

# NANOCHEMISTRY

## INTRODUCTION

The prefix nano in the word nanotechnology means a billionth  $1 \times 10^{-9}$  m. Atoms are very small and the diameter of a single atom can vary from 0.1 to 0.5 nm. It deals with various structures of matter having dimensions of the order of a billionth of meter.

## BASICS OF NANOCHEMISTRY

### 1. Nanoparticles

Nanoparticles are the particles, the size of which ranges from 1-50 nm. Generally they are obtained as colloids. The colloidal particles have a tendency to remain single crystal and hence are called as nanocrystals. A large percentage of atoms in nanocrystals are present on the surface.

Nanocrystals possess electronic, magnetic and optical properties. Since the nanoparticles exhibit an electronic behavior, governed by the quantum physics, they are called as quantum dots.

### 2. Nanomaterials

Nanomaterials are the materials having components with size less than 100 nm at least in one dimension.

Nanomaterials in 1 D	• Thin films & coatings
Nanomaterials in 2 D	• Nanowires and nanorods
Nanomaterials in 3 D	• Colloids & Precipitates

### 2. Nanoscience (or) Nanochemistry

Nanoscience is defined as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales.

### 4. Nanotechnology

Nanotechnology is defined as the design, characterization, production and applications of structures, systems and devices by controlling size and shape at  $10^{-9}$  m scale or the single atomic level.

## DISTINCTION BETWEEN NANO PARTICLES, MOLECULES AND BULK MATERIALS

1. The size of nano particles are less than 100 nm in diameter, molecules are in the range of picometers, but bulk materials are larger in micron size.
2. Molecule is a collection of atoms, nano particles are collection of few molecules that is less than 100 nm but bulk materials contains thousands of molecules.

3. Surface area of nano particles is more than the bulk materials.
4. Hardness of nano materials is 5 times more than the bulk materials.
5. Strength of nano materials is 3-10 times higher than the bulk materials.
6. Nano particles possess size dependent properties, but bulk materials possess constant physical properties.
7. Corrosion resistance is more than the bulk materials, hence localized corrosion in nano materials is stopped.
8. Behavior of bulk materials can be changed, but cannot enter inside the nano particles.
9. Nano particles, due to its size, possess unexpected optical (visible) properties.

**Example:**

- (i) Gold nano particles appear deep red to black colour in solution compared to yellow colour with gold.
  - (ii) ZnO nano particles possess superior UV blocking property compared to bulk material.
  - (iii) Absorption of solar radiation in photovoltaic cell containing nano particles are higher than the film (bulk material).
10. Nano particles possess lower melting point than the bulk materials.

**Example:**

Gold nano particles melt at lower temperature (300°C) for 2.5 nm, but gold slab melts at 1064°C.

11. Sintering of nano particles takes place at lower temperature and in short time than the bulk materials.
12. Electrical properties, resistivity of nano particles are increased by 3 times.
13. Suspension of nano particles is possible, because nano particles possess high surface area, but bulk materials cannot.
14. The wear resistance of nano particles are 170 times higher than the bulk materials.

**COMPARISON OF ATOM/ MOLECULE, NANO PARTICLES/ CLUSTER, BULK MATERIALS**

S. No	Properties	Atom/ Molecule	Nano particles/ Nano cluster	Bulk material
1	Size of constituting particles	Few Angstroms (Å) $10^{-10}$ m	Angstrom nanometer $10^{-10}$ m to $10^{-9}$ m	Microns to higher
2	Number of constituting particles	1 for atom, many for molecules.	2 to several thousands	Infinite
3	Electronic structure.	Confined.	Confined.	Continuous.

4	Geometric structure.	Well-defined structure and predictable.	Well-defined structure and predictable.	Crystal structure decides.
	Example	NaCl, HCl	(NaCl) <sub>n</sub>	Gold bar & Silver bar

## PROPERTIES OF NANO-MATERIALS

### 1. Melting points

Nano-materials have a significantly lower melting point and appreciable reduced lattice constants. This is due to huge fraction of surface atoms in the total amount of atoms.

### 2. Optical properties

Reduction of material dimensions has pronounced effects on the optical properties of nano-materials are different from bulk forms.

The change in optical properties is caused by two factors

- (i) The quantum confinement of electrons within the nano-particles increases the energy level spacing.

