Nanochemistry

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Objectives

At the end of this, we will be able to-

- Know about the nanomaterials including their properties and applications
- Explain the mechanism of synthesis of nanomaterials
- Apply the knowledge of nanomaterials in the respective applications considering environmental issues.

Contents

- Nanomaterials
- Classification and properties of nanomaterials
- Synthesis and processing of nanomaterials
- Characterization techniques of nanomaterials
- Nanowires, carbon nanotubes, graphene
- Application of nanomaterials in energy storage and environmental issues (air, water, and fuel purification)

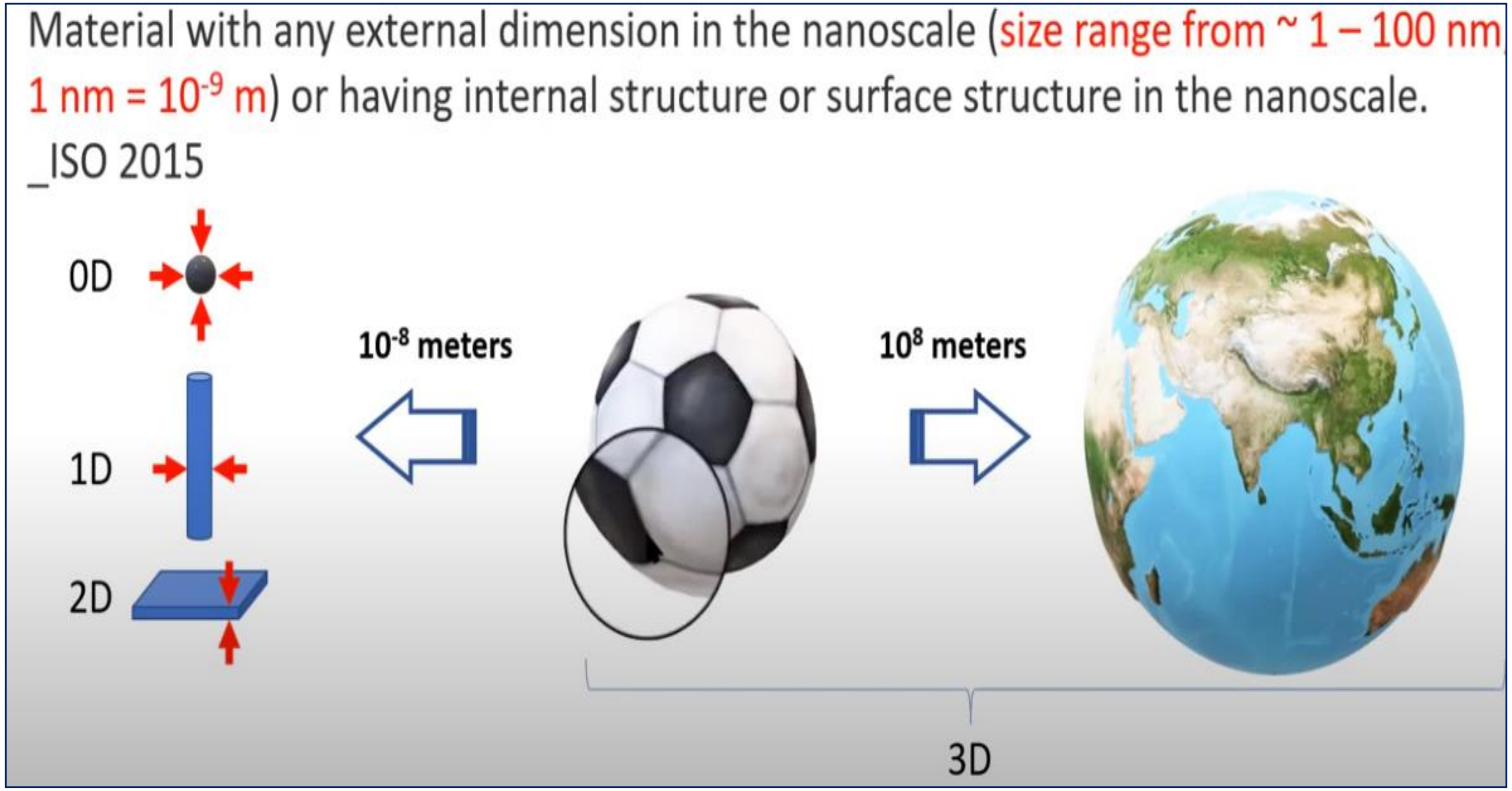
Introduction to Nanomaterials

Nanoscale materials are defined as a set of substances where at least one dimension is less than approximately 100 nanometers.

A nanometer is one millionth of a millimeter -approximately 100,000 times smaller than the diameter of a human hair.

Nanomaterials are of interest because at this scale unique optical, magnetic, electrical, and other properties emerge.

These emergent properties have the potential for great impacts in electronics, medicine, and other fields.

