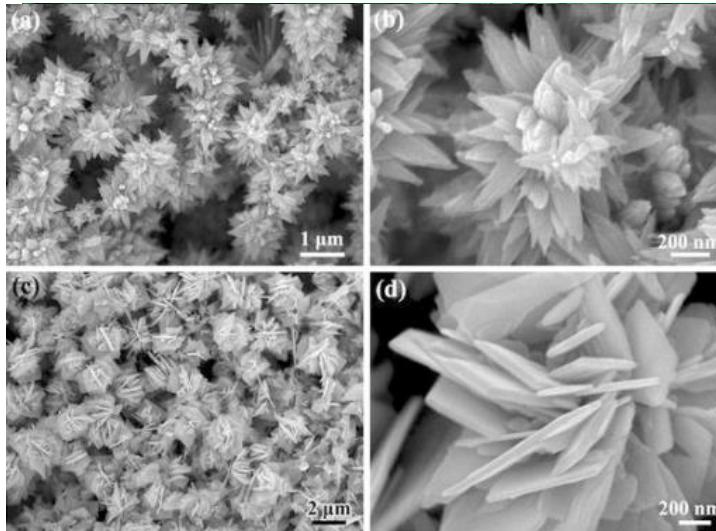
Go, change the world

CHEMISTRY OF FUNCTIONAL MATERIALS (22CHY2C2)

Unit-II Nanomaterials

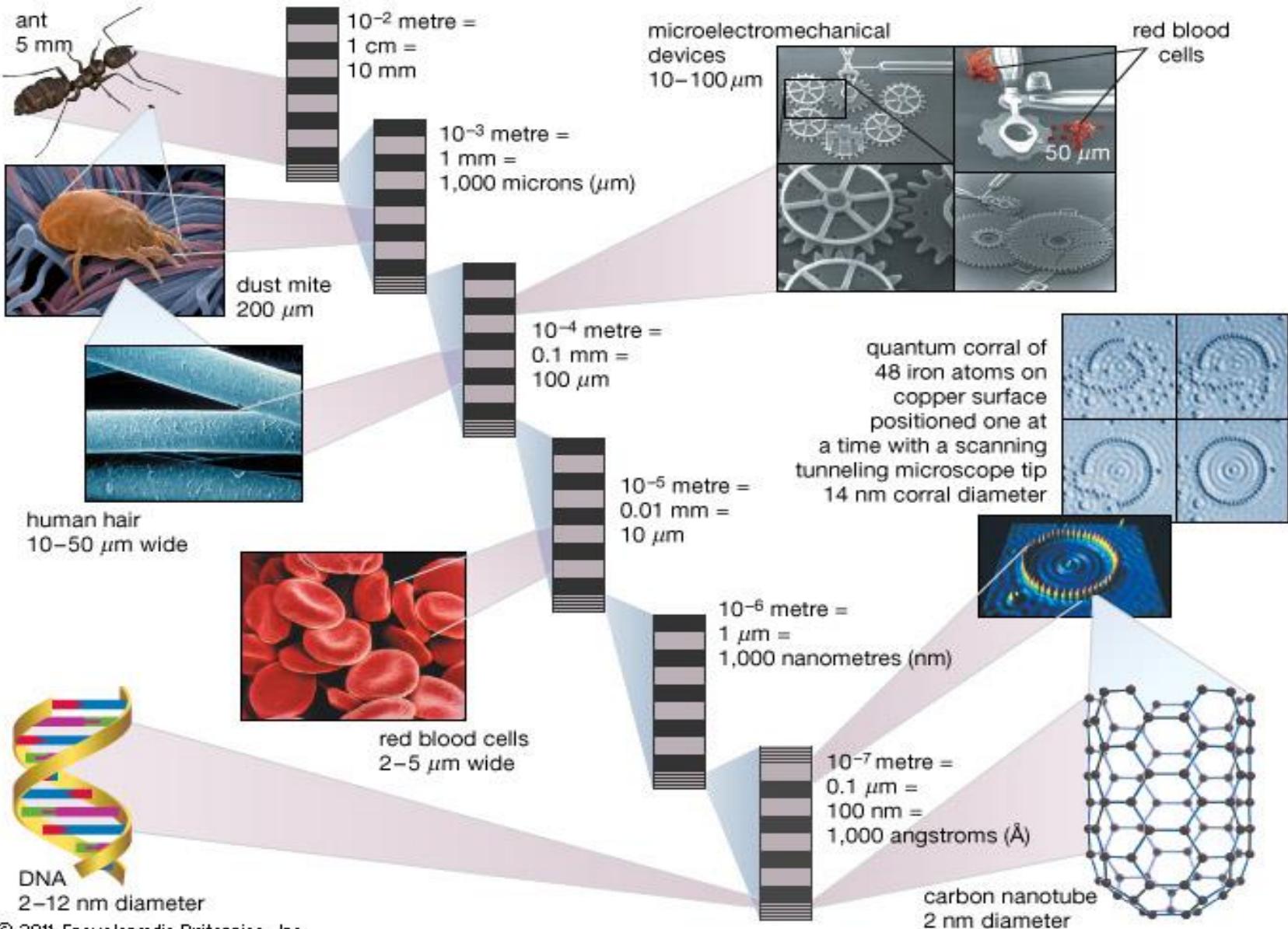


Introduction to Nanomaterials/Science/Technology



- ❖ **Nanomaterials** are commonly defined as materials with an average grain size less than 100 nanometers.
- ❖ The word "**nano**" originates from the Greek word "nanos" which means "dwarf". However, in scientific language it is a prefix which has a value equal to "one billionth, i.e. 10^{-9} ".
- ❖ Therefore, one nanometer is **one billionth of a meter ($1 \text{ nm} = 10^{-9} \text{ m}$)**.

Nano-dimension comparison



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Nanoscience and Nanotechnology

Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years. It has the potential for revolutionizing the ways in which materials and products are created and the range and nature of functionalities that can be accessed. It is already having a significant commercial impact, which will assuredly increase in the future.

*“**Nanoscience** is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale”*

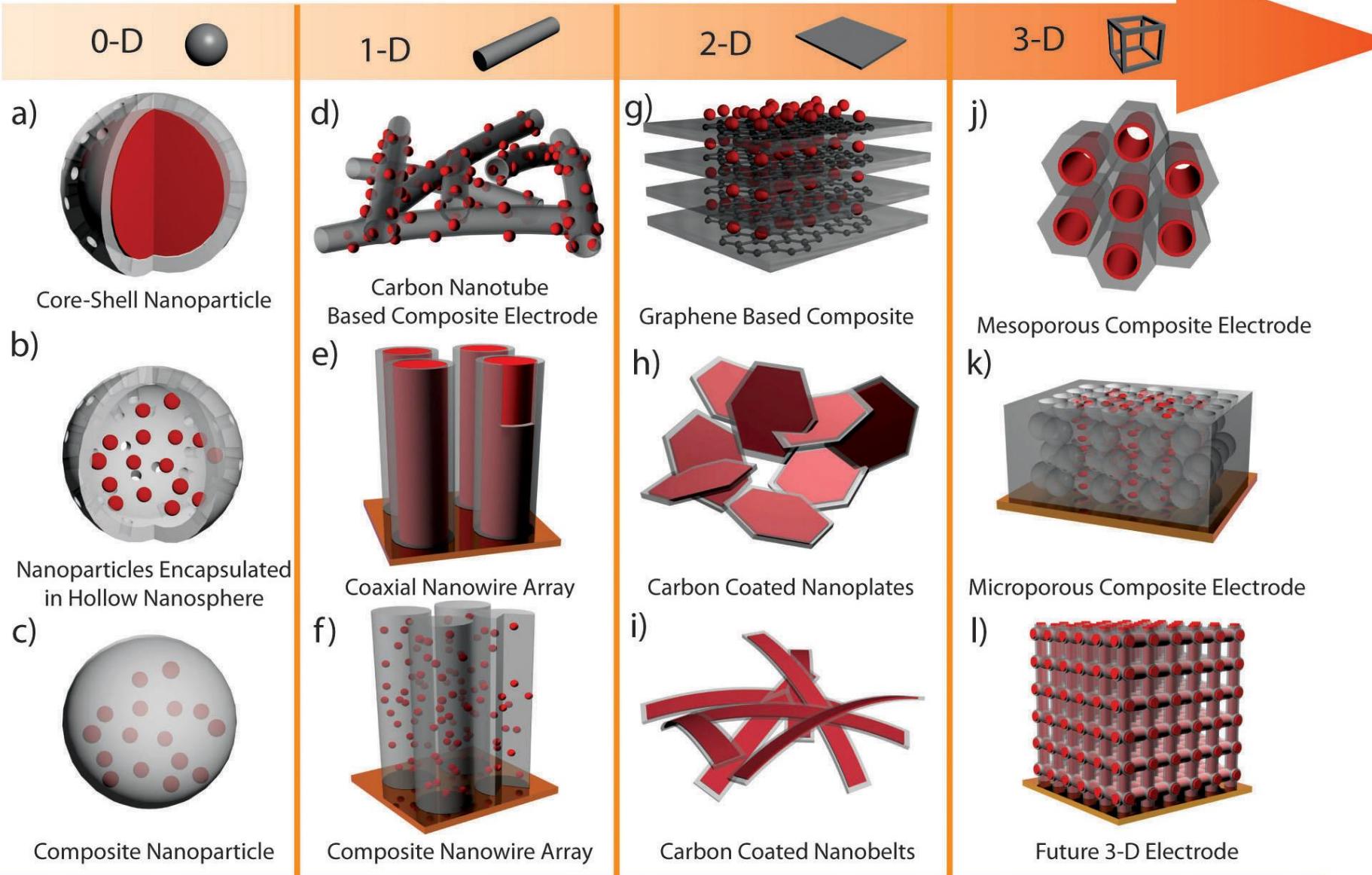
***Nanotechnologies** are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometre scale.*

Classification of Nanomaterials

Nanostructured materials are classified as

- a) ***Zero dimensional***: Nanomaterials are less than 100nm in all three dimensions.
- b) ***One dimensional***: Nanomaterials are less than 100nm in any two dimensions.
- c) ***Two dimensional***: Nanomaterials are less than 100nm in any one dimensions, and
- d) ***Three dimensional nanostructures***: Nanomaterials are aggregations of any of the above (0, 1, 2D) dimensional nanomaterial with greater than 100nm in all the three dimensions.

Heterogeneous Nanostructured Materials with Different Morphologies



Properties of Nanomaterials in comparison to bulk: Surface area, Optical, Catalytic properties

Properties of Nanomaterials

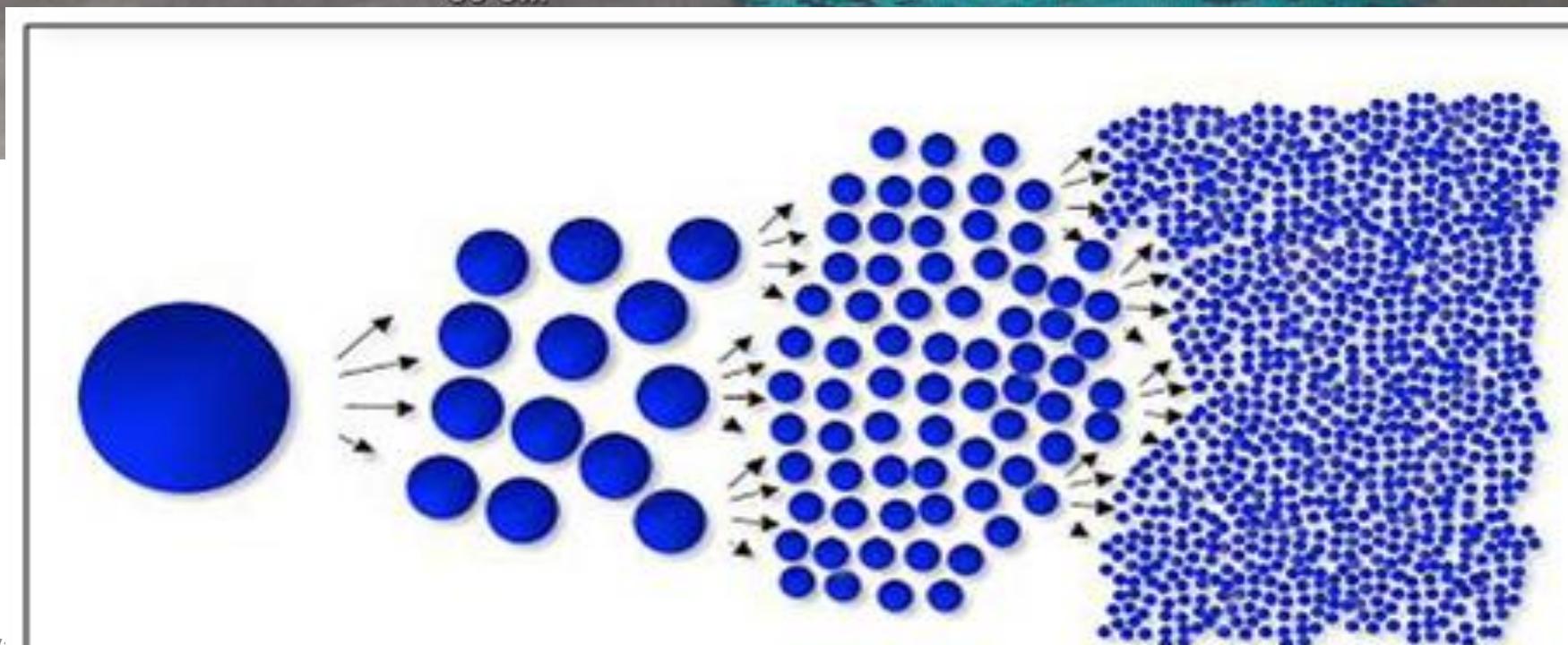
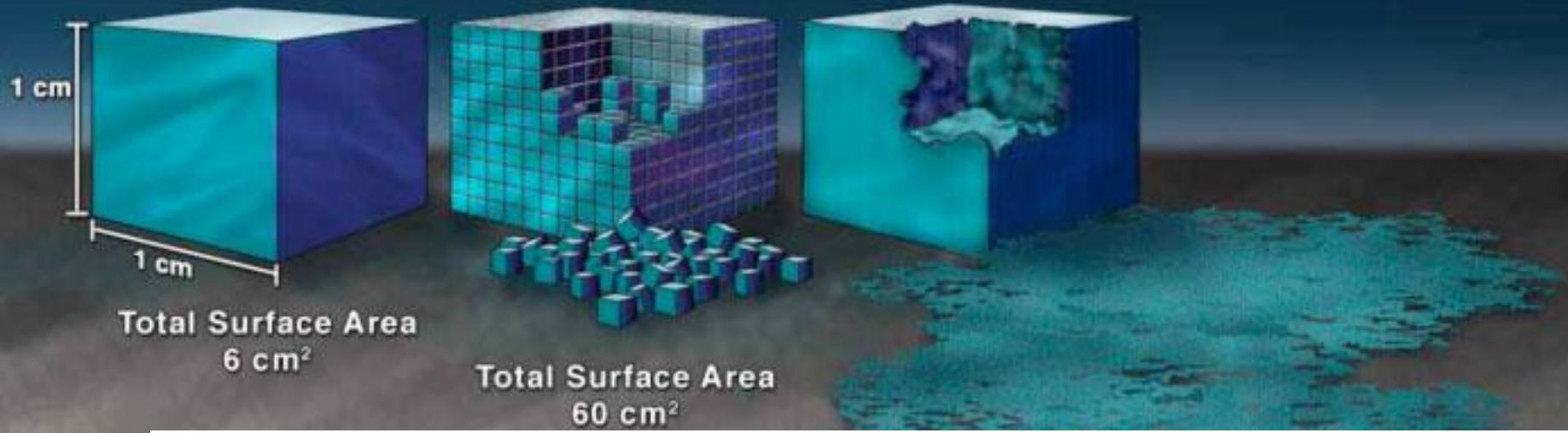
Nanomaterials have the structural features in between of those ***of atoms and the bulk materials.*** The properties of materials with nanometer dimensions are significantly different from those of atoms and bulks materials. This is mainly due to the nanometer size of the materials which render them:

- (i) large fraction of surface atoms;***
- (ii) high surface energy;***
- (iii) spatial confinement,***
- (iv) reduced imperfections,***

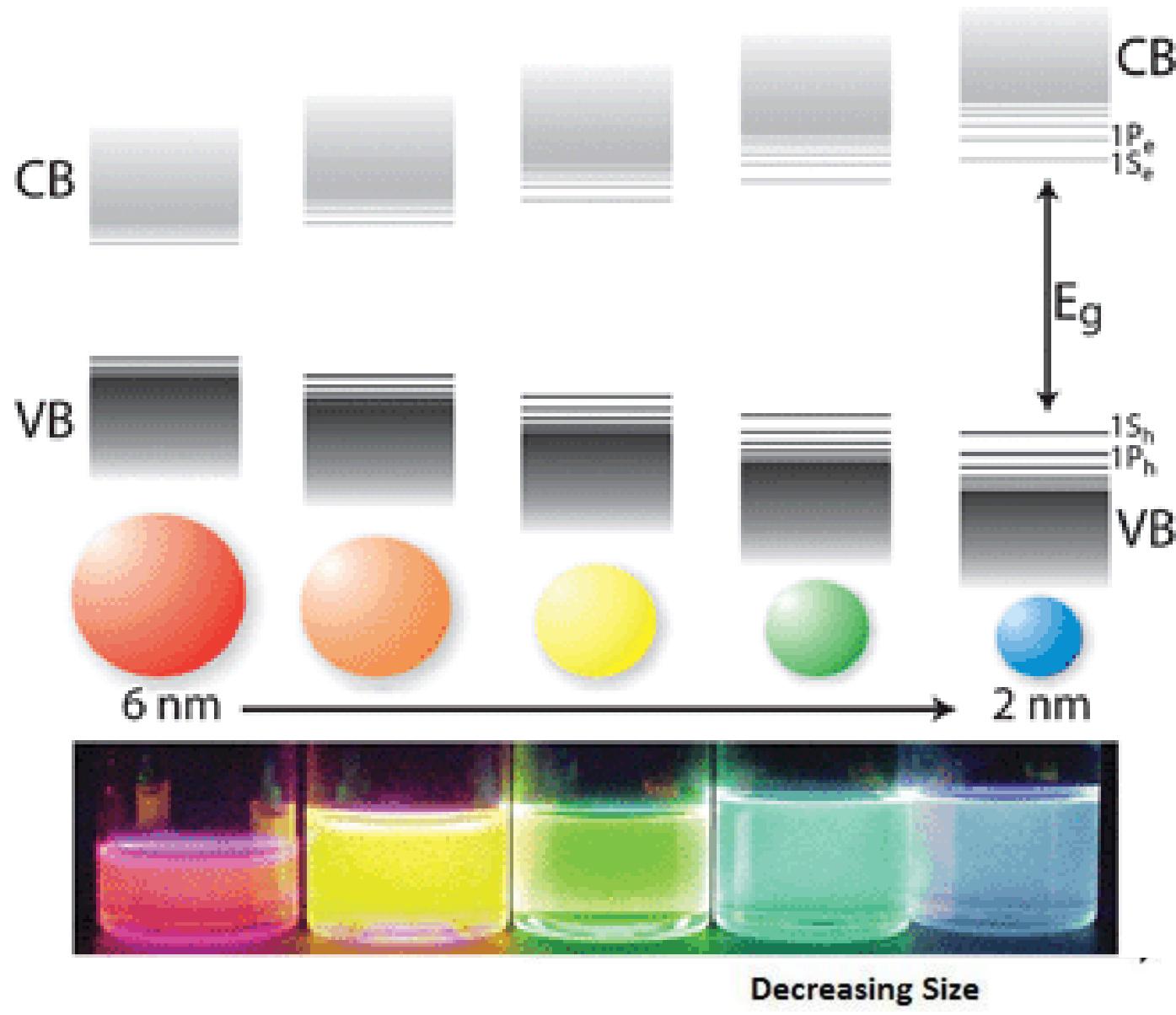
which do not exist in the corresponding bulk materials.