#### Example:

The optical absorption peak of a semiconductor nano-particles shifts to a short wavelength, due to an increased band gap.

- (ii) Surface plasma resonance, which is due to smaller size of nano –particles than the wavelength of incident radiation.

#### Example:

The colour of metallic nano-particles may change with their sizes due to plasma resonance.

### 3. Magnetic properties

Magnetic properties of nano materials are different from that of bulk materials. Ferro-magnetic behavior of bulk materials disappear, when the particle size is reduced and transfers to super-paramagnetics. This is due to the huge surface area.

### 4. Mechanical properties

The nano-materials have less defects compared to bulk materials, which increases the mechanical strength.

- (i) Mechanical properties of polymeric materials can be increased by the addition of nano-fillers.
- (ii) As nano-materials are stronger, harder and more wear resistant and corrosion resistant, they are used in spark plugs.

**Example:**

Nano-crystalline carbides are much stronger, harder and wear resistant and are used in micro drills.

**5. Electrical properties**

- (i) Electrical conductivity decreases with a reduced dimension due to increased surface scattering. However it can be increased, due to better ordering in micro-structure.

**Example:**

Polymeric fibres.

- (ii) Nanocrystalline materials are used as very good separator plates in batteries, because they can hold more energy than the bulk materials.

**Example:**

Nickel-metal hydride batteries made of nanocrystalline nickel and metal hydride, require far less frequent recharging and last much longer.

**6. Chemical properties**

Any heat treatment increases the diffusion of impurities, structural defects and dislocations and can be easily push them to the nearby surface. Increased perfection will have increased chemical properties.

**SIZE DEPENDENT PROPERTIES**

Nearly all the properties like hardness, strength, ductility, melting point and density change for nano materials. These behaviours vary so significantly by a mere reduction in grain size. Nanomaterials are composed of grains and grain boundaries. Nanometre sized grains contains only a few thousands of atoms within each grain.

A large number of atoms reside at the grain boundaries. As the grain size decreases, there is a significant increase in the volume fraction of grain boundaries or interfaces.

The mechanical and chemical properties of nanomaterials are significantly altered by defect dynamics. The elastic property of nanomaterials are different from that of bulk alloys due to the presence of increased fraction of defects.

**Example**

- i. Nano crystalline ceramics are tougher and stronger than those with coarse grains.
- ii. Nano-sized metals exhibit significant decrease in toughness and yield strength increases.

**SYNTHESIS OF NANO MATERIALS**

Nano materials are synthesised based on two approaches.

- (i) Top-down or Physical or Hard methods
- (ii) Bottom-up or Chemical or Soft methods

## TOP-DOWN METHODS

It involves conversion of large particles in to smaller particles of nano-scale structure. This method is carried out by the following processes.

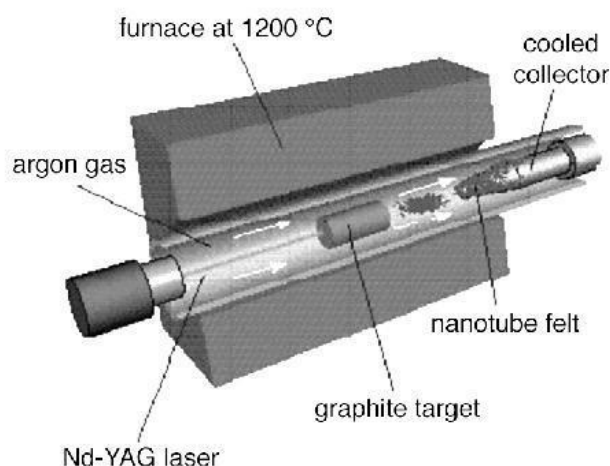
- (i) Laser ablation
- (ii) Chemical vapour deposition
- (iii) Electro-deposition

### 1. Laser Ablation

In laser ablation high power laser pulse is used to evaporate the matter from the target. The total mass ablated from the target per laser pulse is referred to as the ablation rate.

#### Reaction setup

A typical laser ablation setup is shown in the figure.



When a beam of laser is allowed to irradiate the target, a supersonic jet of particles is evaporated from the target surface. Simultaneously an inert gas such as argon or helium is allowed into the reactor to sweep the evaporated particles from the furnace zone to the colder collector.