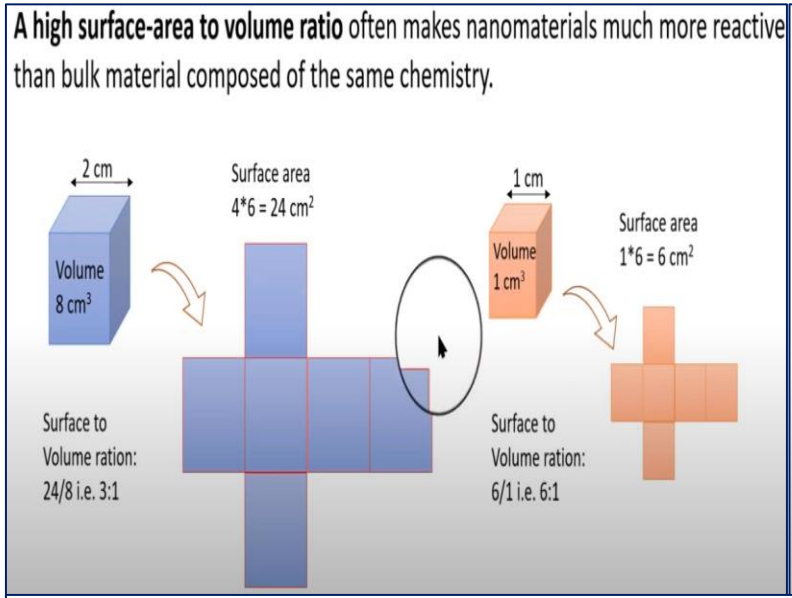


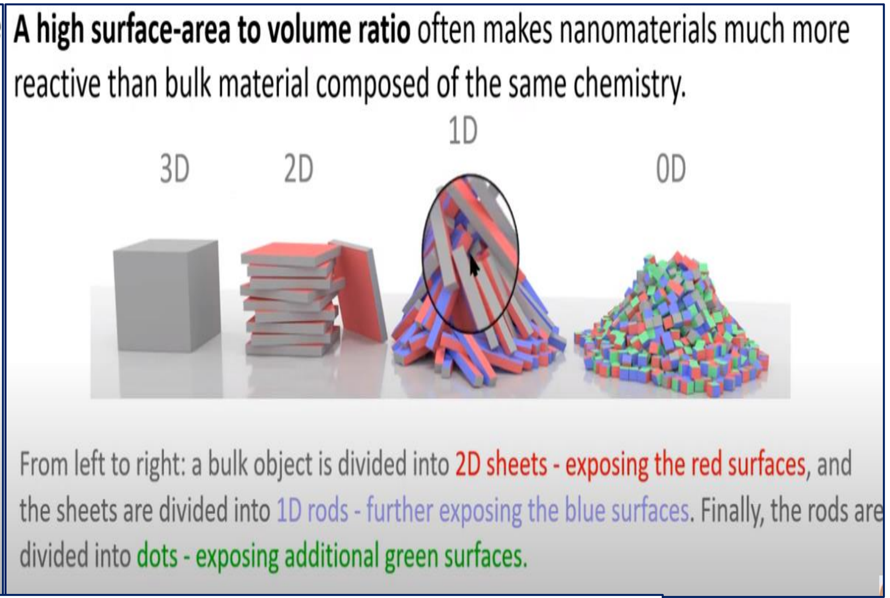
1 nm	10^{-9} m
Piece of paper	100,000 nm thick
Human hair	80,000 nm thick
DNA	2.5 nm diameter
Gold atom	0.3 nm diameter

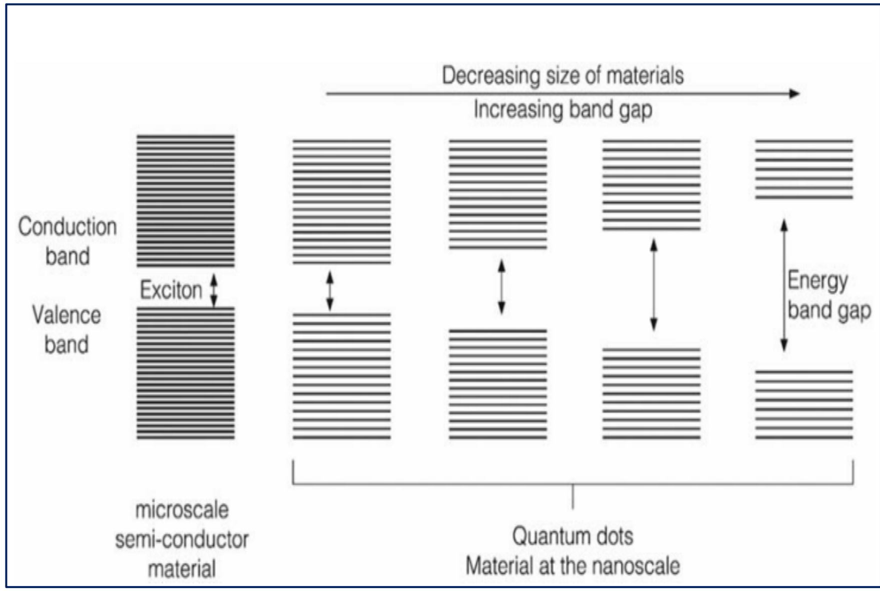
Why Nanomaterials?