Surface area of Nanomaterials and bulk materials

- ❑ When particles are created with dimensions of about 1–100 nanometers (where the particles can be “seen” only with powerful specialized microscopes), the materials’ properties change significantly from those at larger scales.
- ❑ Properties such as **Optical, electrical, magnetic, and chemical reactivity** change as a function of the size of the particle.
- ❑ Nanoscale materials have far **larger surface areas** than similar masses of larger-scale materials. As surface area per mass of a material increases, a ***greater amount of the material can come into contact with surrounding materials, thus affecting reactivity.***



Band gap of nanomaterial increases with decrease in the size



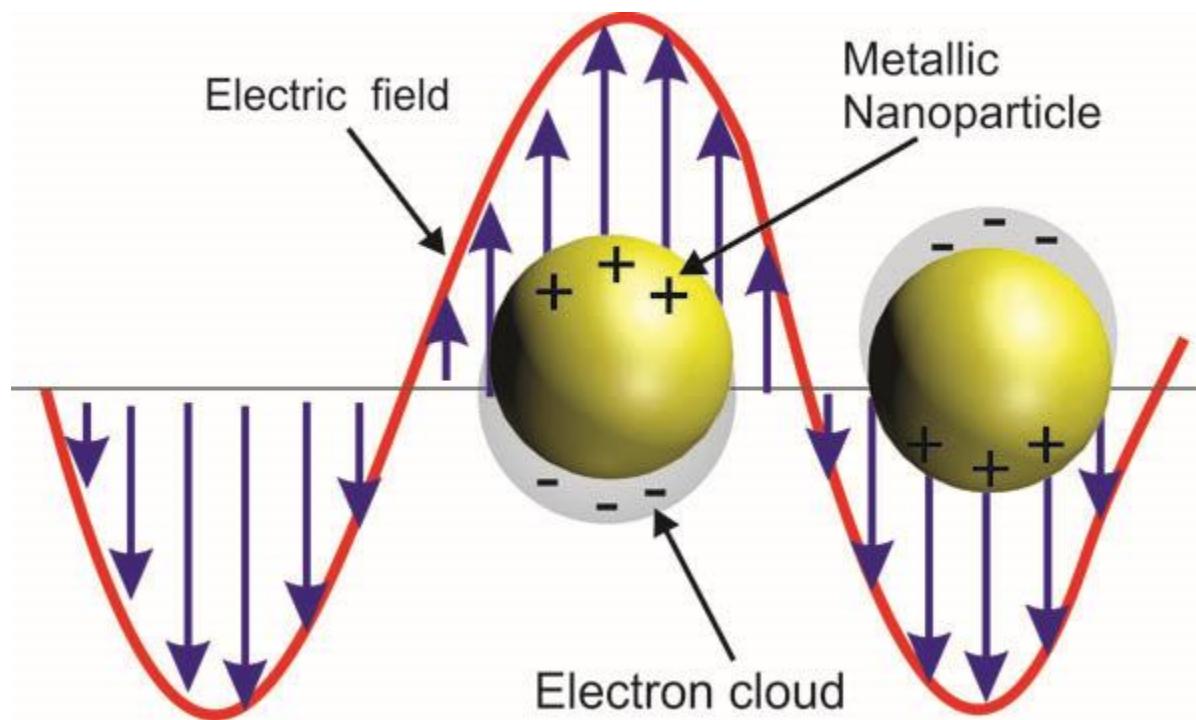
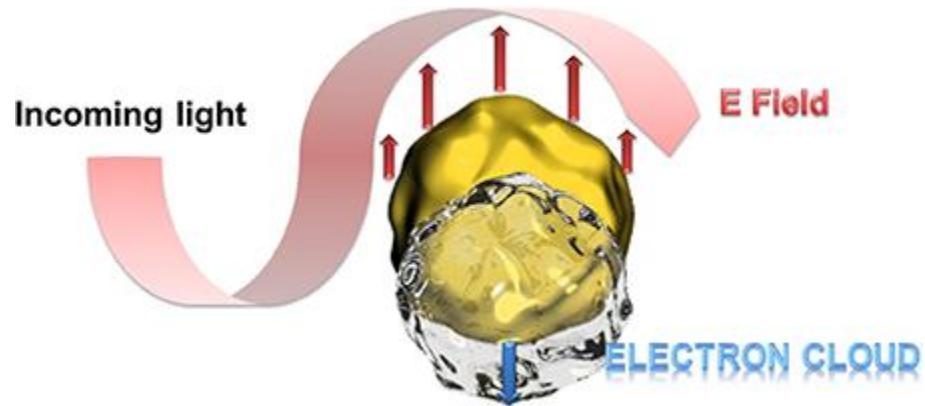
Optical Properties of Nanomaterials

One of the most fascinating and useful aspects of nanomaterial is their **optical properties**.

The change in optical properties is mainly due to the surface plasmon resonance and the increased energy level spacing.

Surface Plasmon Resonance (SPR): *The coherent excitation of entire free electrons in the conduction band may produce an in-phase oscillation with incident visible light, called surface Plasmon resonance.* When the size of a metal nanocrystal is smaller than the wavelength of incident radiation, a surface plasmon resonance is generated. Thus, plasmon resonance depends **on the particle size**.

In solid state physics, the plasmon represents the collective oscillation of a free charge in a metal, and may be considered as a kind of plasma wave. The positive electrical charge in the metal is fixed and the free electron is free to move around it. An applied external electric field, as from a light source, causes the free electrons at the surface of the metal to vibrate collectively, giving rise to surface plasmons.



- “Since electrons are also **particles with an electric charge**, when they vibrate they also **generate an electric field**, and when the electric field from the vibration of free electrons and the applied external electric field (e.g., electromagnetic waves) resonate the resulting phenomenon is referred to as a **surface plasmon resonance**” that takes place at the surface of the metal.
- However, if light irradiates a solution that contains dispersed metal nanoparticles smaller than the wavelength of light, then depending on the electric field of light, the deviation produces a free electron at the surface of the metal. As a result, the weak or thick portions of the electric field appear on the nanoparticle surface and can be considered as a kind of polarization.

- Nanoparticles absorb visible light and produce surface plasmons.
- Small nanoparticles absorb blue-green wavelength of light, but they reflect red light.
- When size of the nanoparticles increases, wavelength of plasmon resonance absorption moves to longer wavelength (red wavelength) side. Now red light is absorbed and blue light is reflected, resulting in pale blue or purple colour for the particles.
- When particle size increase towards critical limit, SPR wavelength shifts to the IR spectrum of the radiation and visible lights are reflected. ***These properties find potential applications in biosensors.***

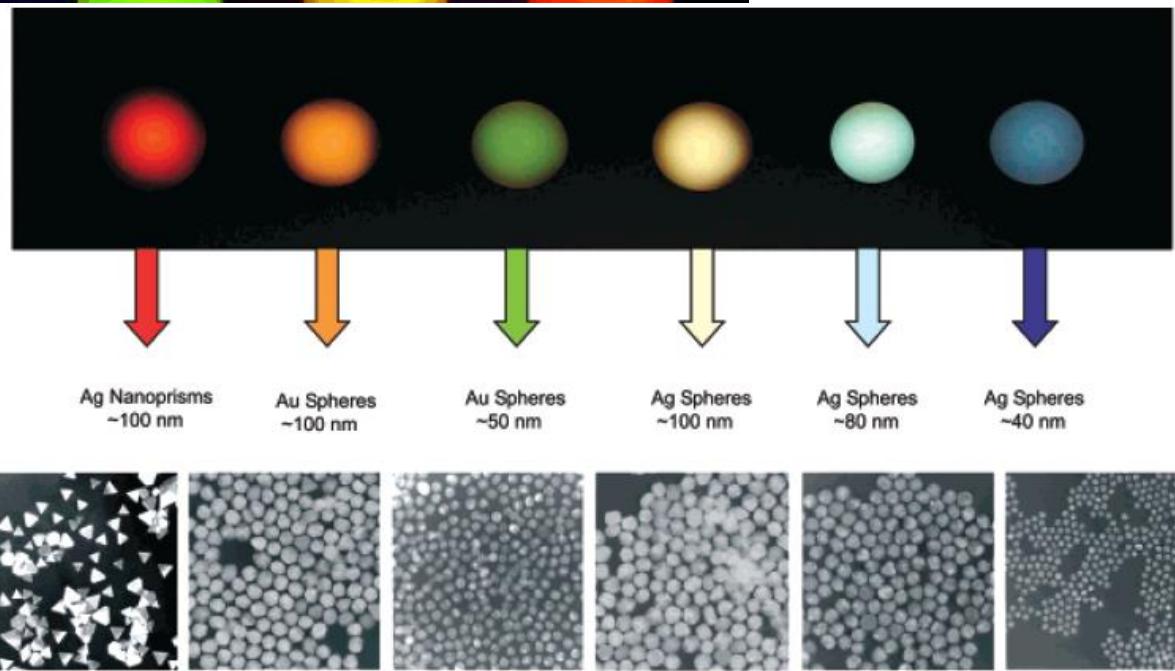
It should be noted that, metal nanorods exhibit two SPR modes, one due to **transverse** and the other due to **longitudinal** excitations. The wavelength of transverse mode is usually set at nearly **520 nm for gold and 410 nm for silver**. However, their longitudinal modes can be tuned to span from **visible region to near IR region** by controlling their aspect ratios.

The wavelength corresponding to the SPR depends on the kind of metal, the shape of the metal nanoparticle, and the extent of aggregation of the metallic nanoparticles.

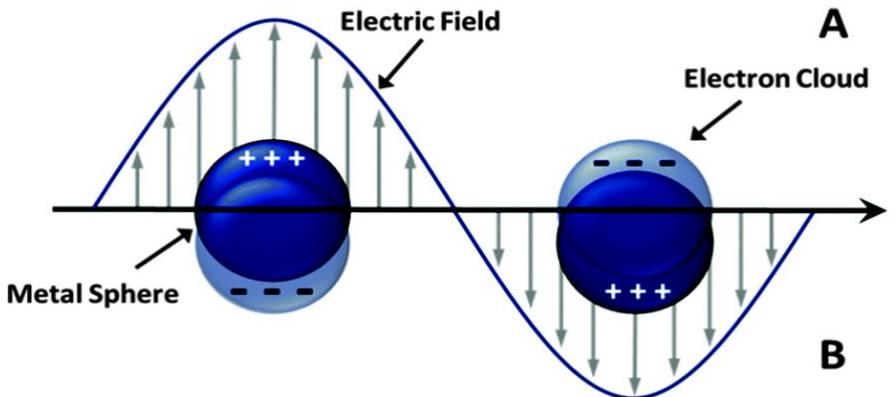
- ❖ For example, the wavelength of the SPR band maximum of a spherical **Au nanoparticle** is **520–550 nm**. If a colloidal Au nanoparticle solution is now irradiated with visible light at these wavelengths (520–550 nm), the visible light corresponding to the **green color** is absorbed and the particles now display a **red purple** color, which is the **complementary color to green**.
- ❖ In a colloidal **Ag nanoparticle** solution which has a SPR band maximum near **400 nm**, the **blue color** of the visible light is absorbed and the Ag nanoparticles now take on a **yellow color**, the complementary color to blue.



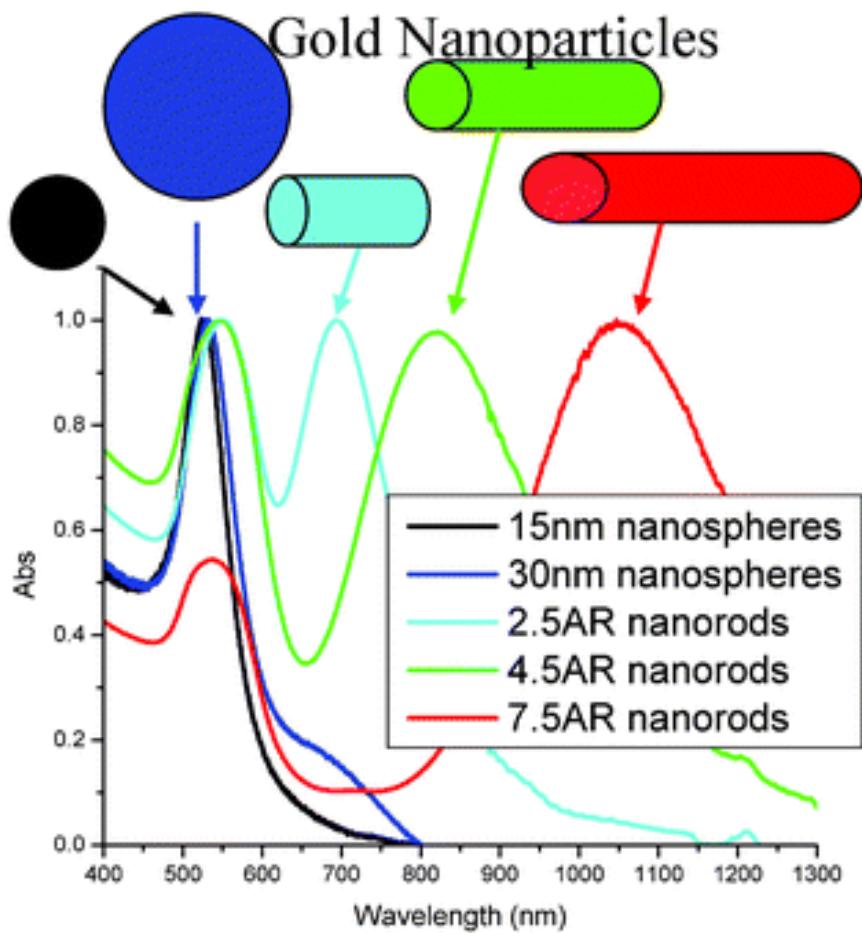
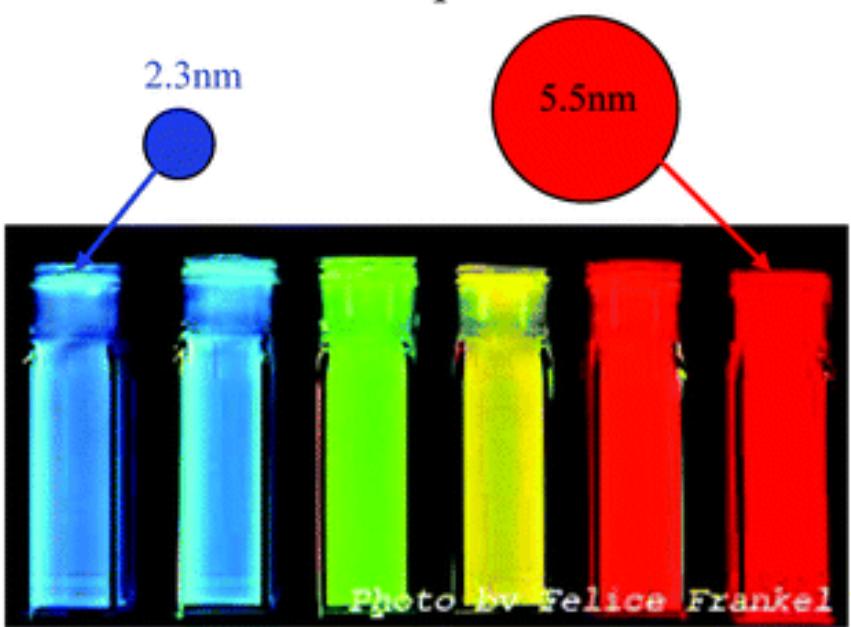
2.0 nm 2.8 nm



■ 200nm (same for all the images)
Chemistry, RVCE

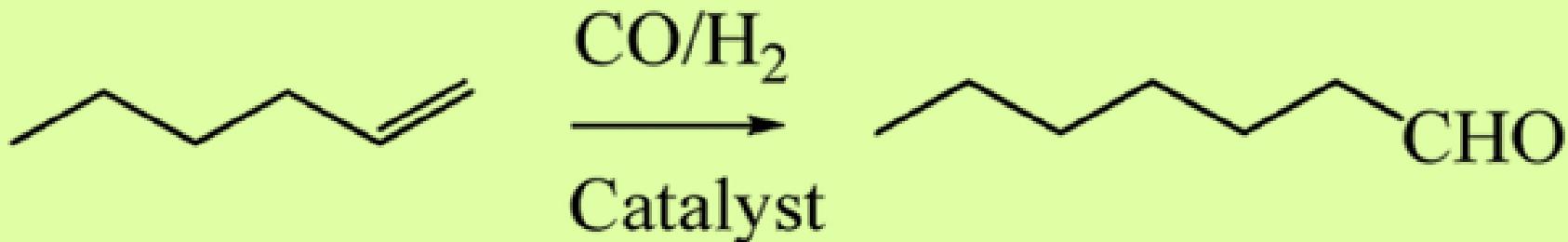


CdSe Nanoparticles



Catalytic Properties of Nanomaterials

- The rate of any chemical reaction depends on the number of active reaction sites on the catalyst.
- The surface area of nanoscaled catalyst is larger than that of bulk material.
- As compared to bulk catalyst, the nanoscale catalyst of same material with same quantity has more number of active sites.
- Because of unsaturated valencies of surface atoms of Nanoparticle catalyst, they catalyze the reactions at much faster rates due to higher surface energies as compared to their respective bulk partners.
- Therefore, the nanoscaled material is found to exhibit very high catalytic efficiency than the corresponding bulk material.



- The highest activity with 100% total conversion and 96% yield of aldehydes was obtained with the **Rh/nano-ZnO catalyst**.
- The **Rh/nano-ZnO catalyst** was found to be more stable and active than the corresponding rhodium catalyst supported on **bulk ZnO (76% yield)**.