The ablated species condense on the collector. The ablation takes place in a vacuum chamber either in vacuum or in the presence of some background gas.

### 2. Chemical vapour deposition (CVD)

It is a process of chemically reacting a volatile compound of a material with other gases to produce a non-volatile solid that deposits automatically on a suitably placed substrate. The substrates can be materials like mica, silica quartz or alumina coated with nanoparticle catalysts. The precursors used for the synthesis of carbon nano tubes are acetylene, ethylene or methane.

CVD reaction requires activation energy to proceed. This energy can be provided by several methods.

#### (a) Thermal CVD

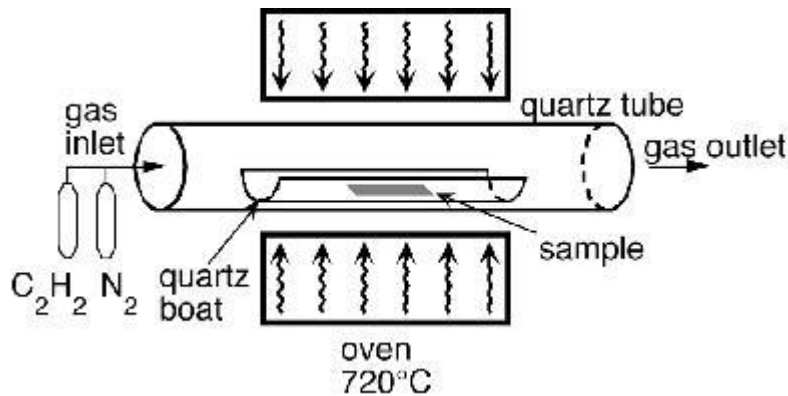
In thermal CVD the reaction is activated by high temperature above  $900^{\circ}\text{C}$ .

#### (b) Plasma CVD

In plasma CVD the reaction is activated by plasma at temperature between  $300\text{-}700^{\circ}\text{C}$ .

### (c) Laser CVD

In laser CVD reaction occur when thermal energy of laser falls on the substrate.



### Various steps involved in the synthesis by CVD

The various steps involved in the synthesis of nanomaterials by CVD are summarized as follows.

1. Transport of gaseous reactants on the surface.
2. Adsorption of gaseous reactant on the surface
3. Catalysed reaction occurs on the surface.
4. Product diffuses to the growth site.
5. Nucleation and growth occurs on the growth site.
6. Desorption of reaction product away from the surface.

### CVD Reactor

#### 1. Hot wall CVD

They are usually tubular in form, and heating is accomplished by surrounding the reactor with resistance elements.

#### 2. Cold wall CVD

In cold wall CVD reactors the substrates are directly heated inductively by graphite susceptors, while chamber walls are air or water cooled.

## ELECTRODEPOSITION

### *Definition:*

Electro deposition is a method by which ions from the solution are deposited at the surface of cathode. The deposited material can form a continuous layer, wires or tubes when suitable template matrixes are used.

Electro deposition can be performed near room temperature from water based electrolytes.

### *Principle*

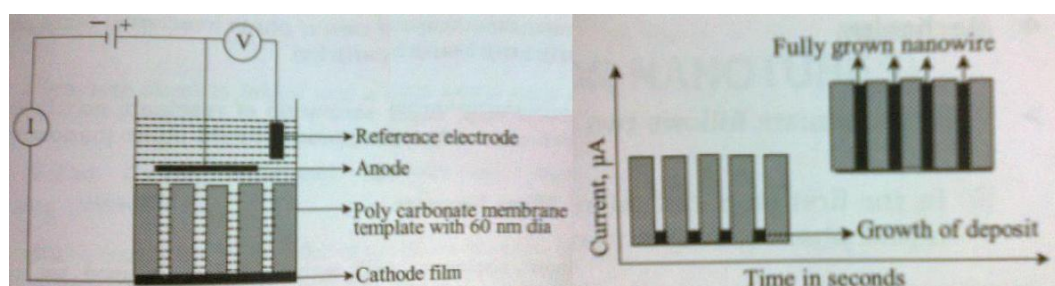
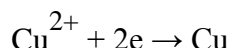
When a voltage is applied between the cathode and anode, due to redox reactions, the cations in the electrolyte solutions are attracted and get reduced (deposited) near the cathode.