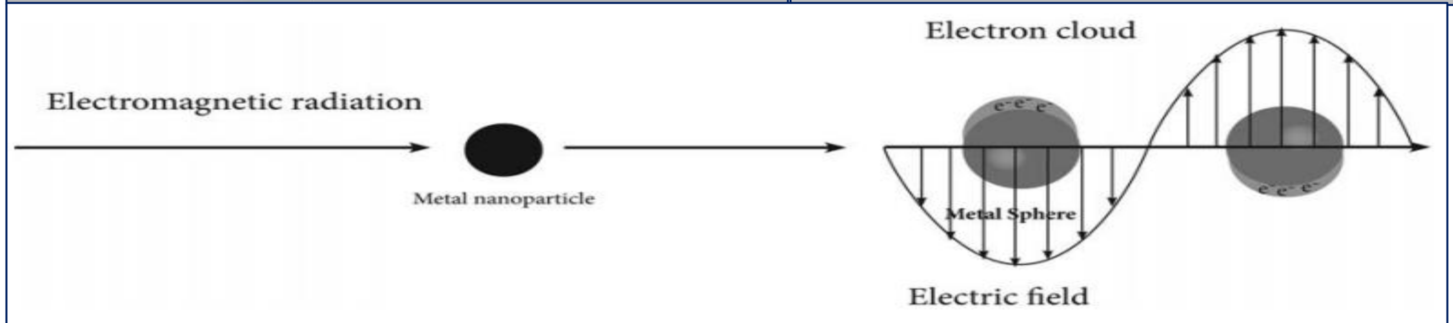
Engineered nanomaterials are resources designed at the molecular (nanometer) level to take advantage of their small size and novel properties which are generally not seen in their conventional, bulk counterparts.
The two main reasons why materials at the nano scale can have different properties are-

- **Increased relative surface area-** Nanomaterials have a much greater surface area to volume ratio than their conventional forms, which can lead to greater chemical reactivity and affect their strength.
- **New quantum effects.** At the nano scale, quantum effects can become much more important in determining the materials properties and characteristics, leading to novel optical, electrical and magnetic behaviors.





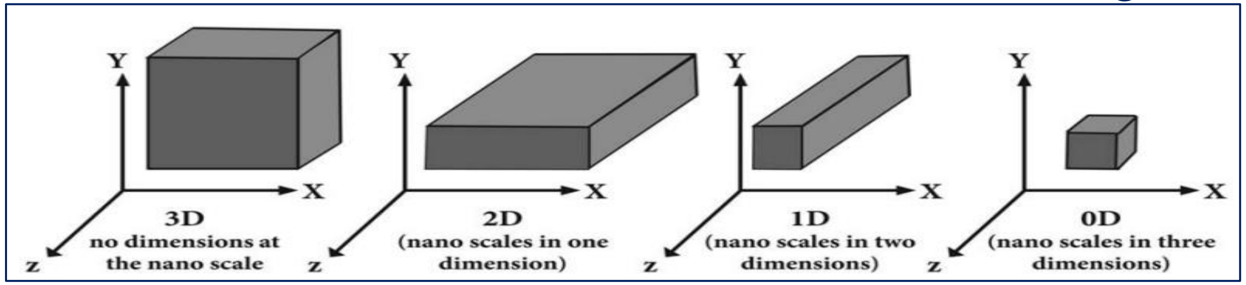




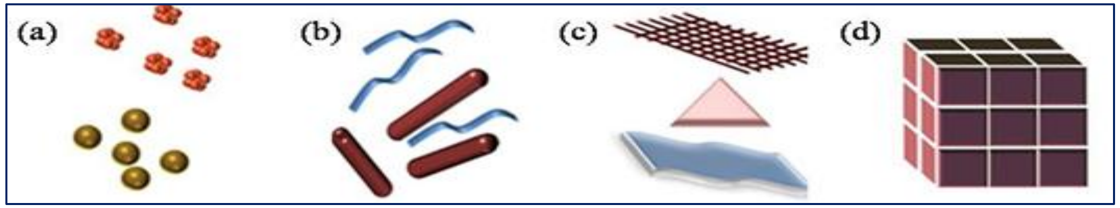
Schematic illustration of localized surface Plasmon resonance (LSPR) of metal Nanoparticles.

Classification of Nanomaterials

Nanomaterials have extremely small size which having at least one dimension 100 nm or less. According to Siegel, Nanostructured materials are classified as Zero dimensional, one dimensional, two dimensional, three dimensional nanostructures.