Article

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Hydroformylation of 1-Hexene over Rh/Nano-Oxide Catalysts

catalysts

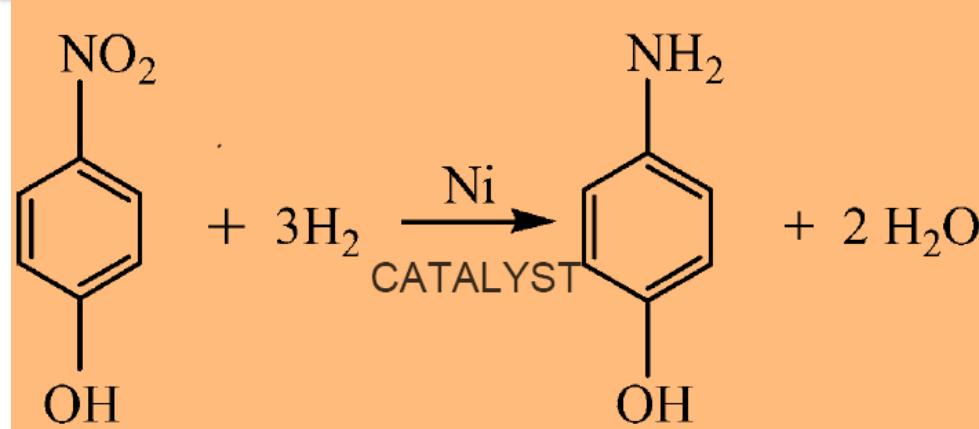
ISSN 2073-4344

www.mdpi.com/journal/catalysts

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Matti Haukka ^{1,2,*}

Catalysts **2013**, *3*, 324-337; doi:10.3390/catal3010324

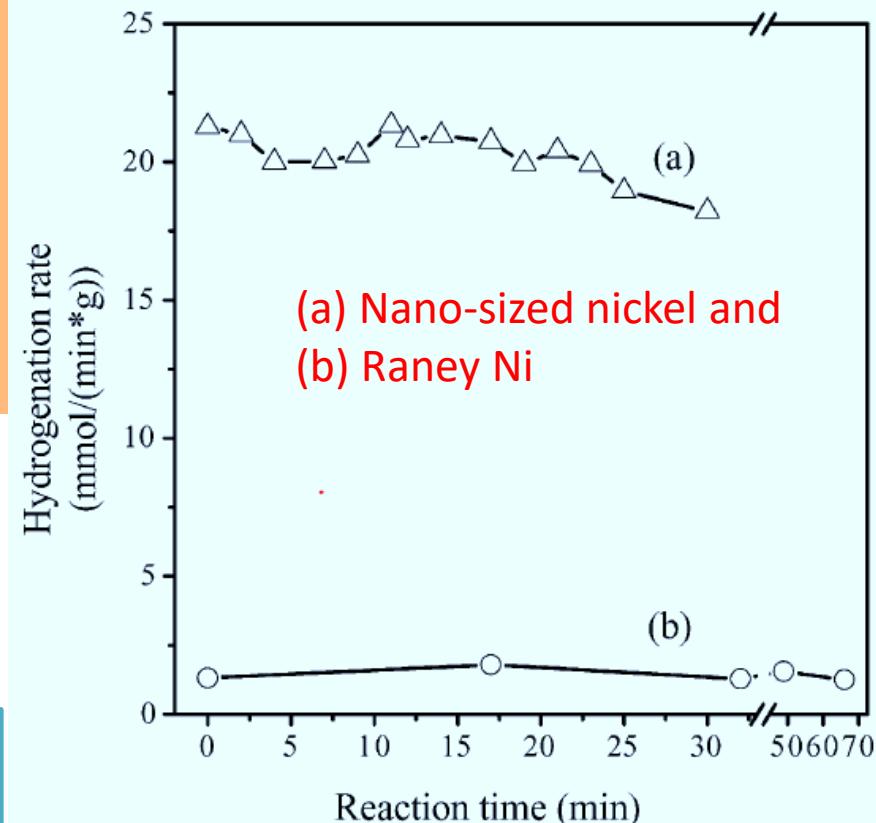
Catalytic hydrogenation of p-nitrophenol to p-aminophenol using nano-sized nickel



The hydrogenation rate of nano-sized nickel is about 15 times higher than that of Raney Ni at similar reaction conditions

The **nano-sized nickel** system suffers 54% deactivation, while the **Raney nickel** system suffers 80.4% deactivation only throughout six continuous hydrogenation cycles.

These results indicate that the catalytic stability of **nano-sized nickel** system is superior to that of the **Raney nickel system**



Synthesis of *p*-aminophenol from *p*-nitrophenol over nano-sized nickel catalysts

Yan Du, Hongling Chen*, Rizhi Chen, Nanping Xu

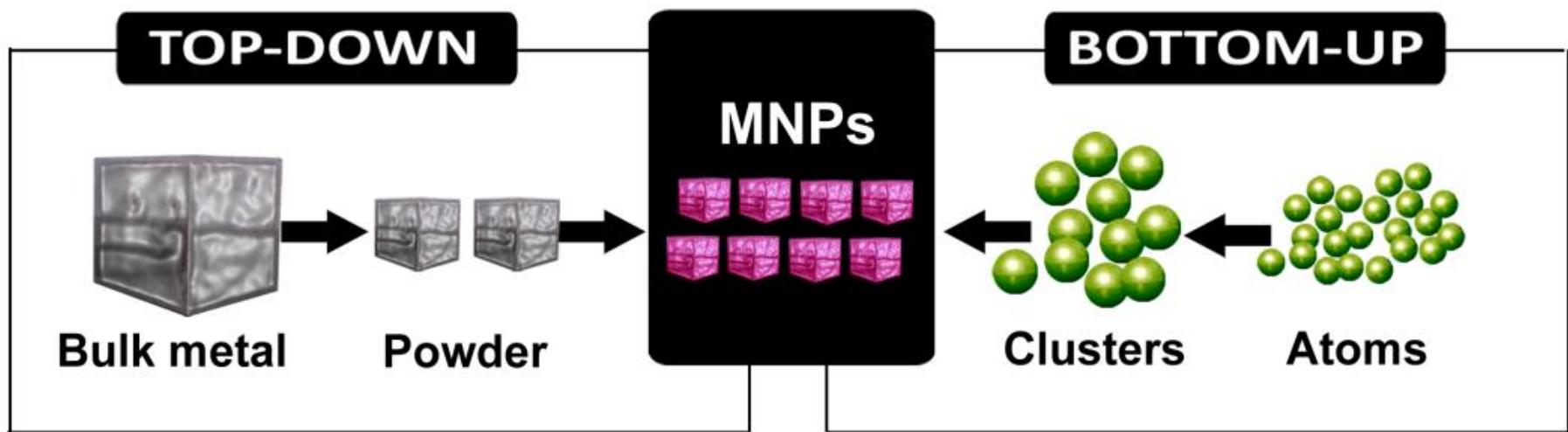
Applied Catalysis A: General 277 (2004) 259–264

Synthesis of Nanomaterials: SCS for metal oxide, Sol-Gel- for TiO_2 nanoparticles Carbon Nano materials

Researchers are active worldwide developing new preparation methods for functionally and technologically useful nanoparticles and nanostructures. Nature efficiently builds nanostructures by relying on chemical approaches. There are many methods developed to prepare nanomaterials, they are listed as chemical methods (bottom up) and physical methods (top down) as shown in Table.1

Table. 1 General methods of synthesis of nanomaterials

CHEMICAL METHODS (Bottom Up)	PHYSICAL METHODS (Top down)
Combustion Synthesis	Inert gas condensation
Hydrothermal	Sputtering
Sol-gel method	Molecular beam epitaxy
Micelles micro emulsion	Lithography
Single crystal growth	Ion beam technique
Colloidal methods	Chemical vapor deposition



1) Low temperature solution combustion (SCS) method

This method was discovered by **Prof. K. C. Patil** when the mixture of $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and urea solution, rapidly heated around 500°C in a muffle furnace. The author observed that the solution mixture undergoes vaporization followed by vigorous ignition with an incandescent flame yielding voluminous white product which was identified as $\alpha\text{-Al}_2\text{O}_3$.

Combustion method: is a low temperature, time saving, energy efficient, self propagating method, involving **spontaneous exothermic redox reaction** between **metal nitrate and organic fuel**, used to prepare nanomaterials.

Principle: The method is based on the utilization of heat energy produced during the exothermic spontaneous redox reaction between an oxidizer (metal nitrate) and a reducing agent (organic fuel). The oxidizer can be of any metal nitrates and reducing agents may be organic fuels, such as glycine, oxalic acid, urea, hexamine, sugar, EDTA, Dextrose etc.

Metal nitrate + Fuel



nano Metal oxide + Gases

The amount of fuel can be calculated in such way that the total oxidizing valency of fuel should match with the total reducing valency of metal nitrate. The following formula can be used to calculate the amount of fuel:

$$\frac{\text{Wt. of fuel}}{\text{Mol. Wt. of fuel}} \times \text{Valency of fuel} = \frac{\text{Wt. of metal nitrate}}{\text{Mol. Wt. of metal nitrate}} \times \text{Valency of metal nitrate}$$

For the calculation of valency of fuel and metal nitrate, the valency to be considered for the elements such as of N, O, H, C, and M^{n+} are 0, -2, +1, +4 and +n respectively.

Procedure:

Step1: Weighing and mixing of the reactants



Weighing of all the reactants (metal nitrate and a fuel) according to stoichiometry, by using the above formula and dissolved in minimum quantity of distilled water in a beaker of suitable size.

The mixture is stirred on a magnetic stirrer till to get uniform solution as shown in figure (left side).

Magnetic stirrer on which uniform redox solution is obtained by stirring

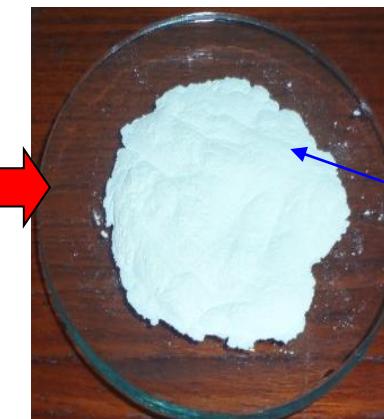
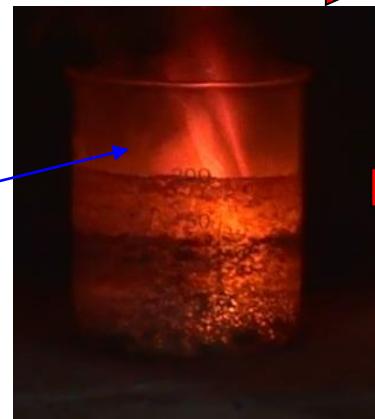
Step 2: Evaporation and combustion

The uniformly mixed solution is kept in a furnace maintained at 500 °C



Evaporation (boiling) of water

Spontaneous/vigorous combustion occurs and propagates throughout the redox mixture



Final nano powder of corresponding metal oxide

- ❖ The clear solution is kept in a furnace (shown below) maintained at 500 °C.
- ❖ Firstly the solution undergoes evaporation that results in more concentrated, uniformly mixed viscous-gel type substance.
- ❖ After some time, the viscous-gel catches fire and propagates spontaneously in the redox mixture in the form of either a flame type or smouldering type.
- ❖ The combustion lasts for about 1-2 min.
- ❖ During the flame propagation large quantity of gasses and high temperature produced helps in the formation of respective nano metal oxide.
- ❖ The SCS has emerged as a viable technique for the preparation of advanced nano-metal oxide.

The most important advantages of SCS process are:

- ✓ It is an easy and fast process that uses relatively simple equipment.
- ✓ High-purity products can be easily prepared by using this method.
- ✓ Composition, structure, homogeneity, size and stoichiometry of the products can be controlled.
- ✓ High exothermicity of the metal nitrate–fuel reaction permits incorporation of desired quantity of dopants in the various hosts of industrially useful phosphors.
- ✓ This is the cheap method as compared to conventional solid state method

Stoichiometry calculation

$$\frac{\text{Wt. of fuel}}{\text{Mol. Wt. of fuel}} \times \text{Valency of fuel} = \frac{\text{Wt. of metal nitrate}}{\text{Mol. Wt. of metal nitrate}} \times \text{Valency of metal nitrate}$$

Valency calculation

	Zn2+	2N	6O	6H2O	Total Valency
Zn(NO ₃) ₂ •6H ₂ O (Zinc Nitrate) 297 g/mol	+2	2x0=0	6x(-2)=-12	6x0=0	-10
Al(NO ₃) ₃ ·9H ₂ O (Aluminium nitrate) 375.14 g/mol	A3+	3N	9O	9H2O	
C ₆ H ₁₂ O ₆ (Glucose,) 180.156 g/mol	+3	3x0=0	9x(-2)=-18	9x0=0	-15
C ₆ H ₁₂ O ₆ (Glucose,) 180.156 g/mol	6C	12H	6O		
NH ₂ -CH ₂ -COOH (Glycine) 75.07 g/mol	6x(+4)=+24	12x(+1)=+12	6(-2)=-12		+24
NH ₂ -CH ₂ -COOH (Glycine) 75.07 g/mol	N	2O	5H	2C	
NH ₂ -CH ₂ -COOH (Glycine) 75.07 g/mol	1x0=0	2x(-2)=-4	5x(+1)=+5	2x(+4)=+8	+9

**Calculate the amount of glycine fuel required to
prepare nano ZnO using**

8g of hydrated Zinc nitrate (Mol. Mass =297g/mol)

$[(\text{Wt} \times \text{Valency})/\text{Mol Mass}] \text{ of Glycine} = [(\text{Wt} \times \text{Valency})/\text{Mol Mass}] \text{ of Zinc nitrate}$

$$[(\text{Wt} \times 9)/75.07] \text{ of glycine} = [(8 \times 10)/297]$$

Wt of glycine =..... g

2. Sol-gel method

It is a wet chemical technique widely used for the fabrication of nano-structured ceramic materials and thin films.

Sol-gel process involves the conversion of precursor solution (usually metal salts or metal alkoxide) into a nano-structured inorganic solid through inorganic polymerization reactions catalyzed by water.

In general, metal alkoxides ($M-OR$) are widely used as precursors, because they readily react with water.

The reactions involved in the sol-gel process are

1) Hydrolysis



2) Condensation



Condensation..... Condensation CondensationofM-O-M results in to a polymer network in all the possible directions.

Process:

Step 1: Preparation of homogeneous solution either by dissolution of metal salt in water or metal alkoxide in an organic solvent (usually alcohol) that is miscible in water.

Step 2: ‘Sol’ formation by hydrolysis: It involves the conversion of homogeneous solution into a “sol”. (A stable dispersion of colloidal particles of precursors in a solvent is known as sol) due to hydrolysis reaction. During hydrolysis, the alkoxide groups (-OR) are replaced via the nucleophilic attack of the oxygen atom of a water molecules, results in release of alcohol and formation of metal hydroxide (sol).

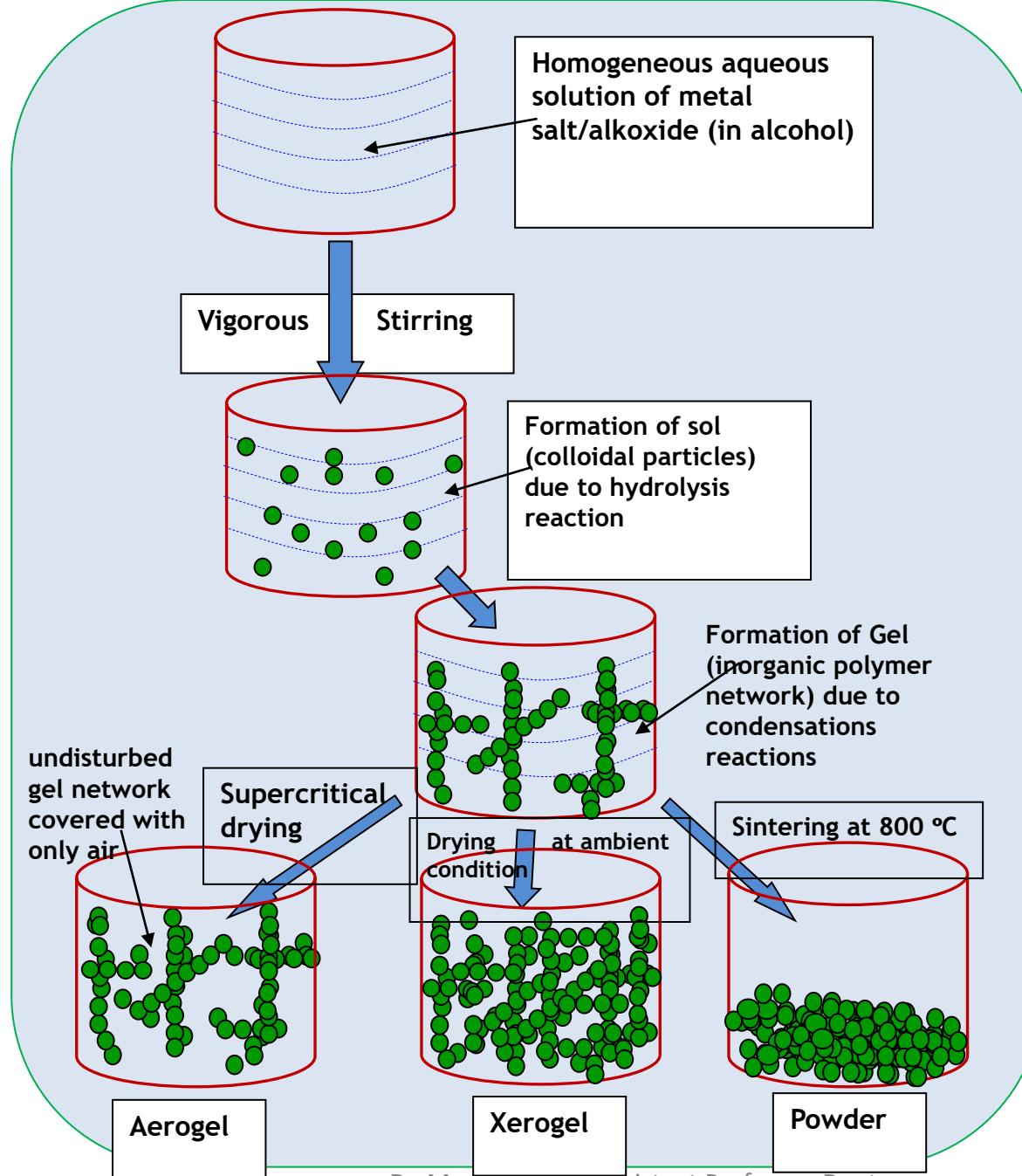
Step 3: ‘Gel’ formation by condensation

The colloidal solution is kept for aging. During aging condensation reaction between two metal hydroxyl/alkoxy species leads to M-O-M bonds with the release of $H_2O/R-OH$. This condensation process continues and finally results in a “gel”, an interconnected, a rigid and porous inorganic network covered completely with liquid phase. This transformation is called **Sol-Gel transition**.

Step 4: Drying of gel:

It involves removal of liquid phase from gel network. There are different ways of drying gel:

- If the gel medium is dried, by removing the liquid solvent (under hyper critical conditions) without destroying the gel network, **“aerogel”** is produced.
- If the solvent is dehydrated by under ambient conditions (removal of R-OH groups), **“xerogel”** are produced.
- If the gel network is sintered at high temperature ($800^{\circ}C$), densification, decomposition of gel results in complete collapse of gel net into powder.