Without a template, thin films are formed by electrodeposition with template, nanowires and nano rods can be fabricated by this method.

The amount of deposited material, thickness of the layer or wire length depends upon the deposition time and matrix structure.

***Template based growth of nanowires using electrochemical deposition:***

Template is attached to the cathode which is subsequently brought into contact with aqueous solution containing metal cations to be deposited the anode is placed in the deposition solution parallel to the cathode. When an electric potential is applied, cations diffuse into the pores and reduced at the cathode, resulting in the growth of nanowires inside the pores of the template.



Metal nanowire including Ni, Co, Cu and Au can be fabricated by this method.

**BOTTOM UP (OR) CHEMICAL (OR) SOFT METHOD (OR) SMALL TO BIG METHODS:**

It involves building-up of materials from the bottom by atom by atom, (0.1 nm) molecule by molecule or cluster by cluster. This method is carried out by the following process.

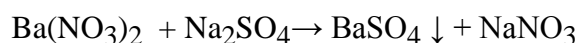
**1. PRECIPITATION**

Generally nanoparticles are synthesised by the precipitation reaction between the reactants in presence of water soluble inorganic stabilizing agent.

Examples:

***(i) Precipitation of BaSO<sub>4</sub> nanoparticles:***

10 gm. of sodium hexametaphosphate (stabilizing agent) was dissolved in 80 ml of dissolved water in 250 ml beaker with constant stirring. Then 10 ml of 1M sodium sulphate solution was added followed by 10 ml 1M Ba(NO<sub>3</sub>)<sub>2</sub> solution the resulting solution was stirred for 1 hr. precipitation occurs slowly, the resulting precipitate was then centrifuged, washed with distilled water and vacuum dried



In absence of stabilizing agent, bulk BaSO<sub>4</sub> is obtained.

### ***(ii) Precipitation by reduction***

Reduction of metal salt to the corresponding metal atoms. These atoms act as nucleation centres leading to formation of atomic clusters are surrounded by stabilizing molecule that prevents that the atoms agglomerating.

## **2. THERMOLYSIS**

Thermolysis is characterized by subjecting the metal precursors (usually organometallic compounds in oxidation state zero) at high temperatures together with a stabilizing agent. Nano particles show an increase in size relating to the temperature rise. This is due to the elimination of stabilizing molecule, generating a greater aggregation of the particles.

### **(a) Hydrothermal synthesis**

#### **Definition and principle**

Hydrothermal synthesis generally refers to processing aqueous solution of metal salts on autoclaving of precursor material at elevated temperatures (100-300 °C) and pressure above 1 atm.

Hydrothermal process, water is mixed with metal precursors and the solution mixture is placed in an autoclave and maintained at relatively high temperatures and pressures to carry out the growth of nanoparticles.

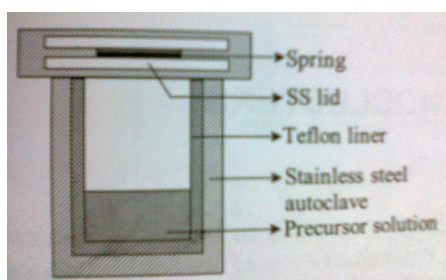
At these super critical conditions:

1. Solubility of most ionic species increases
2. Viscosity of water decreases and exhibits greater mobility
3. The increase of mobility allows Ostwald ripening to continue at a faster rate increasing the uniformity of the precipitate.

Size and morphological control in hydrothermal reactions is achieved by controlling the conditions of time and temperature.

The reactant conditions of precursor, material and pH dictate the phase purity of nanoparticles.

#### **DIAGRAM**



#### **Advantages:**

1. Most of materials can be made soluble in proper solvent by heating and pressuring the system close to its critical point.
2. Easy and precise control of the size, shape distribution.

#### **Disadvantages:**

- Expensive autoclave is required.
- Safety issues during the reaction.
- Could not monitor and observe the reaction



## **(b) Solvothermal synthesis**

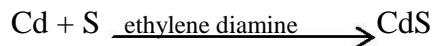
In solvothermal synthesis, non-aqueous solvents such as benzene, xylene, dimethoxyethane ethylene diamine etc. are used in place of water used in hydrothermal synthesis. This is because the precursors used are sensitive to water.

Solvothermal methods are successfully employed as solution routes to produce 1-D nano structure such as CdS, GaN, InP nanorods etc.