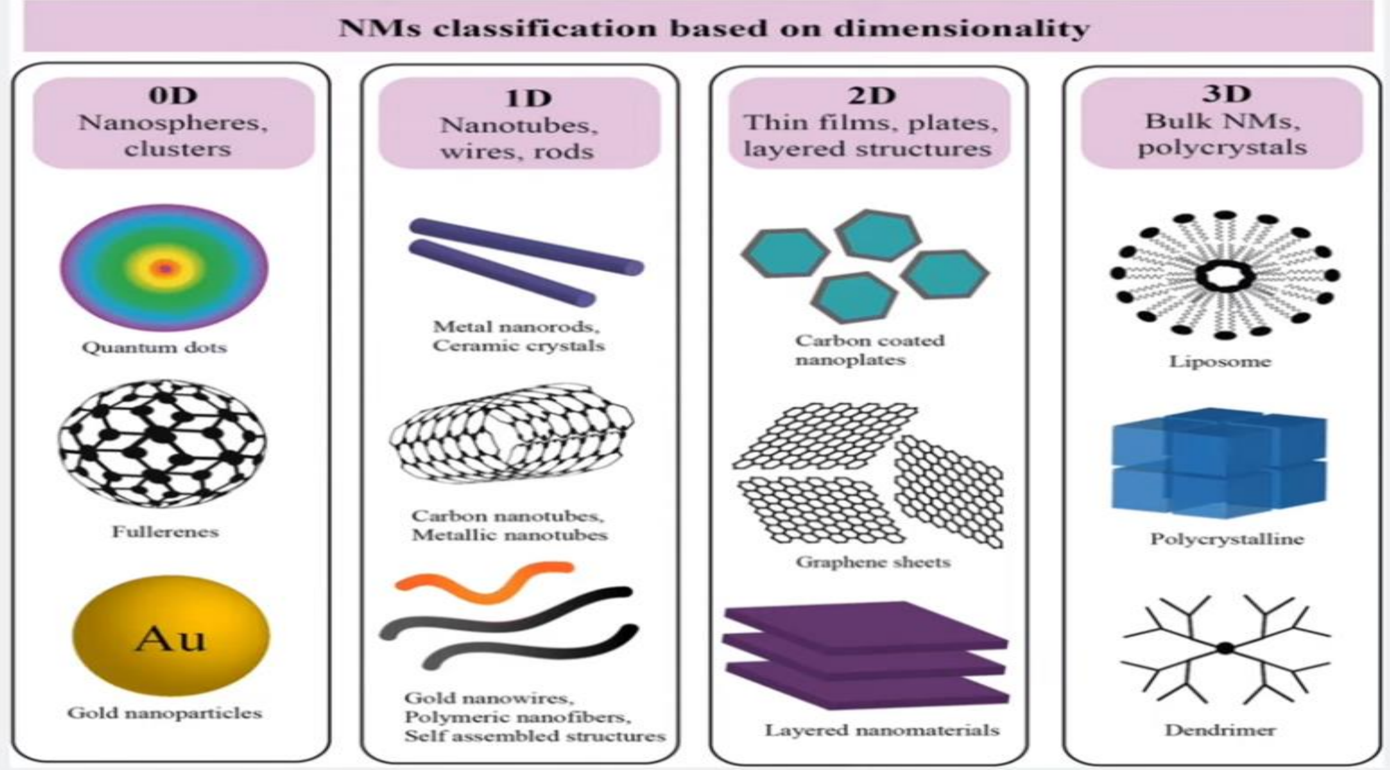
Types of nanostructured materials based on number of nanoscale dimensions



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

- Nanomaterials with at least one dimension in the nano scale are called as nanolayers
  Example of Nanolayers are thin films or surface coatings
- If two dimensions of a nanomaterial are in the nano scale they are categorized as nanotubes or nanowires
  Examples of nanotubes and nanowires are Carbon Nano Tubes and Carbon Nano fibers

- Nanomaterials that have all the three dimensions in the nano scale are called as nanoparticles
  Example of nanoparticles are Gold, Silver