Example: Preparation of TiO_2 by Sol-gel method:

Chemicals required: Titanium isopropoxide [$Ti(O(CH(CH_3)_2)_4$], absolute alcohol, distilled water, HNO_3

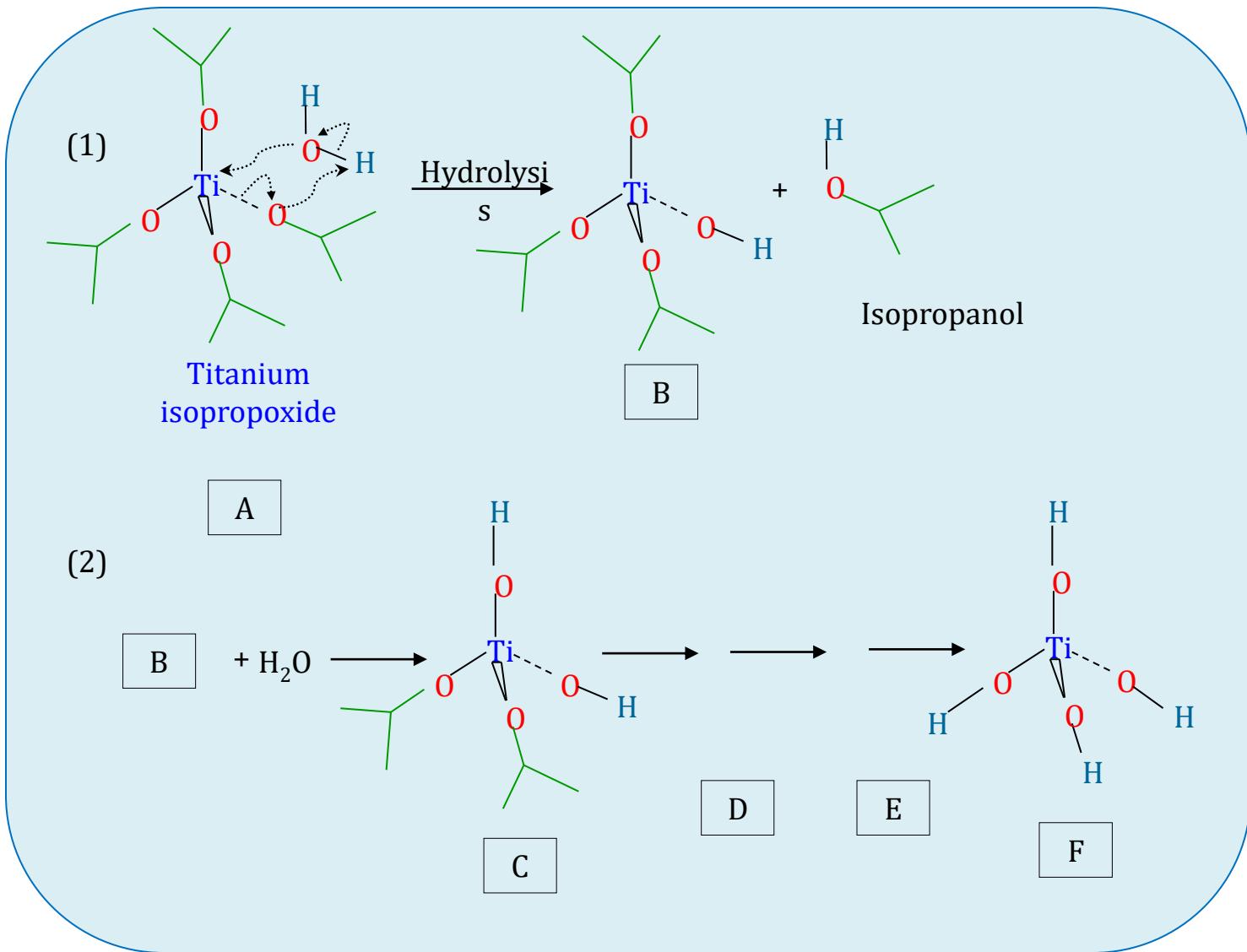
Equipments/glassware:

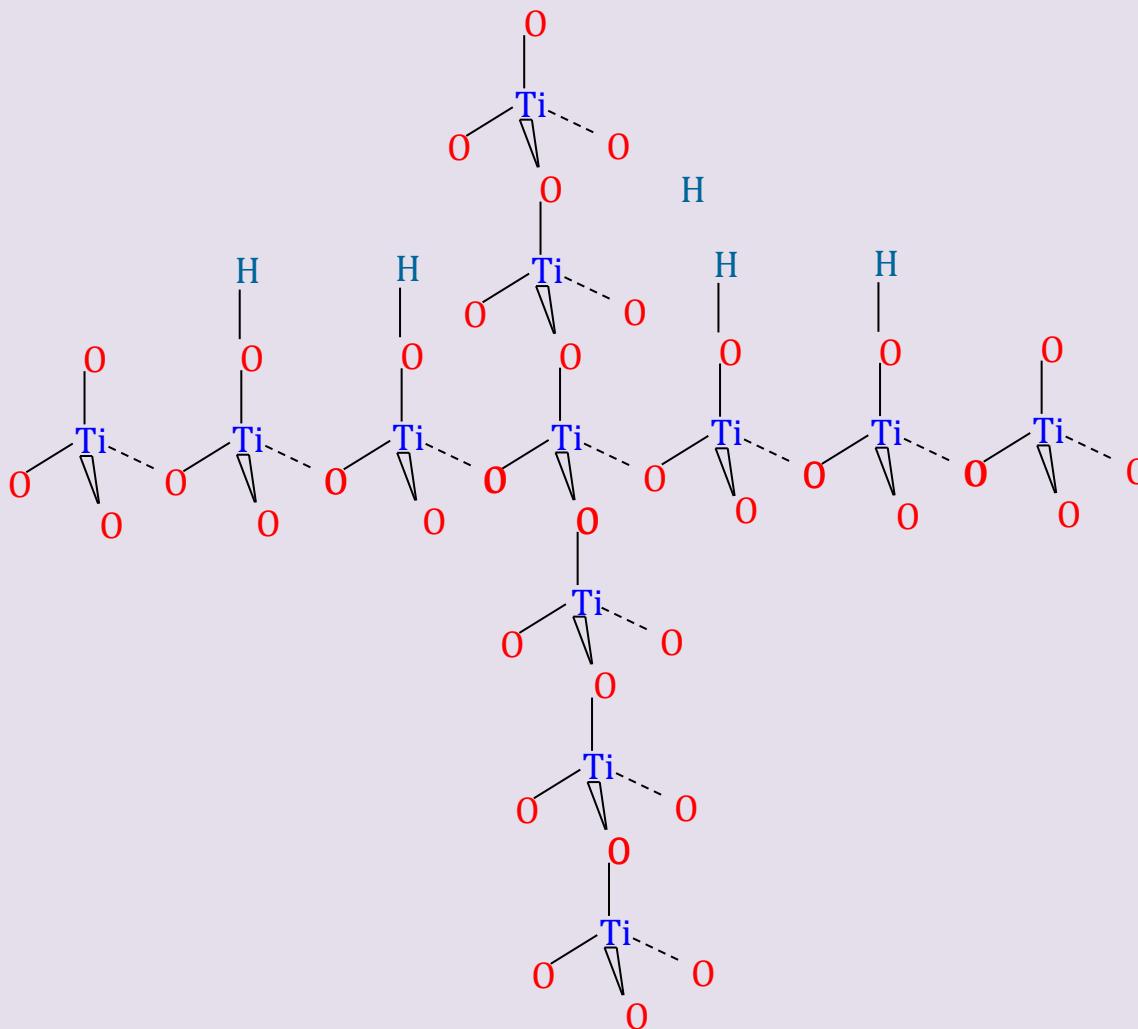
- 250 ml glass beaker, magnetic stirrer, Furnace, oven.

Procedure: Stoichiometric quantity of titanium (IV) isopropoxide is dissolved in absolute ethanol and distilled water in the ratio of $Ti:H_2O=1:4$. HNO_3 is added to adjust pH and restrain the hydrolysis process of the solution.

- The solution is vigorously stirred for 30 min in order to form sol (a suspension of colloidal particle).
- The sol is kept for aging for about 24 h. During aging sol is transformed into gel. (It is due to polycondensation and formation of inorganic network).
- In order to obtain TiO_2 nanoparticles, the gels are dried at 120 °C for 2 h to evaporate water and organic solvent. Then the dry gel is sintered at 450 °C for 2 h to obtain TiO_2 nanoparticles.

Reaction mechanism: Nucleophilic (H_2O) attack on alkoxy group.



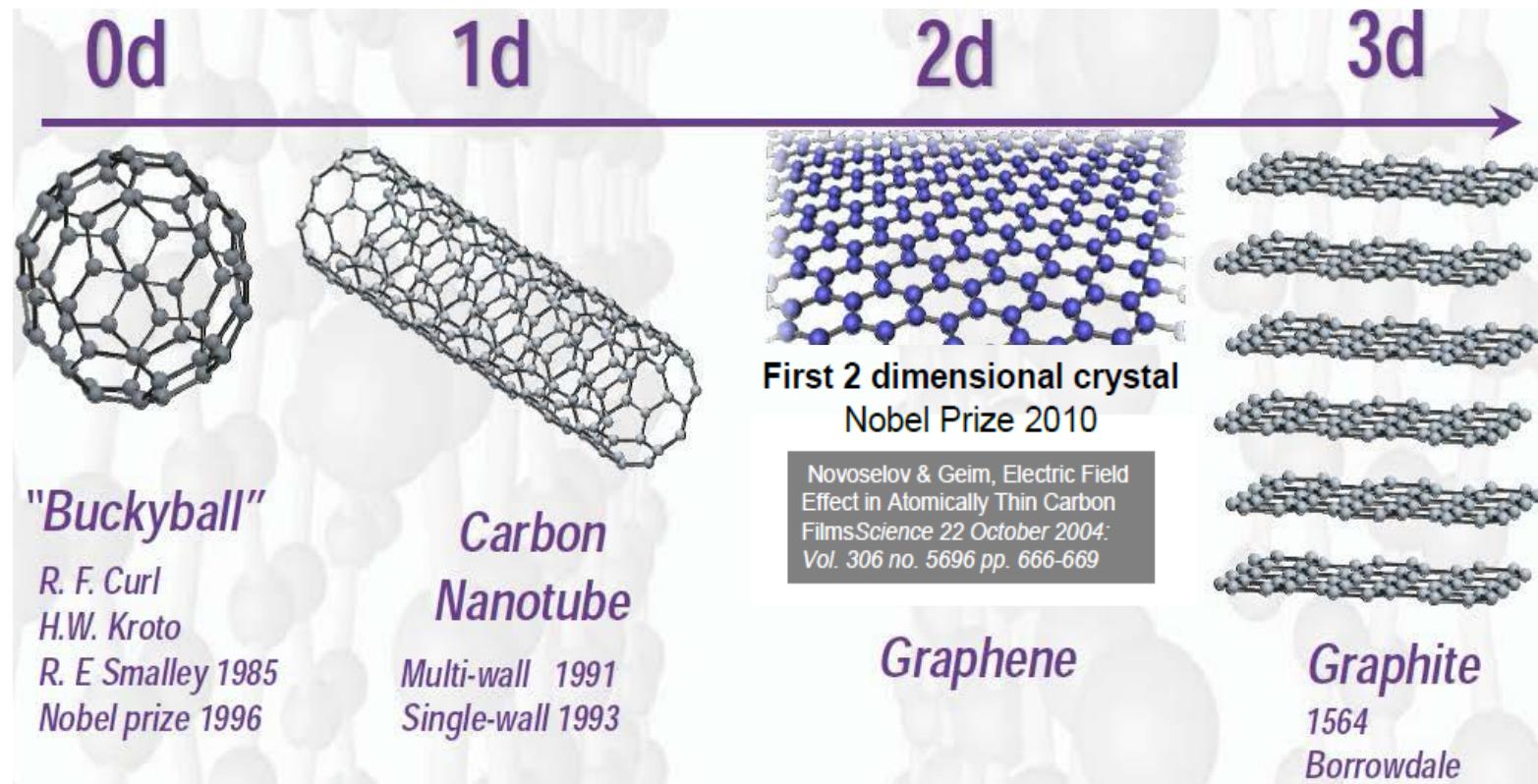


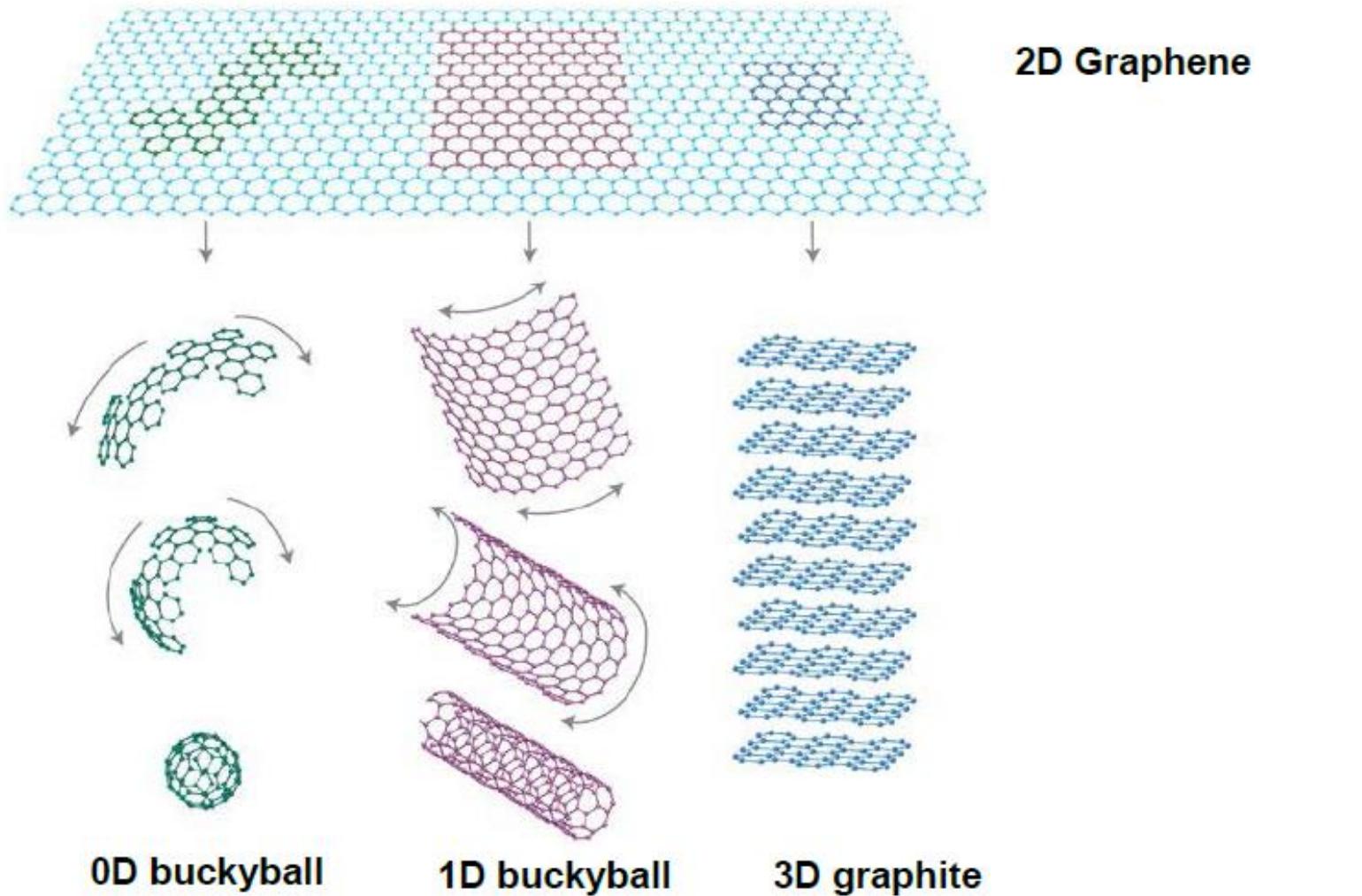
The advantages of this technique are evident.

- ❖ It is a simple and economic technique, as the fabrication does not need expansive machinery or apparatuses.
- ❖ It offers a high flexibility as one can produce materials with a wide range of stoichiometry and additional dopants.
- ❖ It allows the fabrication of high quality coatings.
- ❖ The starting materials are easily to obtain, not expensive and available in a high purity.
- ❖ Nanomaterials of variety of shapes can be prepared.