In this process, organic solvents are mixed with metal precursors with suitable templating agents such as amines to produce nanorods. The solution mixture is placed in an autoclave maintained at relatively high temperatures and pressures to carry out the process.

### **Preparation of semiconducting nanorods**

Cadmium sulphide (CdS) nanorods can be prepared by adding an appropriate amount of sulphur dissolved in ethylene diamine and cadmium powder into an autoclave filled with ethylene diamine .the autoclave was maintained at 120-190 °C under pressure for 3-6 hr. and cooled to room temperature a bright yellow product was obtained.



### **USES:**

1. Many geometries including thin film, bulk powder, single crystals can be prepared.
2. Thermodynamically stable novel materials can also be prepared easily.

## **Nanowires**

Nano-wire is a material having an aspect ratio (length to width ratio) greater than 20 and length 10-100 nm. Nano-wires are also referred to as “quantum wires”.

Examples:

Nano-wires of metals: Au, Ni, Pt

Nano-wires of semiconductors: In P, Si, GaN

Nano-wires of insulators: SiO<sub>2</sub>, TiO<sub>2</sub>

Molecular nano-wires: DNA

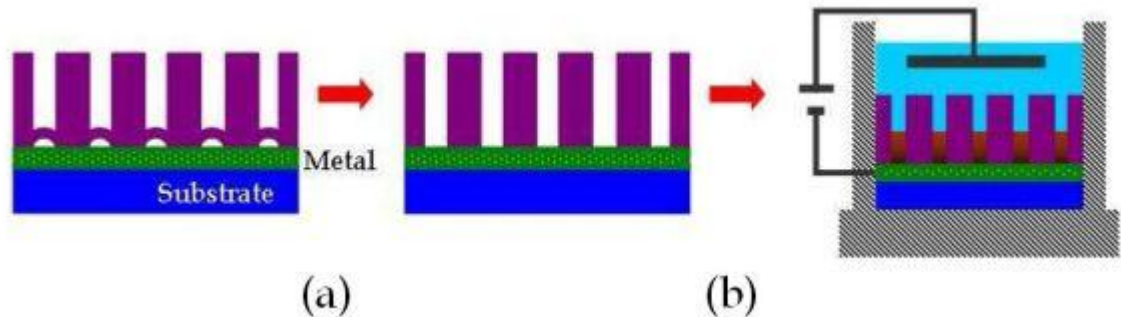
### **Characteristics of nano-wires**

1. Nano-wires are two-dimensional material.
2. Conductivity of a nano-wire is less than that of the corresponding bulk materials.
3. It exhibits distinct optical, chemical, thermal and electrical properties due to this large surface area.
4. Silicon nano-wires show strong photoluminescence characteristics.

## Synthesis of Nano-wires

Nano-wires can be synthesized by any one of the following methods.

### 1.) Template-assisted synthesis



Template assisted synthesis of nanowires is simple way to fabricate nanostructures.

These templates contain very small cylindrical pores or voids within the host material and the empty spaces are filled with the chosen material to form nanowires.

### 2.) VLS method

It involves the absorption of the source material from the gas phase into a liquid droplet of catalyst. Upon super saturation of the liquid alloy, a nucleation event generates a solid precipitate of the source material. This seed serves as a preferred site for further deposition of material at the interface of the liquid droplet, promoting the elongation of the seed into a nanowire.

## Applications of nano-wires

- 1.) Nano-wires are used for enhancing mechanical properties of composites.
- 2.) It is also used to prepare active electronic components such as p-n junction and logic gates.
- 3.) Semiconductor nano-wire crossings are expected to play an important role in future of digital computing.
- 4.) Nano-wires find applications in high-density data storage either as magnetic read heads or as patterned storage media.

## Nano-rods

Nano-rods is a two dimensional cylindrical solid material having an aspect ratio less than 20.

### Characteristics of Nano-rods

- 1.) Nano-rods are two-dimensional materials.
- 2.) It also exhibits optical and electrical properties.

## Synthesis

Nano-rods are produced by direct chemical synthesis. A combination of ligands acts as shape control agents and bond to different facets of the nano-rods with different strength.

## Applications

It finds applications in display technologies and micro mechanical switches.

## Nano Cluster

Aggregates of atoms or molecules in nano-scale dimension (1-10 nm) are known as nanoclusters.