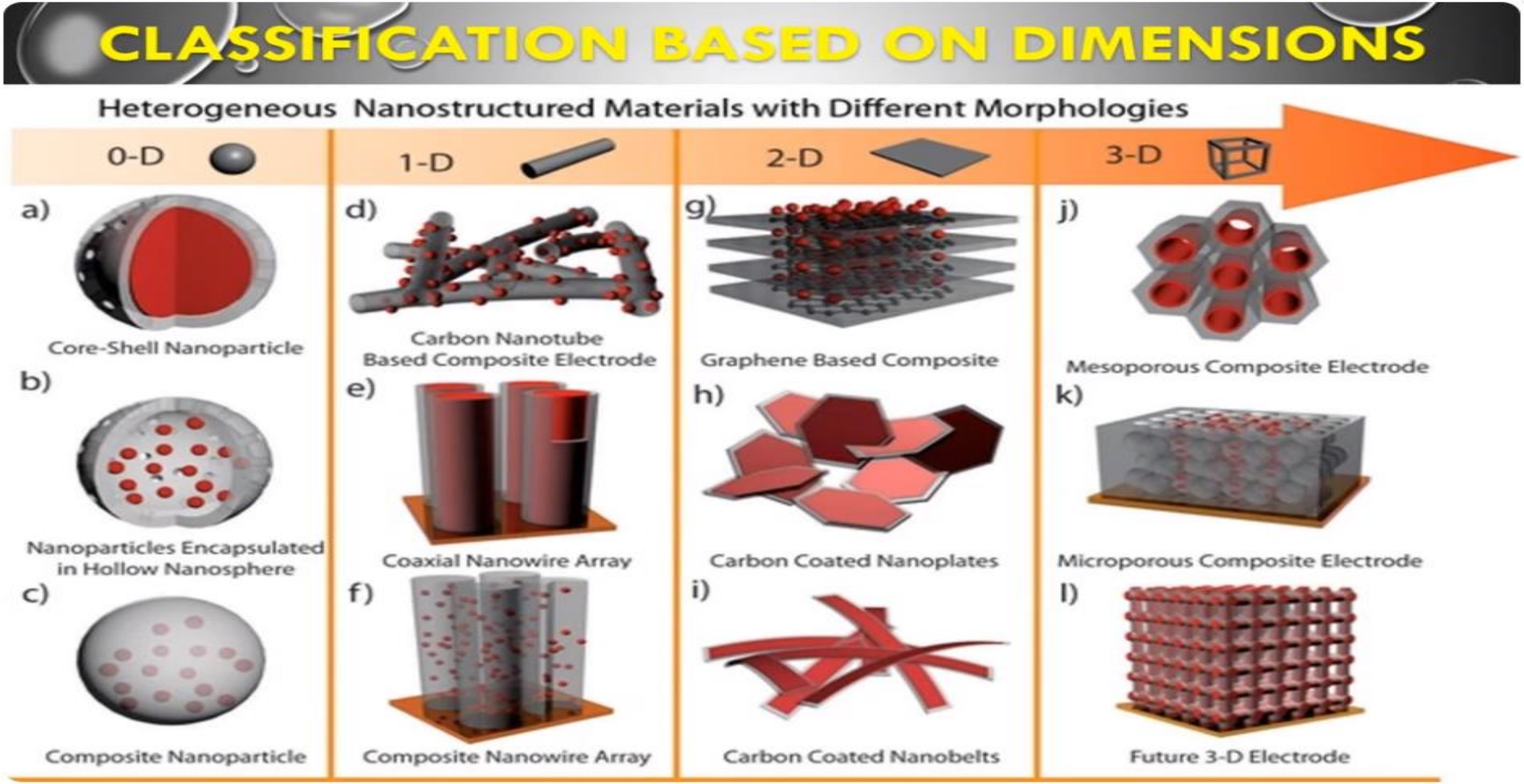
All dimensions are in nm range

One dimension is outside of nm range

Two dimensions are outside of nm range

no dimension is in nm range

Classification of Nanomaterials



Classification of Nanoporous materials-Based on Pore Diameters

Nanoporous materials is classified by the diameter size of their pores, since most of the properties, which are interesting for the applications of adsorption and diffusion are dependent on this parameter. The prefix nano- means a typical dimension between 1 and 100 nm. In this range material properties change drastically, when materials interact with other molecules. In fact, pore diameter establishes the size of molecules that could diffuse inside and comparison between the pore size and the dimension of guest molecule gives an idea about diffusion and interaction properties. If the two dimensions are same, we can expect that the molecule-wall interaction will be prevalent along with the molecule-molecule interaction. If guest molecules are smaller than the pore size, there will be less molecule wall interaction than the molecule-molecule interaction during the diffusion process. According to IUPAC definition, nanoporous materials are classified in three main groups depending on their pore dimensions:

Microporous materials (d< 2 nm): These materials have very narrow pores. They can host only small molecules, such as gases or linear molecules, and generally show slow diffusion kinetics and high interaction properties. They are generally used in gas purification systems, membrane filters or gas-storage materials. Example: Na-Y and naturally occurring clay materials, zeolites, organic frame works and surgical tape.

Mesoporous materials (2<d<50 nm):
Pores of these materials could host very large molecules, such as poly-aromatic systems or small biological molecules, and interactions with pore walls are often secondary respect to the interactions with other molecules, in the case of very small guest molecules. These materials are principally used as matrices to store functional molecules, as scaffolds to graft functional groups, such as catalytic centers, and as sensing materials, thanks to the quick diffusion of chemical species in the pore system. Example: Carbon micro tubes, Porous gels and porous glasses. Mobile Crystalline Materials (MCM-41), Mesoporous Molecular Sieves, Xerogels, Silica, Alumina, titanium Oxide and Niobium oxide materials.

Macroporous materials: They are materials having the average pore diameter greater than 50nm. Ex: Porous glasses and Aerogels.

Nanoporous materials-Some Related Terms

Porosity – It is the ratio of pore volume to its total volume. Here, pore volume is the difference between the total volume and solid volume.
Pore diameter - The average or effective diameter of the openings in a membrane, screen, or other porous material is known as pore diameter.

Wafer - A wafer is a thin slice of semiconductor or substrate material.
Sol - It is a colloidal suspension of very small solid particles in liquid medium. Ex: ink and blood.
Gel - It is a colloidal suspension of very small liquid particles in solid medium Ex: agar, gelatin, jelly and tooth- paste.
Aerogel - It is a synthetic porous ultra light material derived from a gel, in which the liquid component of the gel has been replaced with a gas.
Ex: Silica aerogel, Alumina aerogel and carbon aerogel.
Silica aerogel is a best insulator as well as lowest density solid. It porosity is 99%, surface area is 1000 m^2/gm, Its average pore size is 2-50 nm.
Xerogel - A solid formed from a gel by drying with unhindered shrinkage is called a xerogel.

At Nanoscale- Properties

Size Dependent Properties of Nanomaterials

The various properties, which get tremendously altered due to the size reduction in at least one dimension are:

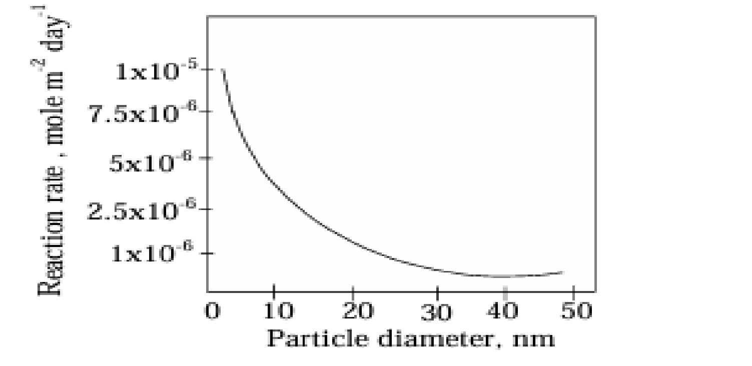
- Chemical properties: Reactivity; Catalysis.
- Thermal property: Melting point temperature.
- Electronic properties: Electrical conduction.
- Optical properties: Absorption and scattering of light.
- Magnetic properties: Magnetization.

Chemical Properties

Based on the surface area to volume effect, nanoscale materials have-

- Increased total surface area.
- Increased number of atoms accessible on the surface.
- Increased catalytic activity of those large number surface atoms.
- Different/tunable surface catalytic properties by the change in shape, size and composition.