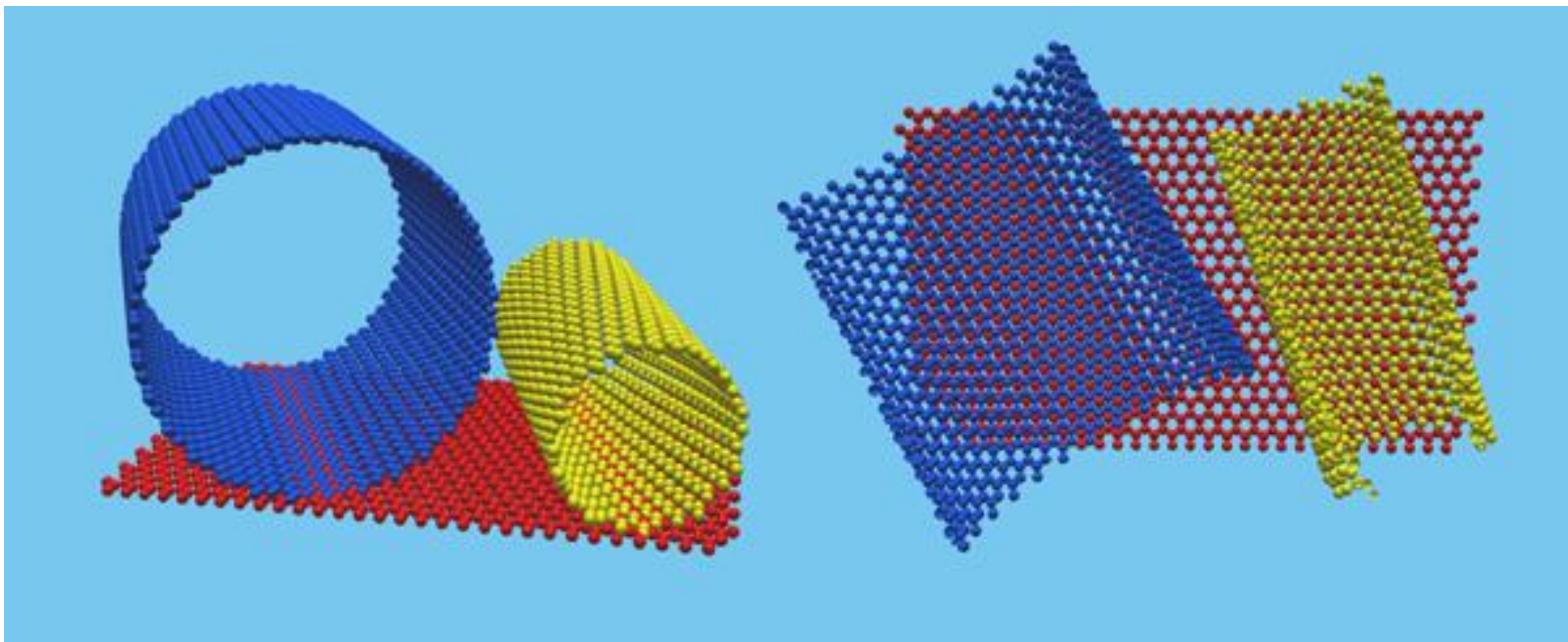
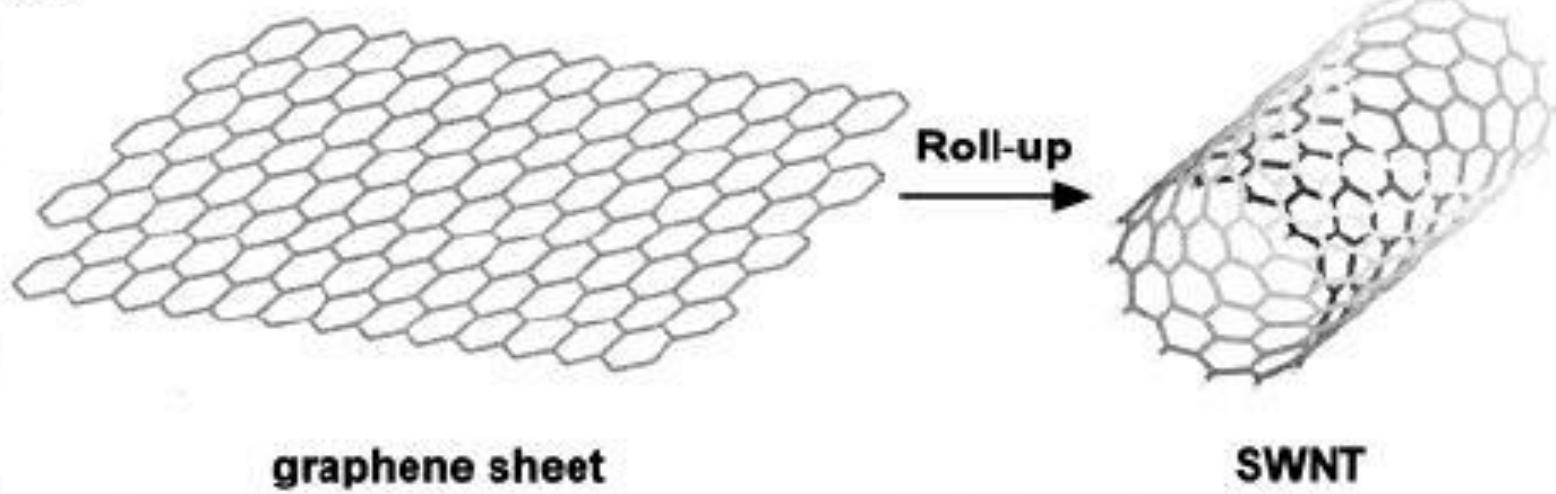
Carbon nanotubes: Introduction, different forms, doping, preparation, functionalization, properties and applications.

Carbon is an incredibly versatile element. Depending on how atoms are arranged, it can produce hard diamonds or soft graphite. Carbon materials can exist in various dimensions. The fig below clearly shows the various forms of carbon materials.





A. K. Geim & K. S. Novoselov
Nature Materials 6, 183 - 191 (2007)

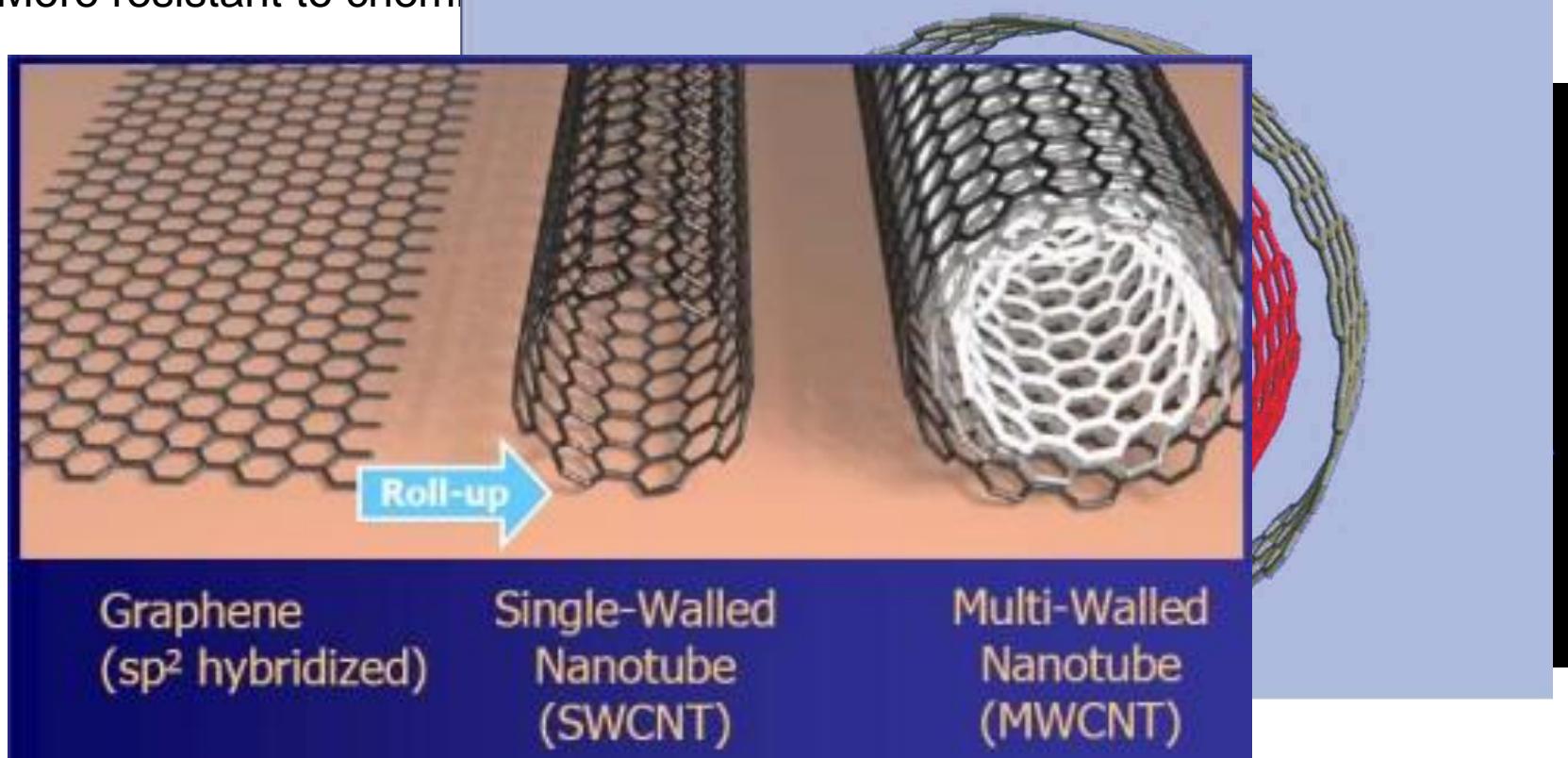
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Different forms : (Types of CNTs)

1) Single-Wall Nanotube (SWNT) (a. Arm Chair, b.Chiral c.Zig-Zag)

2) Multi-Walled Nanotubes (MWNT)

- Multiple rolled layers of graphene sheets
- More resistant to chemi

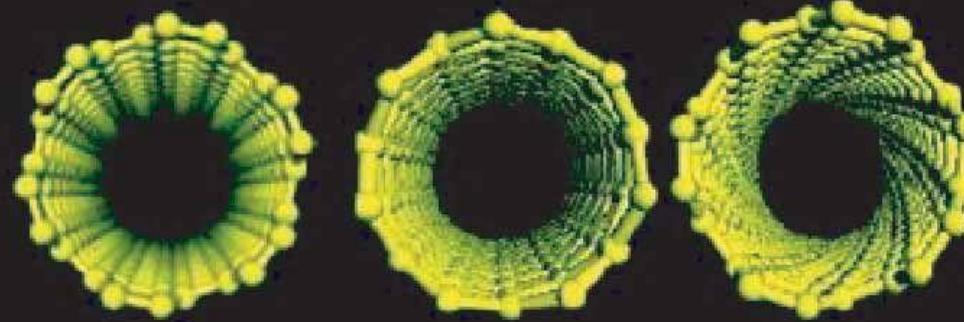
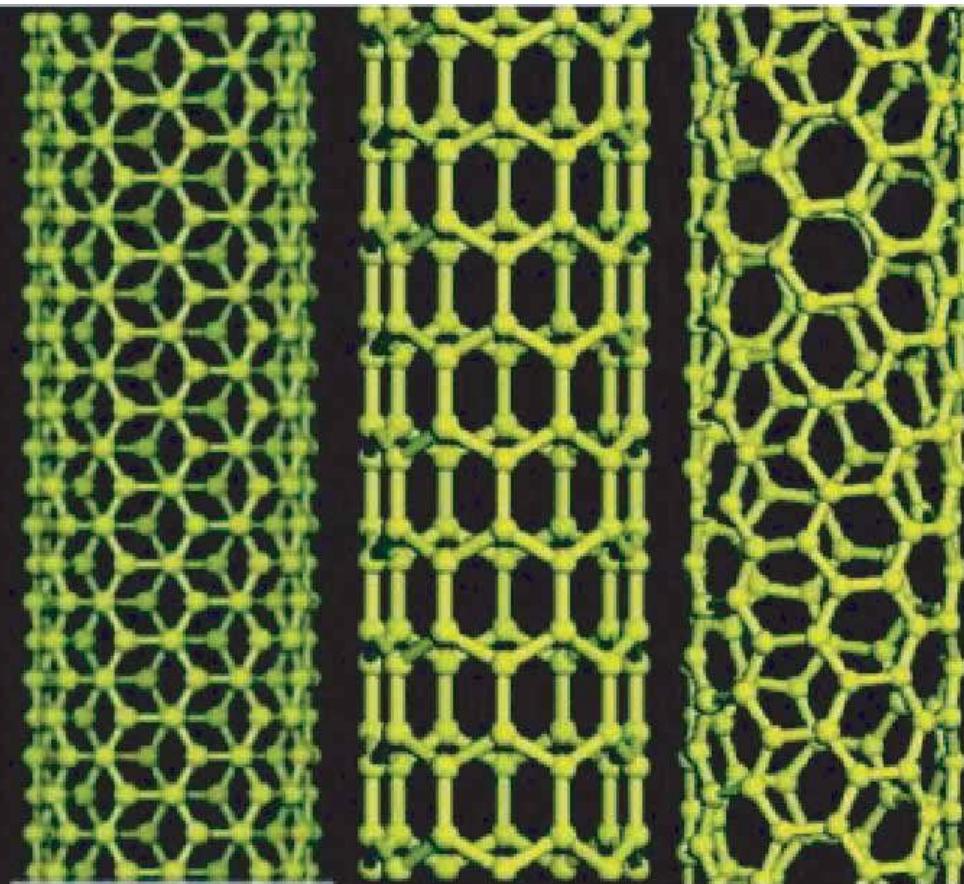


(n,m)

$n = \text{columns}$
 $m = \text{rows}$

If:

$n=m \rightarrow$
 $n \neq m \rightarrow$
 $(n,0) \rightarrow$

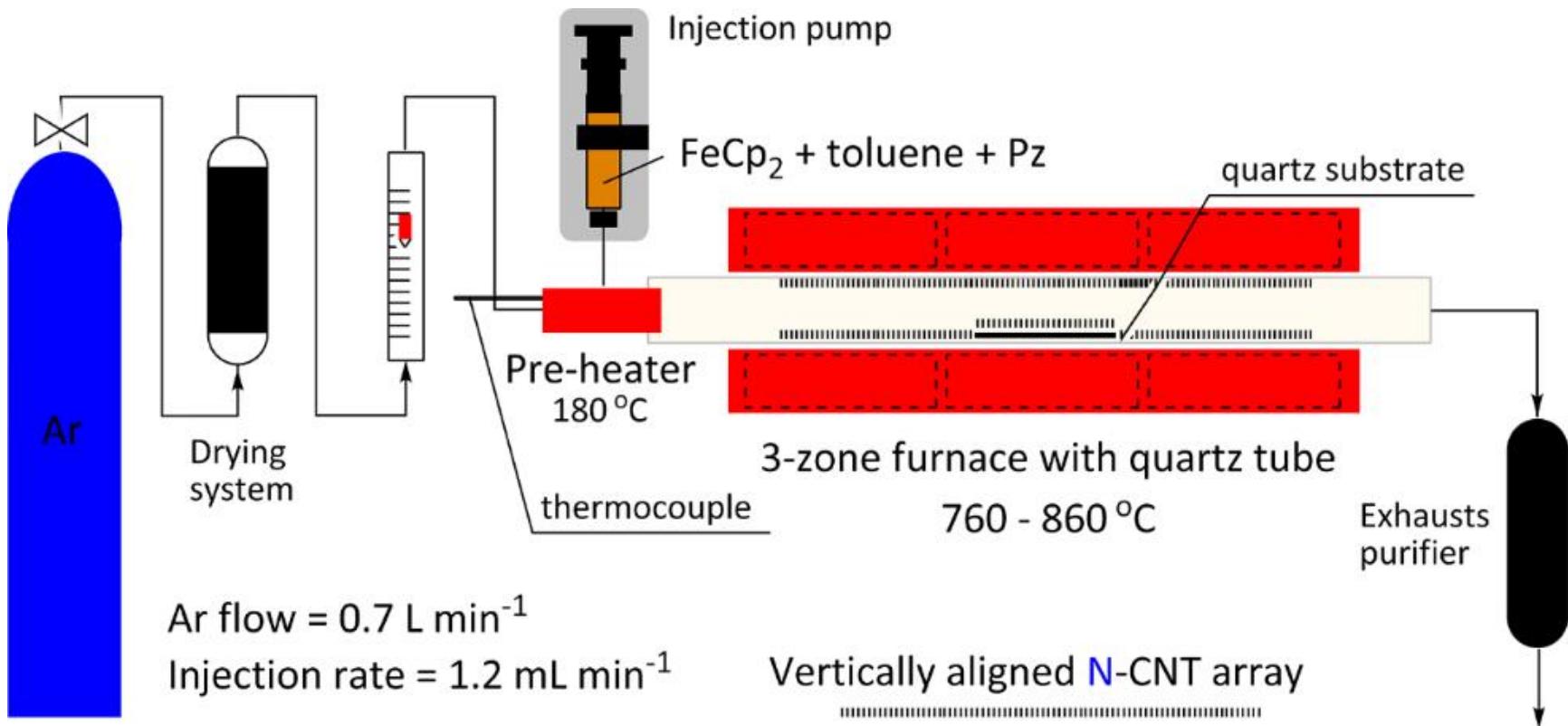


Preparation of CNTs: Chemical Vapor Deposition (CVD)

Chemical vapor deposition is becoming very popular because of its potential for scale up production.

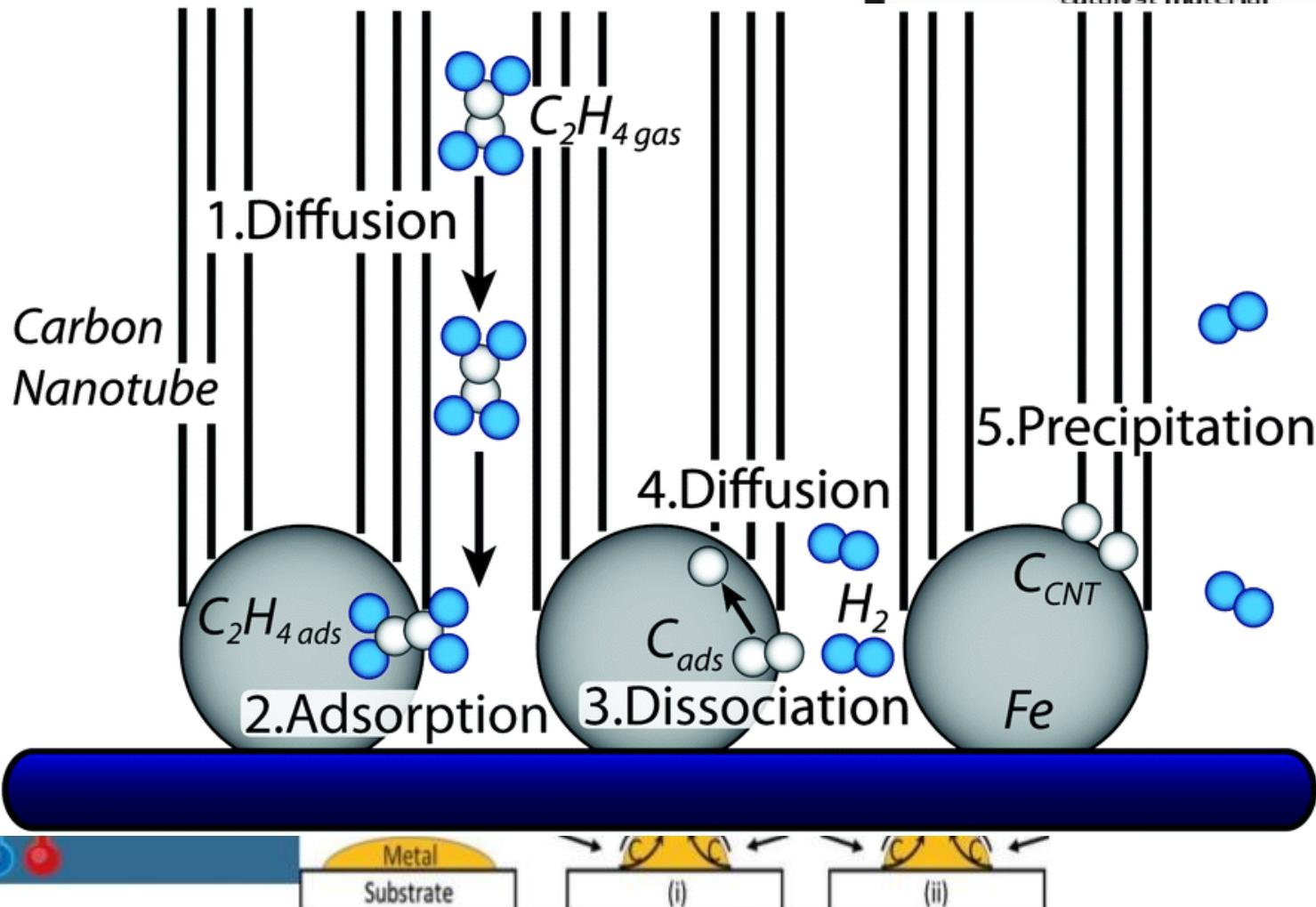
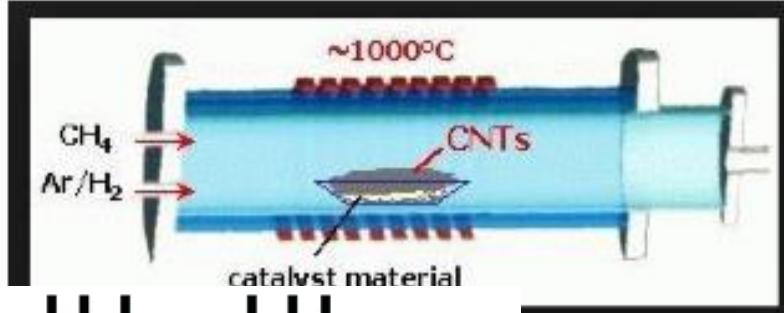
Procedure:

- This method involves pyrolysis of **hydrocarbons** (acetylene, ethylene, propylene, methane, benzene, toluene etc.) or other carbon feedstock (polymers, carbon monoxide) diluted in the stream of **inert gas** (Ar, N₂) in the furnace system over the surface **of metal catalysts** (**Fe, Ni, Co**). They can also grow **on substrates** such as **carbon, quartz, silicon**, etc.
- Decomposed carbon species dissolve in the metal nanoparticles but, due to a finite solubility of carbon in the metallic particles, **supersaturation** will be reached followed by **carbon precipitation out in the form of a fullerene dome extending into a carbon cylinder (CNT)**.
- Typical temperature range for the synthesis **is 500–1,200 °C** at atmospheric pressure.