Nanoparticles are those particles having dimension less than 100 nm. Bulk particles are those particles having dimension greater than  $10^3$  nm.



## Magic number

It is the number of atoms in the clusters of critical sizes with higher stability.

## Properties of nanoclusters

1. The reactivity of nanoclusters are decreased due to their decrease in size.
2. The melting points of nanoclusters are lower than the bulk materials due to high surface to volume ratio.
3. The electronic structure of the nanocluster is more confined than the bulk materials.

## Applications of nanocluster

1. Nanoclusters are used as catalysts in many reactions.
2. It is used in nano based chemical sensors.
3. It is also used as a light emitting diode in quantum computers.

## Carbon nanotubes (CNT)

Carbon in solid phase exists in different allotropic forms like diamond, graphite, fullerene, buckminster and nanotubes.

A single sheet of graphite is called **graphene**. Carbon nanotubes are described as a graphene sheet rolled up to into a shape of the cylinder.

## Definition:

Carbon nanotubes are large molecules of pure carbon that are long, thin and shaped

like tubes about 1-3 nm diameter and 100 – 1000 nm long. Each carbon atoms in the carbon nanotubes are linked by the covalent bond.

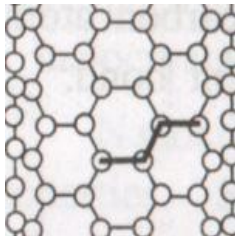
### Structure:

There are two types of nanotubes.

1. Single walled carbon nanotubes (SWCNT) –diameter is 1nm
2. Multi walled carbon nanotubes (MWCNT) –diameter is 10 nm

SWCNT consists of one sheet of graphite cylinder. Its diameter is 1 nm.

It forms the three types of structures such as arm chair, Zig zag and chiral structure.

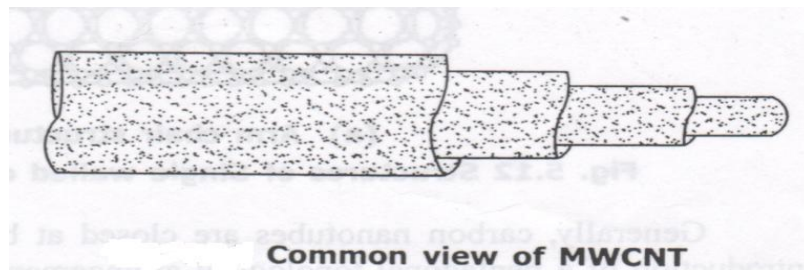


Arm chair structure



Zig zag structure

### MWCNT:



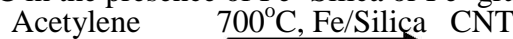
### Synthesis of carbon nanotubes:

Carbon nanotubes are prepared by the following methods.

1. Pyrolysis of hydrocarbons.
2. Laser evaporation
3. Carbon arc method
4. Chemical vapour deposition.

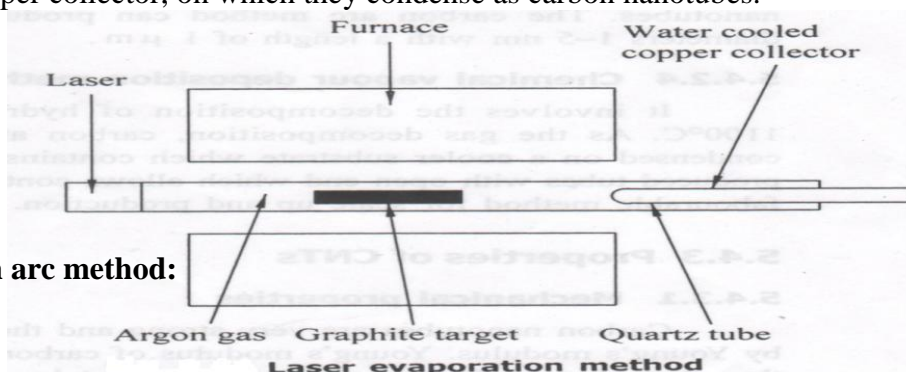
#### 1. Pyrolysis of hydrocarbons:

Carbon nanotubes are synthesized by the Pyrolysis of hydrocarbons such as acetylene at about 700<sup>0</sup> C in the presence of Fe- Silica or Fe- graphite catalyst under inert conditions.