Hence, nanoscale catalysts can increase the rate, selectivity and efficiency of various chemical reactions.

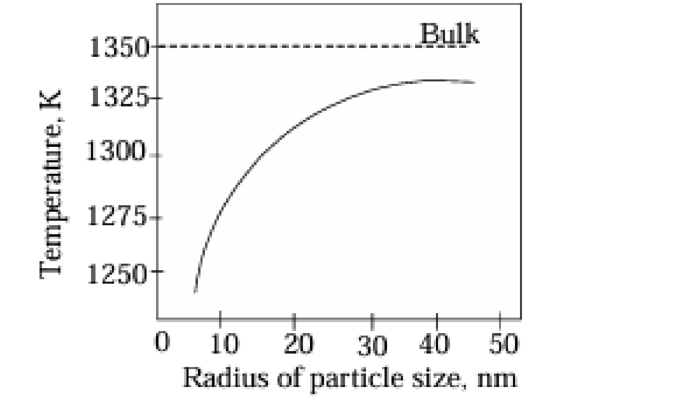


Effect of Particle Size on the Reaction Rate

Thermal Properties

The melting point of a material directly correlates with the bond strength.

In bulk materials, the surface to volume ratio is small and hence the surface effects can be neglected. In nanomaterials, the melting temperature is size dependent, and it decreases with the decrease particle size diameters. The reason is that in nanoscale materials, surface atoms are not bonded in direction normal to the surface plane and hence the surface atoms will have more freedom to move.



Effect of Particle Size on the Melting Point

At Nanoscale- Properties

Electronic Properties

In bulk materials, conduction of electrons is delocalized, that is, electrons can move freely in all directions.

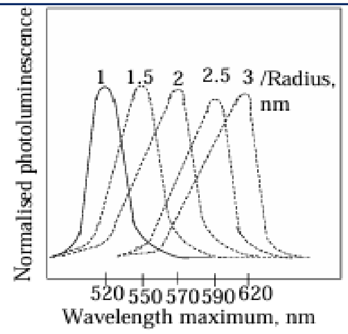
When the scale is reduced to nanoscale, the quantum effect dominates.

- **For zero dimensional nanomaterials, all the dimensions are at the nanoscale and hence the electrons are confined in 3-D space. Therefore, no electron delocalization (freedom to move) occurs.**
- **For one dimensional nanomaterials, electrons confinement occurs in 2-D space and hence electron delocalization takes place along the axis of nanotubes/nanorods/nanowires.**

Due to electron confinement, the energy bands are replaced by discrete energy states which make the conducting materials to behave like either semiconductors or insulators.

Optical Properties

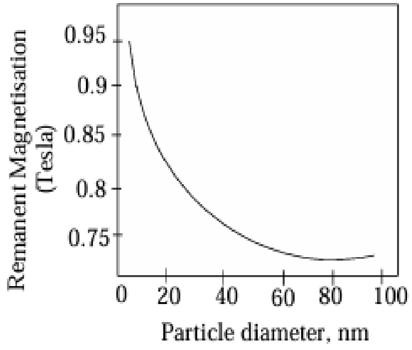
Because of the quantum confinement in nanomaterials, the emission of visible light can be tuned by varying the nanoscale dimensions. It is observed that the size reduction in nanomaterials shifts the emission of peak towards the shorter wavelength (blue shift).



Effect of particle size on photoluminescence

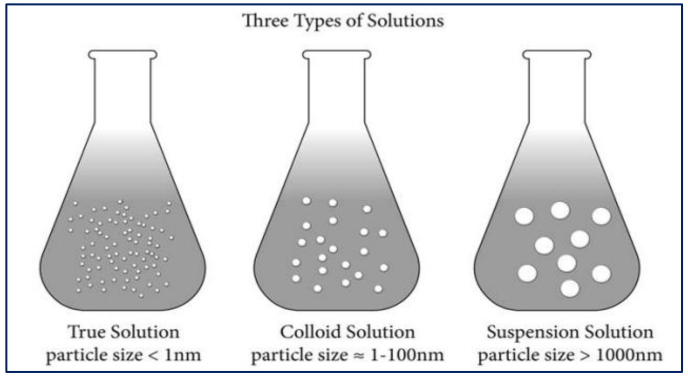
Magnetic Properties

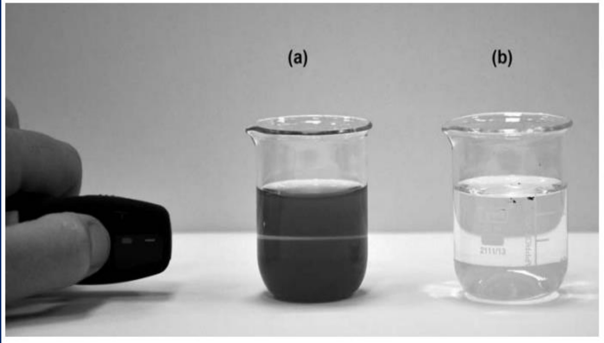
The size of magnetic nanoparticles also influences the value magnetization. The figure illustrates the effect of particle size on the saturation magnetization of zinc ferrite. The magnetization increases significantly below a grain size of 20nm. Hence, by decreasing the particle size of a granular magnetic material, it is possible to improve the quality of magnets fabricated from it.