- ❖ The above figure shows the schematic diagram of a typical catalytic chemical vapor deposition system.
- ❖ It is equipped with a horizontal tubular furnace as the reactor. The tube is made of quartz, 30 mm in diameter and 1000 mm in length.
- ❖ Ferrocene and Benzene/toulene vapors acts as the catalyst (Fe) and carbon atom precursors respectively were transported either by argon, hydrogen or mixture of both into the reaction chamber, and decomposed into respective ions of Fe and carbon atoms, resulting into carbon nanostructures.
- ❖ The growth of the nanostructures occurred in either the heating zone, before or after the heating zone, which is normally operated between 500°C and 1150°C for about 30 min. 200ml/min of hydrogen is used to cool the reactor.

CNT growth mechanism in CVD



Importance of CVD:

- ❑ The three main parameters for CNT growth in CVD are the atmosphere, carbon source, catalyst, and growth temperature.
- ❑ Low-temperature (600–900°C) yields MWNTs, whereas a higher temperature (900–1,200°C) reaction favors SWNTs growth.
- ❑ The most commonly used catalysts for CNT growth are the transition metals (Fe, Co, Ni) from carbon sources like organometallocenes (ferrocene, cobaltocene, nickelocene), nitrates and others.
- ❑ A correlation was found between the size of catalyst particles and the nanotube diameter. Hence, metal nanoparticles of controlled size can be used to grow CNTs of controlled diameter.
- ❑ The CVD method allows CNT growth in a variety of forms, *such as powder, thin or thick films, aligned or entangled, straight or coiled, or even a desired architecture of nanotubes at predefined sites on a patterned substrate.*
- ❑ It also offers better control over growth parameters in comparison to other synthesis methods.



Functionalization of Carbon Nanotubes

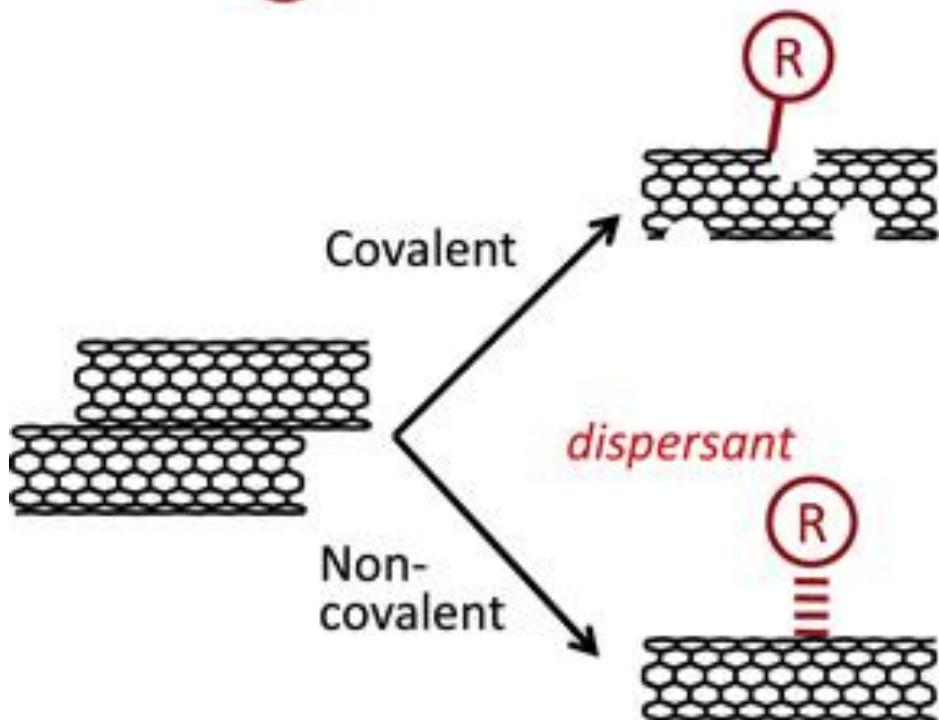
Despite CNTs's exceptional properties, there are two main limitations that hinder its use. The surface energy of CNTs is significantly different from that of matrices such as common organic solvents or polymers and ***CNTs may not have chemical affinity to the organic matrices*** and thus, the dispersion of CNTs into matrices is the biggest obstacle in practice.

The modification/ functionalization of CNTs with other materials, makes it the most attractive and ultimate candidate for a many applications which includes nanodevices, to organic electronics. The modification/ functionalization of CNTs can be simply divided into

- a) Chemical (covalent) and b) Physical (noncovalent) functionalization

Chemical functionalization is based on the covalent bond of functional groups onto carbon form of CNTs. It can be performed at the end caps of nanotubes or at their sidewalls which have many defects. Direct covalent sidewall functionalization is associated with a change of hybridization from ***sp₂* to sp₃** and a simultaneous loss of p-conjugation system.

(R) = ▶ functional groups



(R) = ▶ small molecules
▶ polymers

advantage

- high dispersion stability

disadvantage

- loss of inherent properties
- structural damage,
- shortening

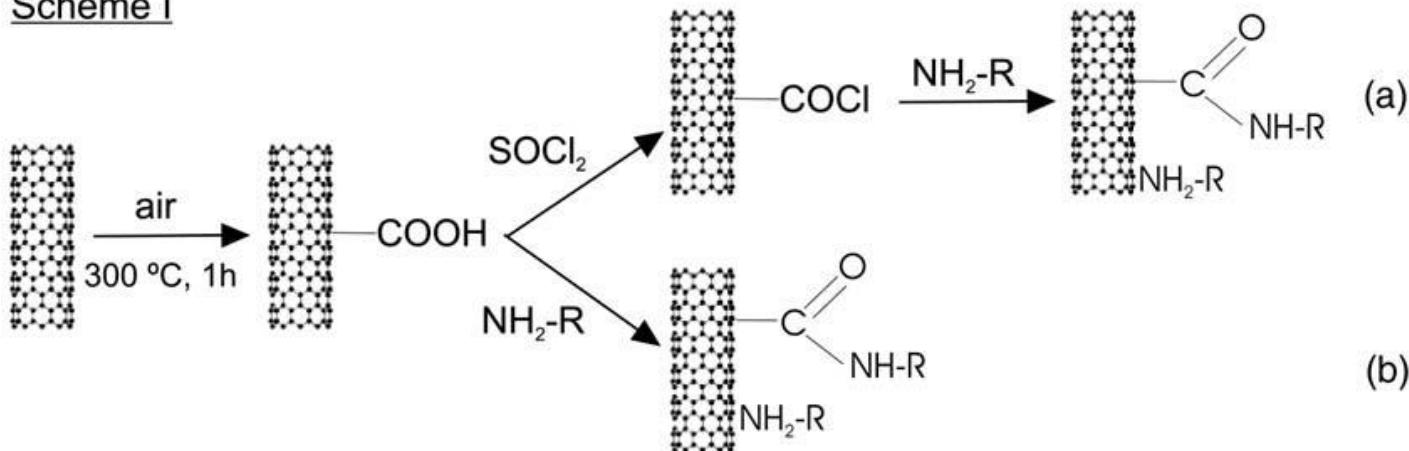
advantage

- easy procedure
- minimum damage

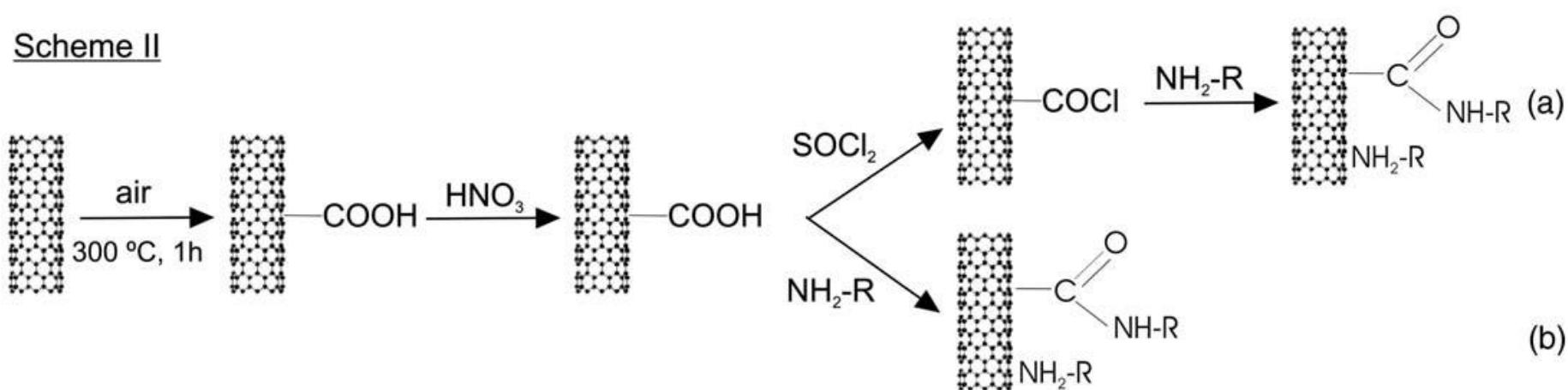
disadvantage

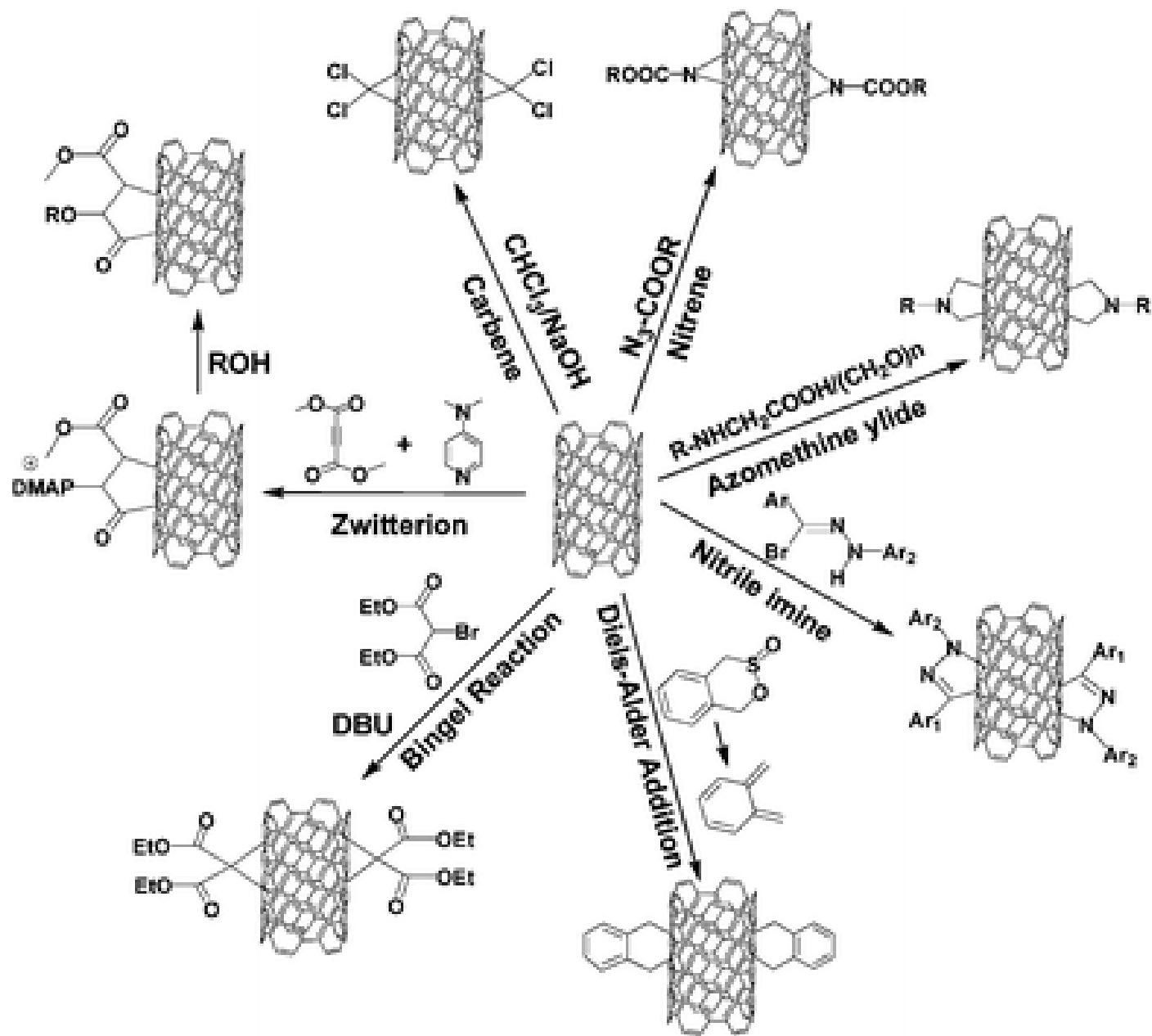
- weak coating stability

Scheme I

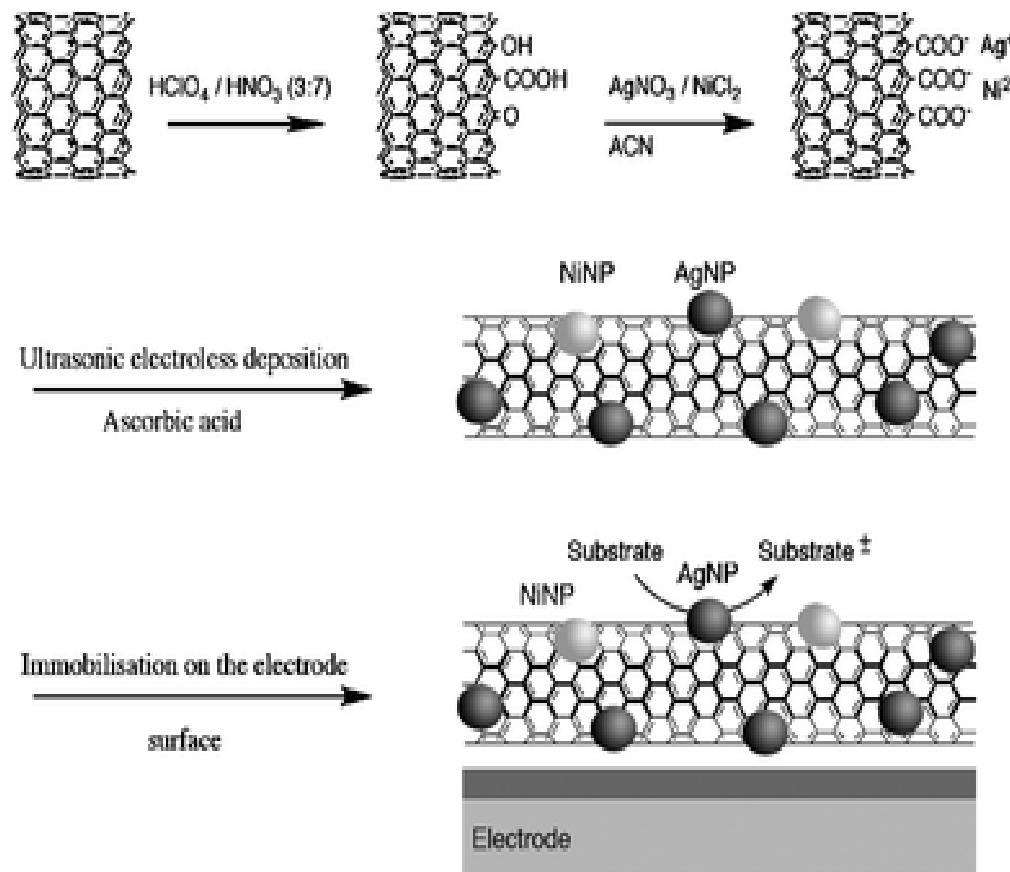


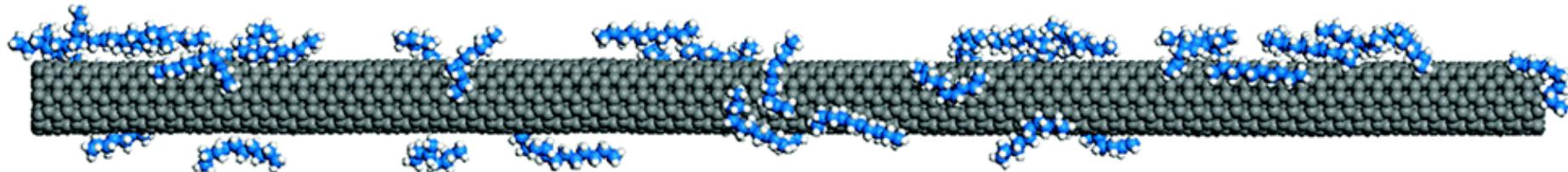
Scheme II



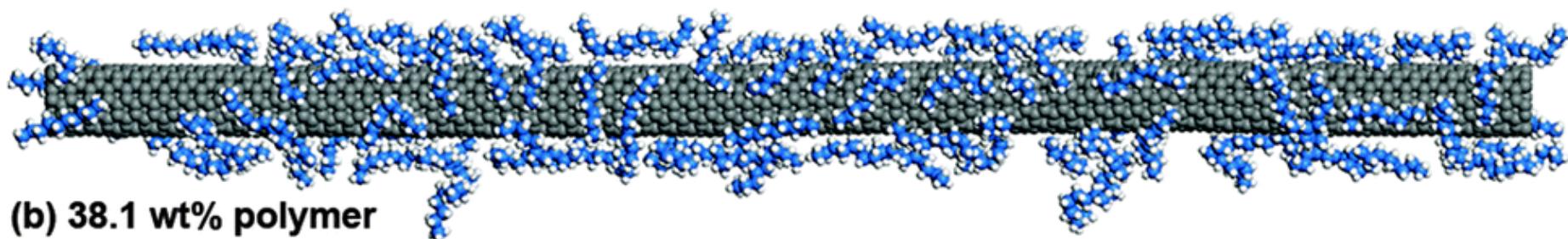


b) Non-covalent functionalization: It **does not destroy the conjugated system** of the CNTs sidewalls, and therefore it does not affect the final structural properties of the material. The CNTs are functionalized **non-covalently** by **aromatic compounds, surfactants, and polymers**, employing **π - π stacking or hydrophobic interactions** for the most part. In this approaches, the non-covalent modifications of CNTs can do much to preserve their desired properties, while improving their solubilities quite remarkably. (Ex: aromatic small molecule absorption, polymer wrapping, surfactants, biopolymers)