#### 2. Laser evaporation:

It involves the vaporization of graphite target containing small amount of cobalt and nickel which acts as catalyst. It is exposed to an intense pulsed laser beam at higher temperature (1200<sup>0</sup>C) in a quartz vessel. An inert gas such as argon is simultaneously allowed to pass through the reactor to drive away the evaporated carbon atoms from furnace to the colder copper collector, on which they condense as carbon nanotubes.



#### 3. Carbon arc method:

Two graphite electrodes of 10 -20  $\mu\text{m}$  dia are taken, connected externally. At high pressure, when 20 -25V DC current is passed, CNT is produced.

#### 4. Chemical vapour deposition:

It involves decomposition of vapour of hydrocarbons such as methane, acetylene at high temperatures ( $1100^{\circ}\text{C}$ ) in presence of metal nanoparticles catalysts like cobalt, nickel, iron supported on  $\text{MgO}$  or  $\text{Al}_2\text{O}_3$ . Carbon atoms produced by the decomposition condense on a cooler surface of the catalyst.

#### Properties of CNTs:

##### Mechanical properties:

**Tensile strength:** It is a measure of amount of stress needed to pull a material. CNTs are very strong. This is due to inter locking of C- C covalent bonds.

**Young's modulus:** It is a measure of stiffness of the material or flexibility of a material.

CNTs have Young's modulus ranging from 1.28 to 1.80TPa. That is, CNT are very stiff and hard to bend.

##### Electrical properties:

1. CNTs can be both metallic or semi-conducting, depending upon the chirality and diameter of CNTs.
2. Basically all armchair tubes are metallic because of their symmetry.
3. Zig zag and chiral tubes can be either metallic or semi-conducting depending upon their chiral vector.
4. The very high electrical conductivity of CNT is due to the minimum defects in the structure.

##### Thermal conductivity:

They have high thermal conductivity. Thermal conductivity of CNTs is ten times greater than that of silver. Thermal conductivity in CNTs is due to the vibration of covalent bonds holding the carbon atoms together. The high thermal conductivity is also due to the minimum defects in the structure.

##### Vibrational property:

CNTs have two normal modes of vibration

- i)  $A_g$  – 'in and out' oscillation of the diameter of the tube.
  - ii)  $E_{2g}$  – squashing of the tube. (Oscillation between sphere and ellipse)
- The frequencies depend on the radius of the tube and are Raman active.

##### Density:

CNTs are light weight with a density of  $1.33\text{-}1.44\text{gm/cm}^3$ .

#### Applications of carbon nanotubes:

##### 1. CNT in storage devices

Carbon nanotubes play an important role in the battery technology, because some charge carriers can be successfully stored inside the nanotubes

##### Examples:

- a. CNT in fuels cells: Hydrogen can be stored in the CNT, which may be

used for the development of fuel cells.

b. CNTs are also used in lithium battery.

## 2. CNT as protective shields

CNTs are poor transmitters of electromagnetic radiation. Hence it can be used as shield, for protecting electronic equipments against electromagnetic radiation.

## 3. Sensors of gases:

The gases like  $\text{NO}_2$  and  $\text{NH}_3$  can be detected on the basis of increase in electrical conductivity of CNTs

## 4. Drug delivery vessels:

CNTs can be effectively used inside the body for drug delivery by placing the drugs within the tubes.

## 5. CNT in microscope:

CNTs attached to the tips of scanning microscope, have been used to image biological and industrial specimens

## 6. Reinforcing elements in composites

The composites of aluminum powder, mixed with CNTs possesses a greater tensile strength compared to pure aluminum

7. CNTs are used for making IMC (Integrated memory circuits)

## 8. Quantum wire:

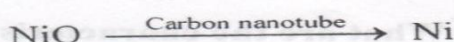
The quantum wires made of metallic carbon nanotubes are found to have high electrical conductivity.

## 9. CNT in catalysis

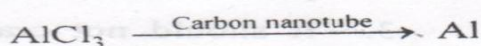
Carbon nanotubes serve as efficient catalysts for some chemical reaction. CNT can be used catalyst supports because they can provide large surface areas, high chemical stability.