Effect of Particle Size on the Saturation Magnetization

Nanoparticle Behavior of Colloid Solution

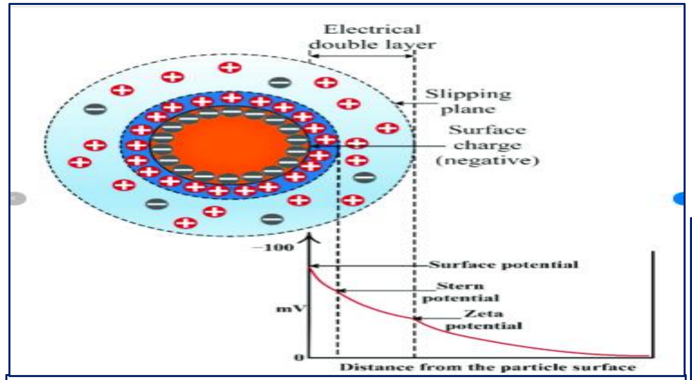




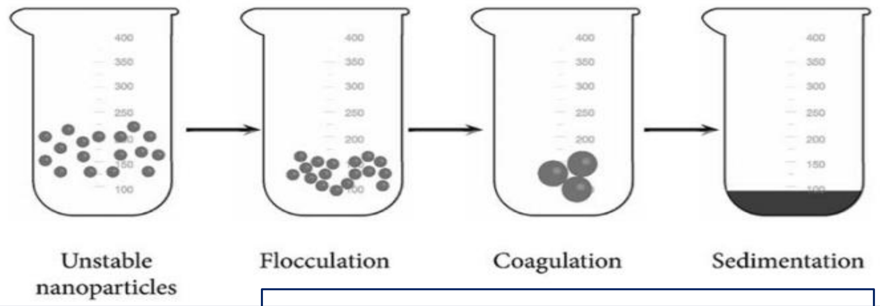
Description of the Tyndall effect: passing of laser beam through, a) colloid solution of silver nanoparticles, b) true solution of silver ions.

Types of colloid solutions depending on the physical state of both the dispersion medium and the dispersed phase

Physical state of dispersion medium	Physical state of dispersed phase	Type of colloid	Examples
Liquid	Solid	Sol	Aqueous colloid solution of gold nanoparticles, paints
Liquid	Gas	Foam	Soap-lather
Liquid	Liquid	Emulsion	Milk, oil in water emulsion
Gas	Liquid	Aerosol	Fog, cloud, mist
Gas	Solid	Aerosol	Smoke
Solid	Liquid	Gel	Jellies
Solid	Gas	Solid sol	Foam rubber
Solid	Solid	Solid sol	Some colored glasses



Schematic illustration of an electrical double layer of negatively charged nanoparticle. and a curve represents electrical potential as a function of distance from the nanoparticle surface.

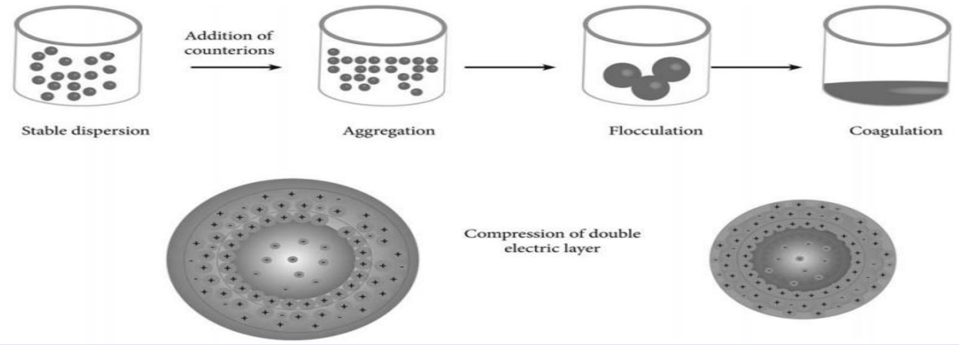


Schematic illustration of aggregation process of unstable nanoparticles

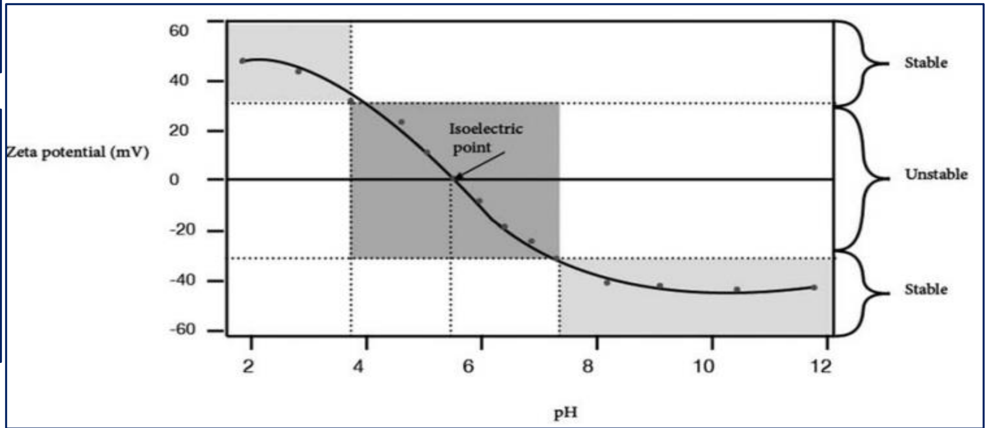
Possible values range of zeta potential and its relationship on the stability and instability of colloidal solutions