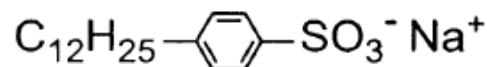


(a) 19.4 wt% polymer

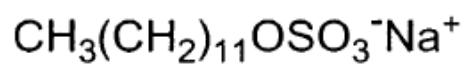


(b) 38.1 wt% polymer

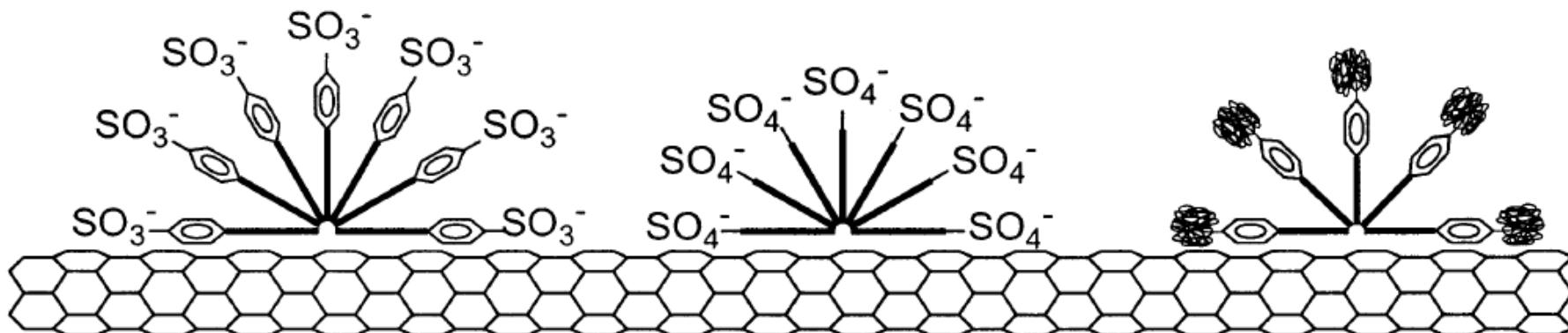
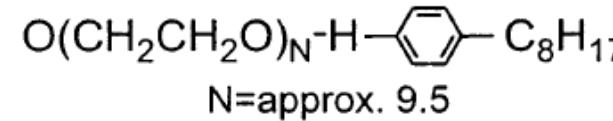
NaDDBS



SDS



Triton X-100



Properties of CNTs:

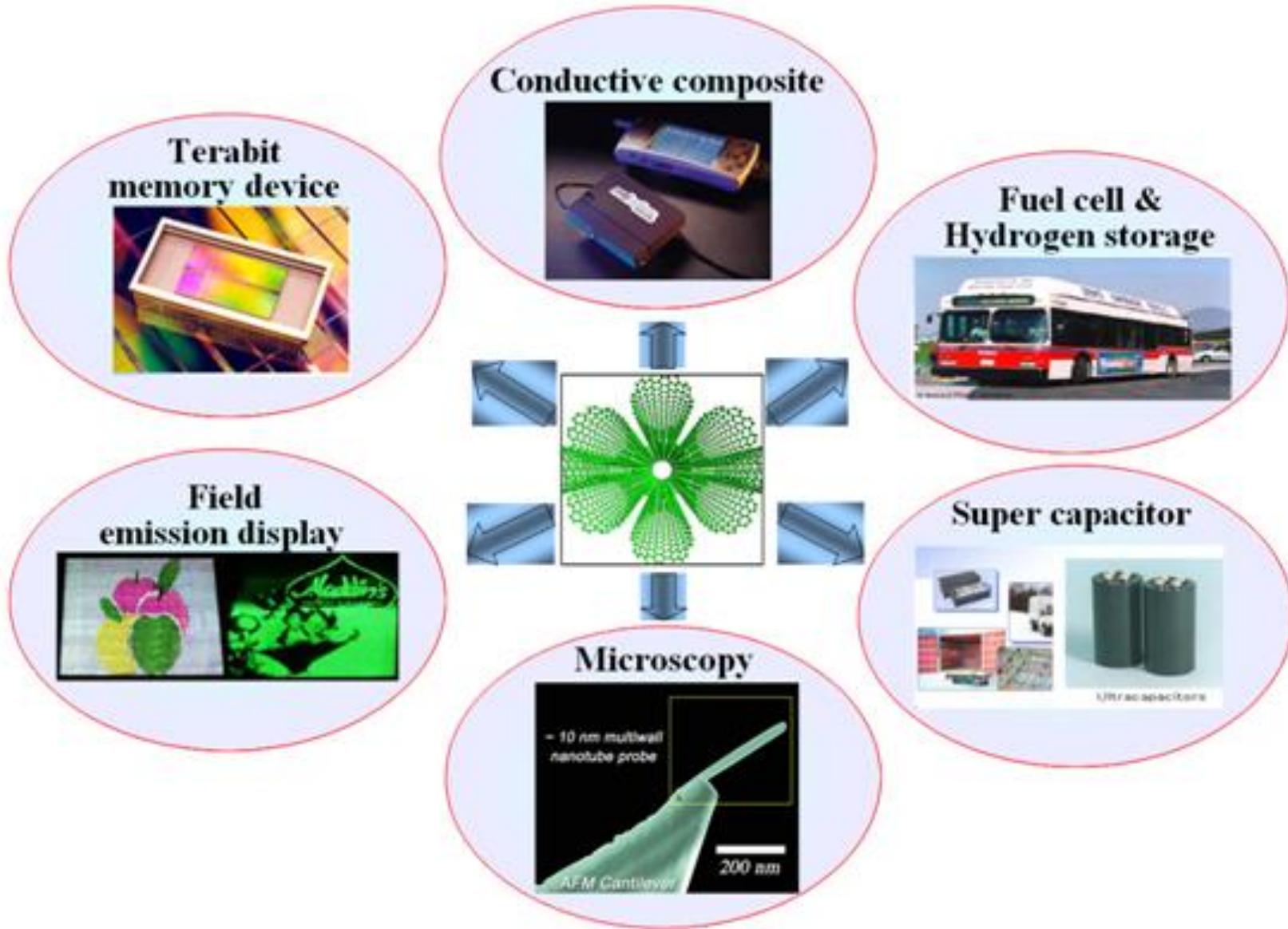
- ❑ Carbon-carbon bonds are one of the strongest bond in nature, **Composed entirely of sp² bonds**
- ❑ 132,000,000:1 Length-To-Diameter Ratio
- ❑ Diameter of 3 to 9 nm
- ❑ Lengths in the millimeter range
- ❑ Extremely high Young's modulus
- ❑ Nanotubes can be either **electrically conductive or semi conductive**, depending on their **helicity**.
- ❑ These one-dimensional fibers exhibit **electrical conductivity as high as copper, thermal conductivity as high as diamond.**
- ❑ Strength 100 times greater than steel at one sixth the weight, and high strain to failure.
- ❑ Can act as both thermal conductors and thermal insulators.

Selected electrical and mechanical properties of carbon nanotubes

Properties	CNTs	Other materials
Thermal conductivity (W/mK)	>3000	Copper= 400 Carbon fiber (pitch)=1000 Carbon fiber (PAN)=8-105
Electrical conductivity (S/m)	10^6 - 10^7	Copper= 6×10^6 Carbon fiber (pitch)= 2 - 8.5×10^6 Carbon fiber (PAN)= 6.5 - 14×10^6
Young's modulus (Tpa)	1-5	Steel=0.18-0.2 Kevlar=0.06-0.18 Diamond= 0.1-0.12
Tensile strength (Gpa)	15-150	Steel=0.38-1.55 Kevlar=3.6-3.8

Applications of CNTs:

- Optoelectronic devices (Field Emission Display (FED))
- As *electrodes in batteries, capacitors and super capacitor electrodes.*
- As *electrode catalyst supports in Polymer Electrolyte Membrane (PEM) fuel cells*
- *Hydrogen Storage material in hydrogen fuel car.*
- As electrically *powered artificial muscles.*
- Elctrocatalyst for water splitting, H₂ production.
- Adsorbent and photocatalyst for organic pollutants degradation.
- Sensor for heavy metal ion, gases, volatile organic compounds and biomolecules.
- Drug carriers



Graphene: *The perfect atomic lattice in single sheet.*

The carbon nanomaterial having only surface.

- Graphene, an excellent electronic material, discovered in 2004 by **A. K. Geim** and **K. S. Novoselov**, and received Nobel prize in chemistry for this discovery in 2010.
- It has enormous potential in the electronic device community, for example, field-effect transistor, transparent electrode, etc.

Graphene is an allotrope of carbon made of a single layer of carbon atoms that are bonded together in a repeating pattern of hexagons.

- It is one million times thinner than paper;
- It is also the basic structural element of other allotropes, including charcoal, carbon nanotubes and fullerenes.
- Spherical carbon nanomaterials are referred to as *fullerenes*, while cylindrical ones are called *carbon nanotubes*.
- SWCNT contains one graphene sheet that rolls up to form a cylinder. MWCNT consist of several graphene sheets rolled up together to form concentric cylinders with large annular space at centre.

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MENU



LATEST



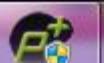
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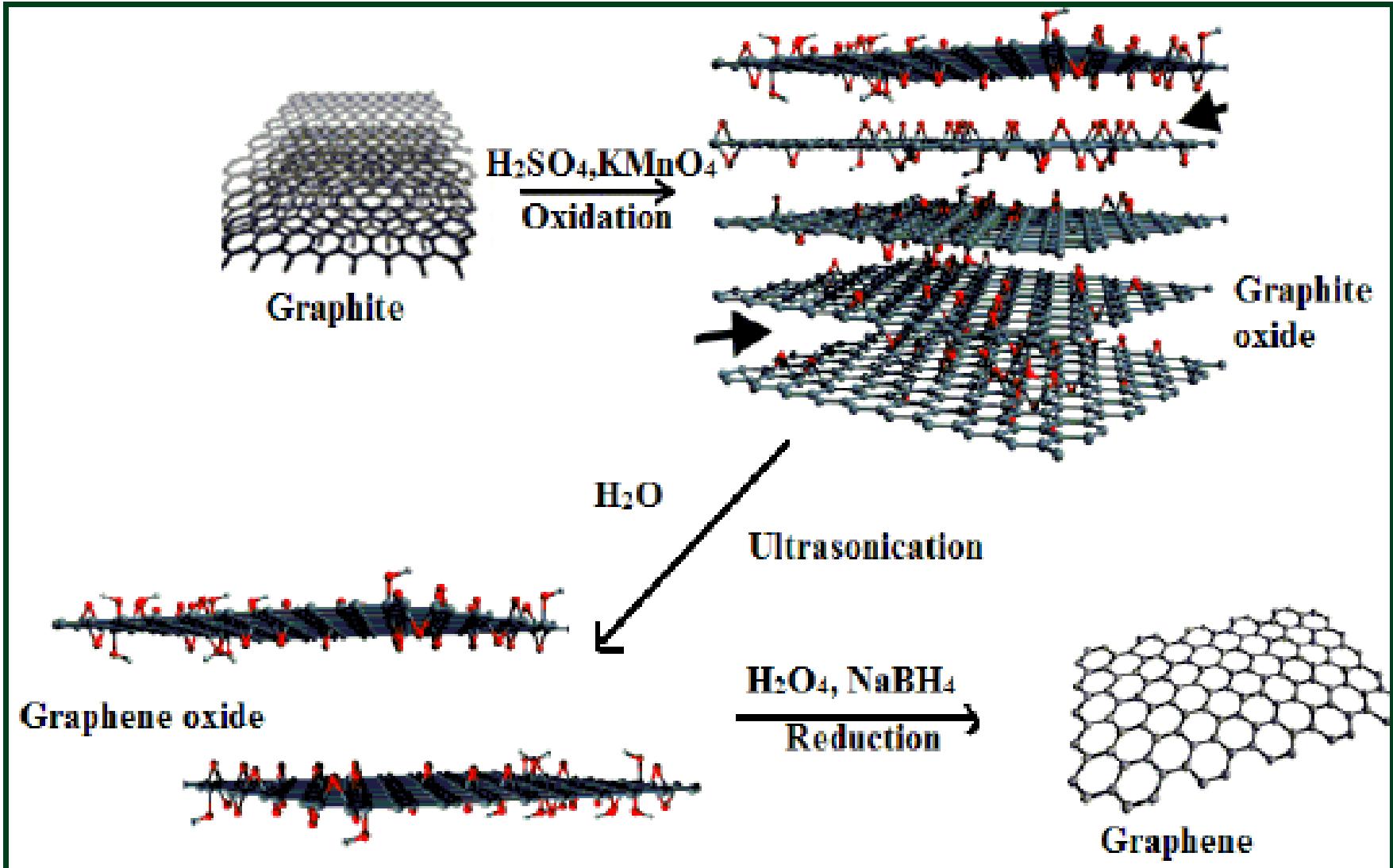
Professor of
Condensed Matter
Physics

School of Physics and
Astronomy

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Synthesis of Graphene Oxide and Reduced Graphene Oxide (rGO)

Modified Hummer's Method



Stage-I: Synthesis of GO (graphene oxide) from graphite powder

Graphite powder (2 g) + 1 g sodium nitrate + 46 ml H₂SO₄ (dissolved with stirring in ice bath)

Slow addition of KMnO₄ (6 g) during stirring of 30 minutes (temperature remains below 20°C)

Stir for 30 minutes at 40°C and add 80 ml of water

Stir for another 90 minutes at 90°C and add 200 ml water and 6 ml H₂O₂

Filter and wash the solution with DI water and HCl

Dissolve filtered paste in 100 ml water and ultrasonicate for 1 hour

Centrifuge the solution and dry the obtained GO powder at room temperature

Stage-II: Synthesis of Graphene from GO (graphene oxide)

GO (100 mg) dissolved in to 100 ml water

Add Hydrazine hydrate (10 μ l, 0.2×10^{-3} mol)

Reflux for one hour at 80°C

Add sodium borohydride (1mg)

Reflux for 36 hours at 100°C

Filter and wash with DI water

Dry at 60°C

Functionalisation of Graphene:

Graphene has been functionalized by both covalent and noncovalent means to disperse or solubilize them in different solvents