### Examples:

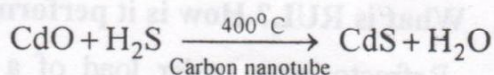
(i) Reduction of nickel oxide ( $\text{NiO}$ ) to the base metal  $\text{Ni}$ .



(ii) Reduction of  $\text{AlCl}_3$  to its base metal

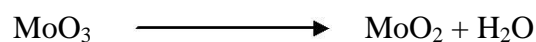


(iv) Cadmium sulfide ( $\text{CdS}$ ) crystals have been formed inside the carbon nanotubes by reacting cadmium oxide ( $\text{CdO}$ ) crystals with hydrogen sulfide gas ( $\text{H}_2\text{S}$ ) at  $400^\circ\text{C}$ .



It reduces  $\text{MoO}_3$  to  $\text{MoO}_2$  with the formation of steam.

$\text{H}_2$ ,  $470^\circ\text{C}$ , MWCNT



## **Applications of Nano Materials or Nanoparticles**

Nanotechnology finds significant impact on all most all the industries and all areas of society. Since nanomaterials posses unique beneficial chemical, physical and mechanical properties, they can be used for a wide variety of applications.

### **I- Medicine**

#### **1. Nano drugs**

Nanomaterials are used as nano drugs for the cancer and TB therapy.

#### **2. Laboratories on a chip**

Nanotechnology is used in the production of laboratories on a chip.

#### **3. Nano medibots**

Nanoparticles function as nano medibots that release anti-cancer drug and treat cancer.

#### **4. Gold coated nanoshells**

It converts light into heat, enabling the destruction of tumours.

#### **5. Gold nanoparticles as sensors**

Gold nanoparticles undergo colour change during the transition of nanoparticles.

#### **6. Protein analysis**

Protein analysis can also be done using nanomaterials.

#### **7. Gold nanoshells for blood immune assay**

Gold nanoshells are used for blood immuno assay.

#### **8. Gold nanoshells in imaging.**

Optical properties of the gold nanoshells are utilized for both imaging and therapy.

#### **9. Targeted drug delivery using gold nanoparticles**

It involves slow and selective release of drugs to the targeted organs.

### **II- Industries**

#### **1. As catalyst**

It depends on the surface area of the material. As nanoparticles have an appreciable fraction of their atom at the surface, its catalytic activity is good.

Example: Bulk gold is chemically inert, whereas gold nanoparticles have excellent catalytic property.

#### **2. In water purification**

Nanofabrication makes use of nanoporous membranes having pores smaller than 10 nm. Dissolved solids and colour producing organic compounds can be filtered very easily from water.

Magnetic nanoparticles are effective in removing heavy metal contamination from waste water.

#### **3. In fabric industry**

The production of smart clothing is possible by putting a nano coating on the fabric.

- (i) Embedding of nanoparticles on fabric makes them stain repellent.
- (ii) Socks with embedded silver nanoparticles kill all the bacteria and makes it odour free.

#### **4. In automobiles**

- (i) Incorporation of small amount of nanoparticles in car bumpers can make them stronger than steel.
- (ii) Specially designed nanoparticles are used as fuel additive to lower consumption in vehicles.

#### **5. In food industry**

The inclusion of nanoparticles in food contact materials can be used to generate novel type of packing materials and containers.

#### **6. In energy sector**

In solar power, nanotechnology reduces the cost of photovoltaic cells by 10 to 100 times.

### **III-Electronics**

1. Quantum wires are found to have high electrical conductivity.
2. The integrated memory circuits have been found to be effective devices.
3. A transistor, called NOMFET, (Nanoparticle Organic Memory field effect transistor) is created by combining gold nanoparticles with organic molecules.
4. Nanowires are used to build transistors without p-n junctions.
5. Nano radios are the other important devices, using carbon nanotubes.
6. MOSFET( Metal Oxide conductor Field Effect Transistor) performs both as a switches and as amplifiers.

### **IV-Bio materials (Biology)**

1. Nanomaterials are used as bone cement and bone plates in hospitals.
2. It is also used as a material for joint replacements.
3. Nanotechnology is being used to develop miniature video camera attached to a blind person's glasses.
4. Nanomaterials are also used in the manufacture of some components like heart valves and contact lenses.
5. Nanomaterials are also used in dental implants and breast implants.
6. CNTs are used light weight shielding materials for protecting electronic equipments against electromagnetic radiation.