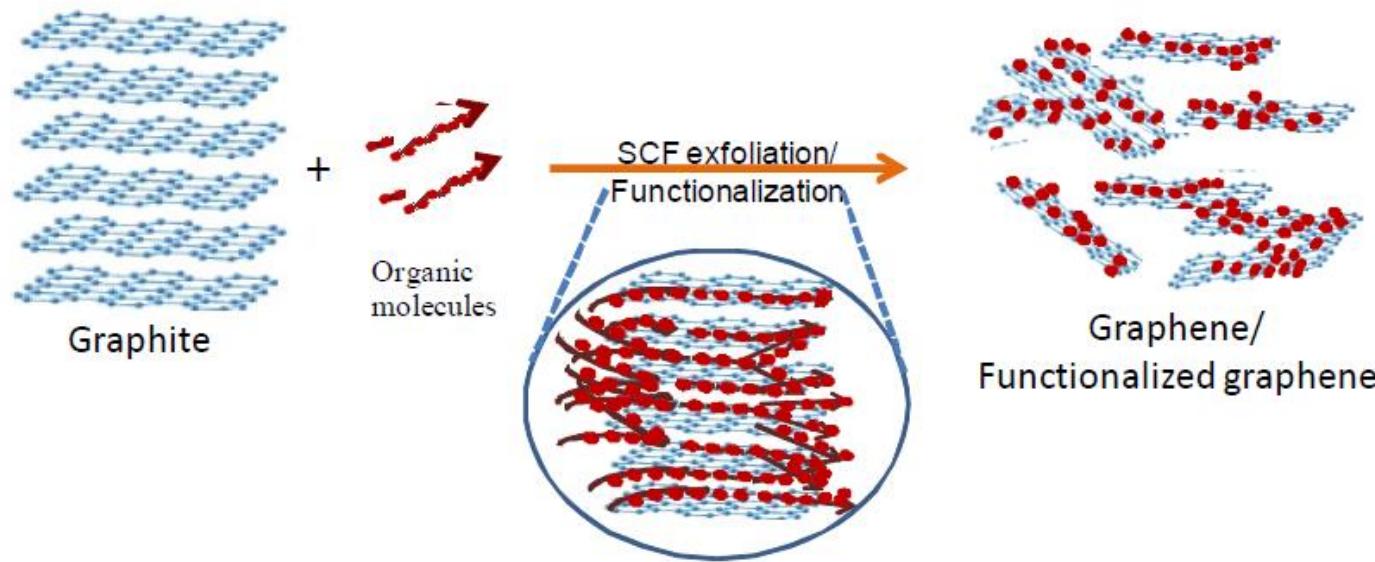
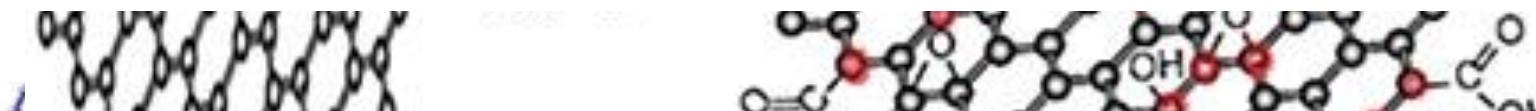
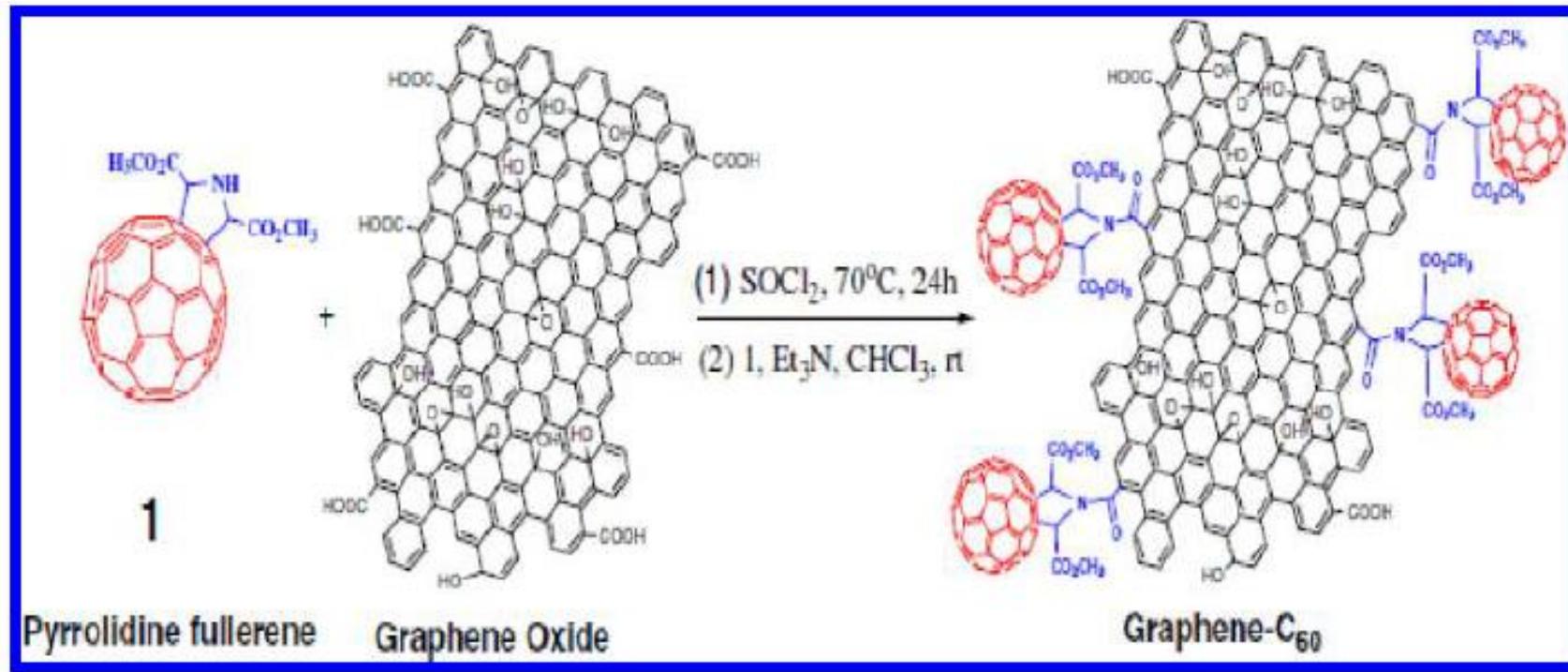
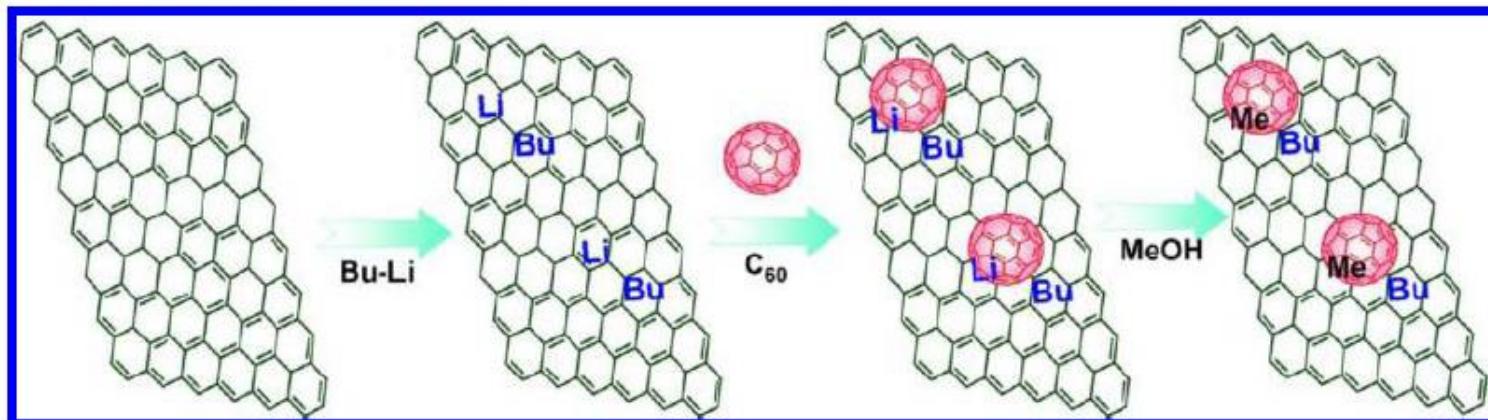
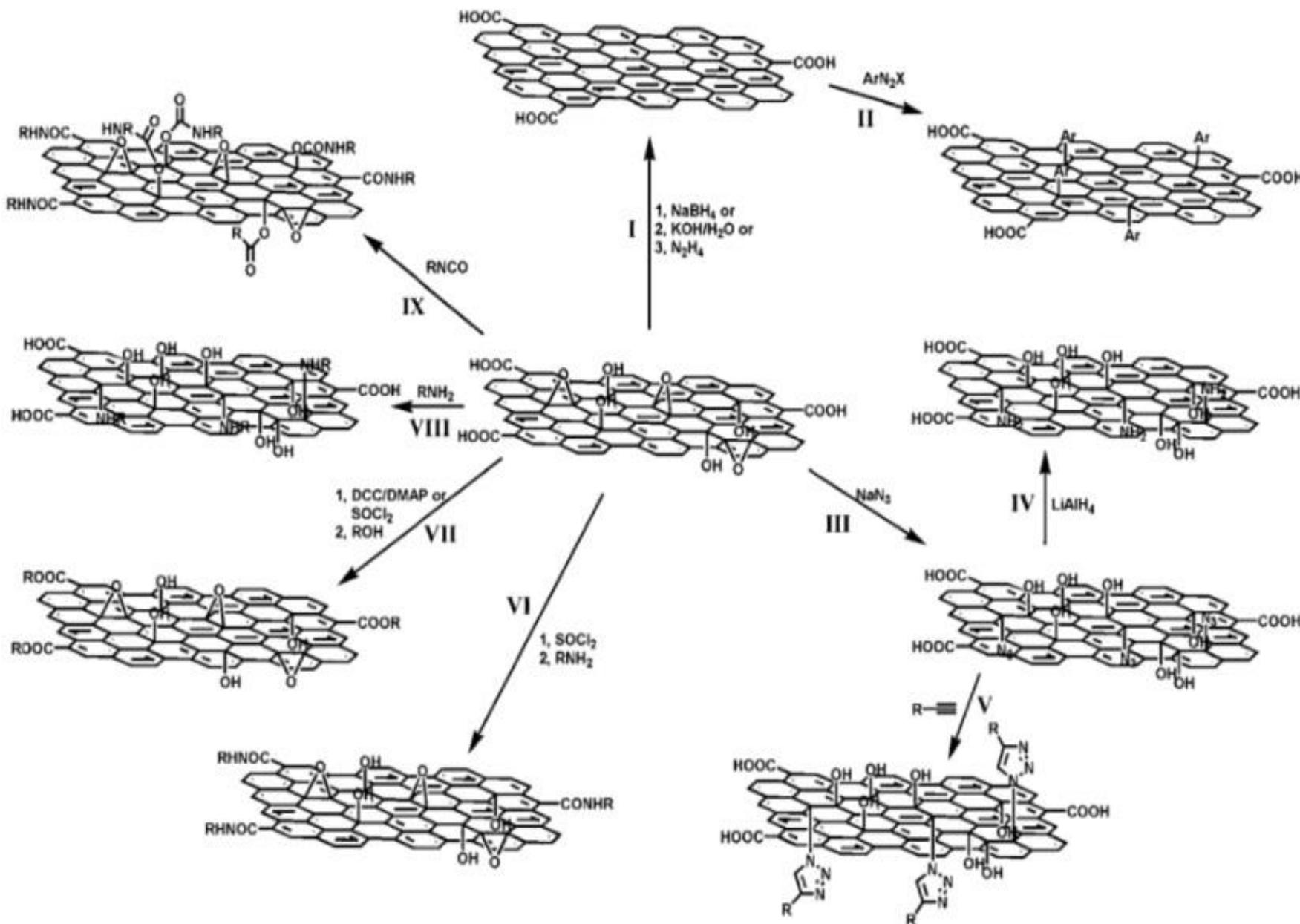


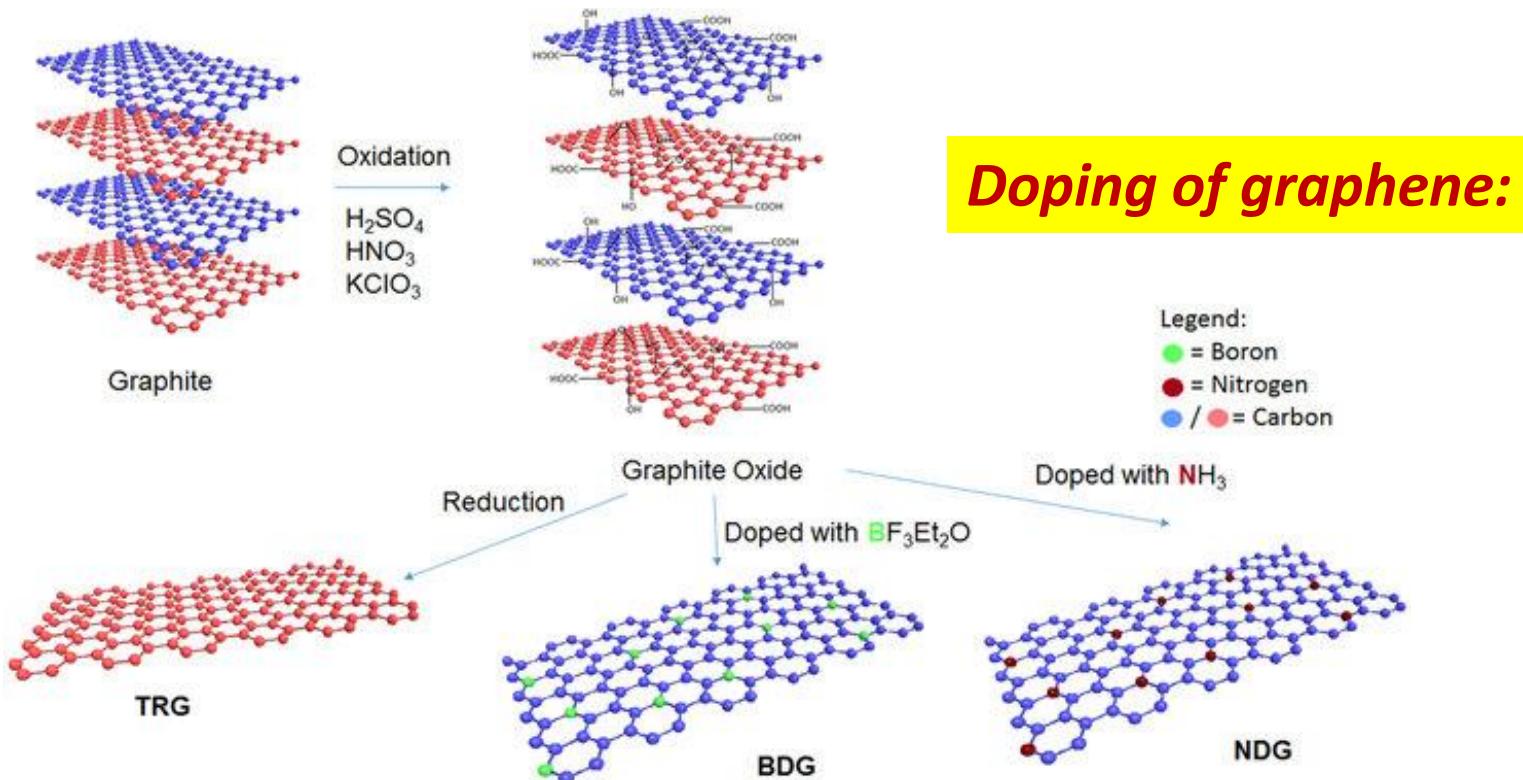
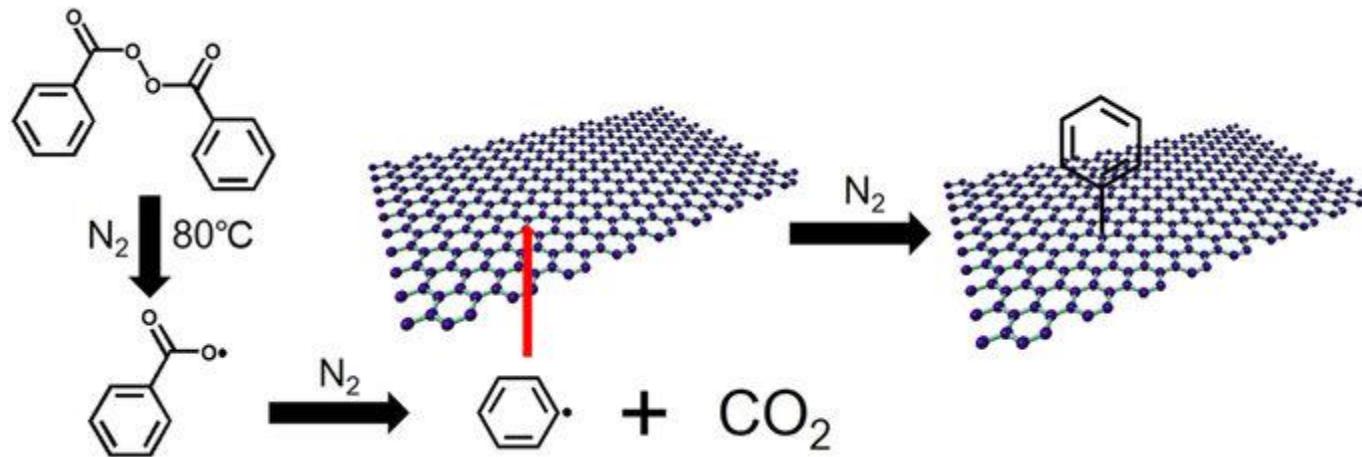
Fig. 5. Schematic illustration of graphene sheet functionalization with organic molecules using supercritical process.



SCHEME 4. Synthetic Route for Grafting C₆₀ onto Graphene through Lithiation Reaction with n-Butyllithium. Adapted from reference 24 with permission. Copyright 2011, American Chemical Society.



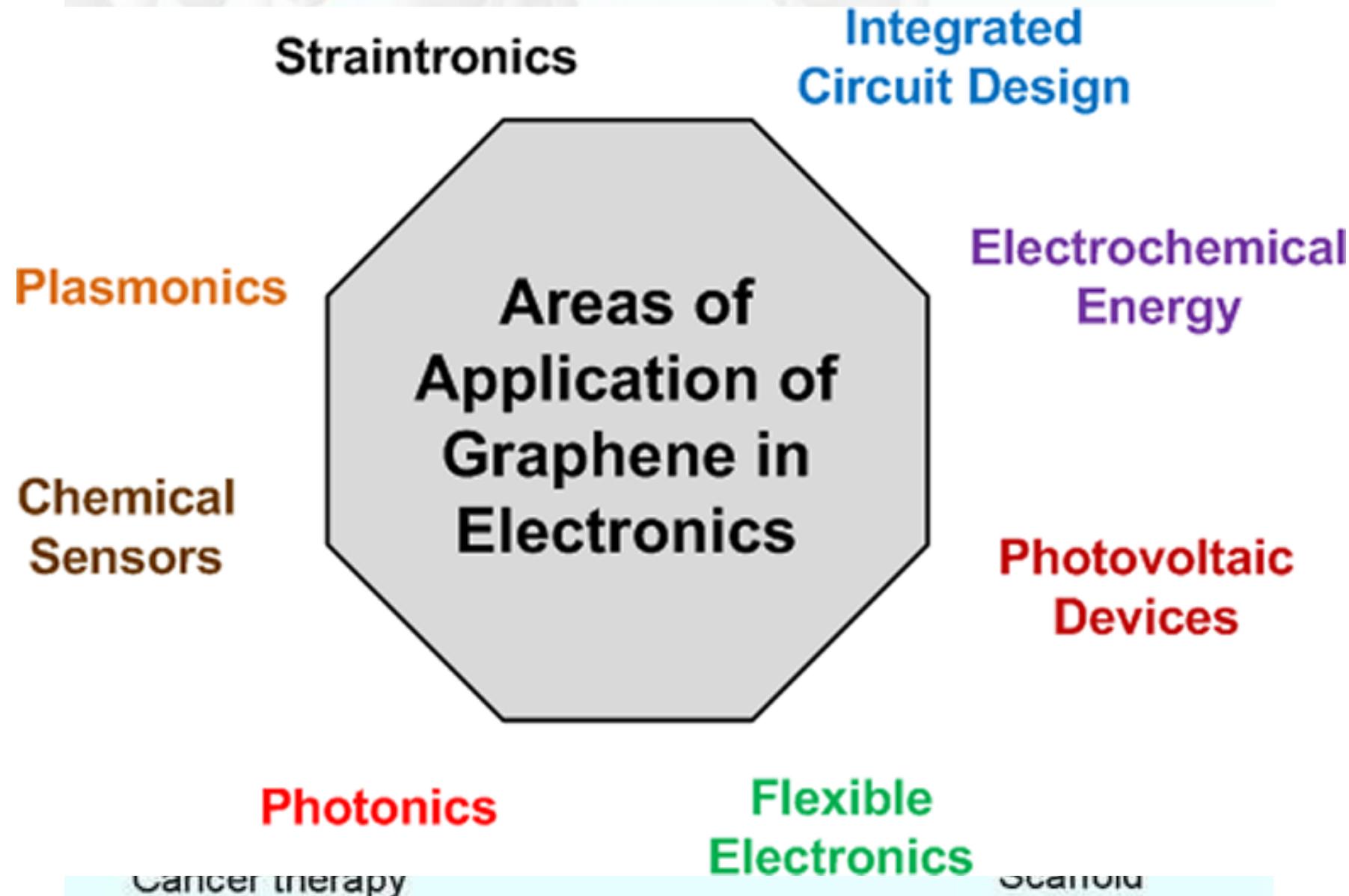




Applications of Graphene

The image is a collage of various applications of Graphene, overlaid on a background of a hexagonal graphene lattice structure.

- Flexible solar cell:** An inset image shows a hand holding a flexible black cylindrical device.
- Large-screen display:** An inset image shows a large-scale display screen showing a map of the world.
- Touch screen device:** An inset image shows a hand holding a smartphone.
- Catalyst for organic reactions:** A diagram shows a green molecular structure (likely an organic reactant) reacting with a black hexagonal lattice (Graphene).
- Electrode:** An inset image shows a dark, granular material in a petri dish.
- Polymer additive:** An inset image shows a small electronic device with a blue and white design.
- Graphene Oxide (GO):** A chemical structure diagram of Graphene Oxide (GO) is shown, featuring a hexagonal lattice with various functional groups: CO₂H, OH, O, and HO.



#####END#####