Values of zeta potential/mV	Degree of stability of a colloidal solution
0 to ±5	Flocculation and coagulation
±10 to ±30	Unstable
> ±30	Stable

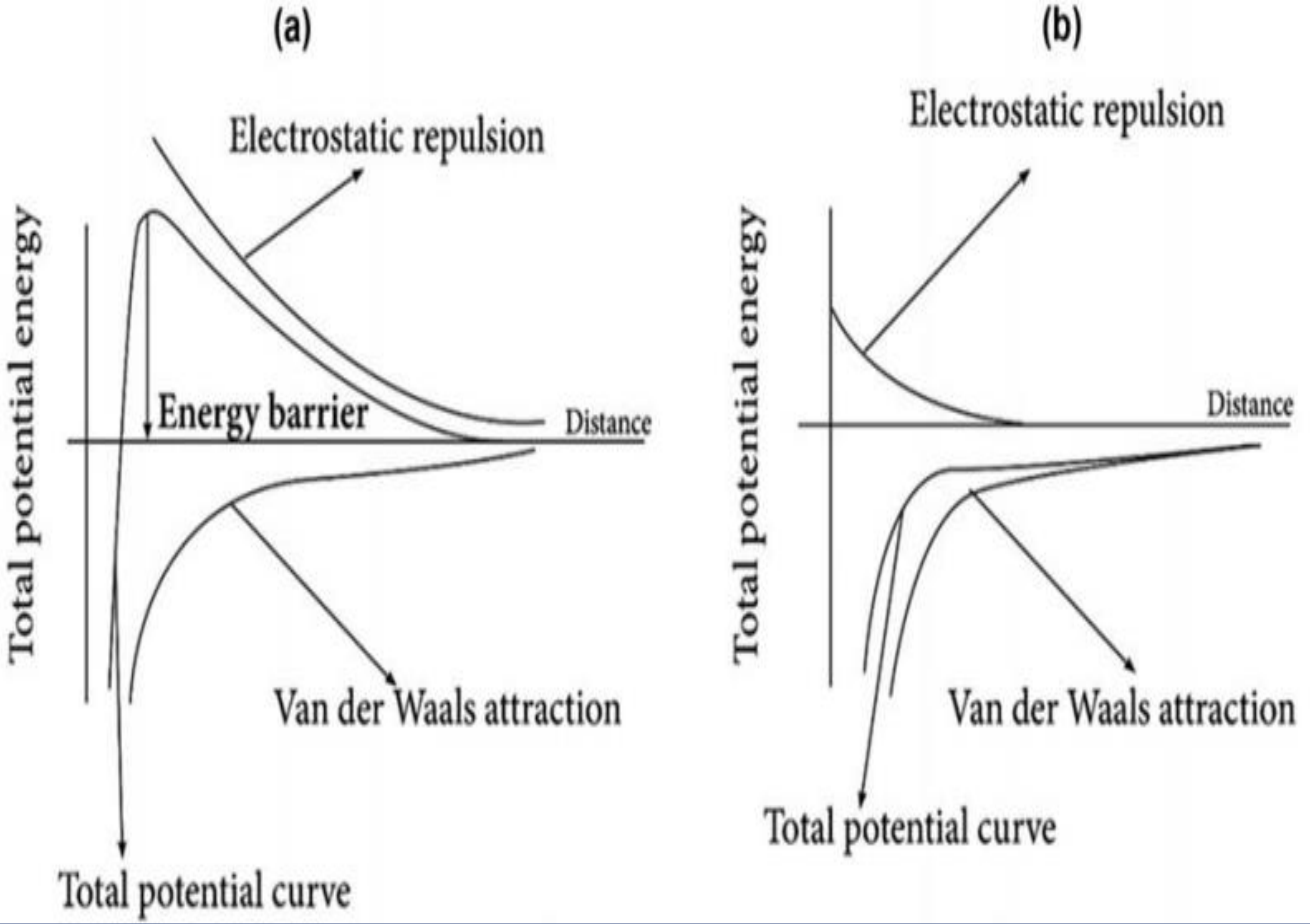
Schematic illustration of aggregation process of electrical charged nanoparticles induced by adding counterions



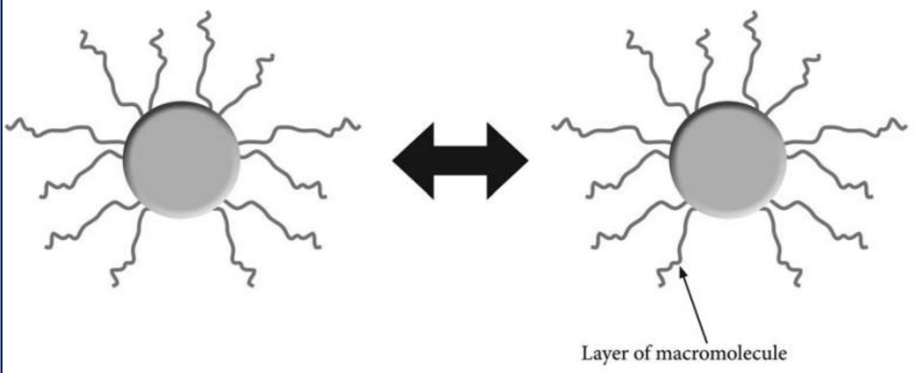
A curve represents zeta potential values versus pH.



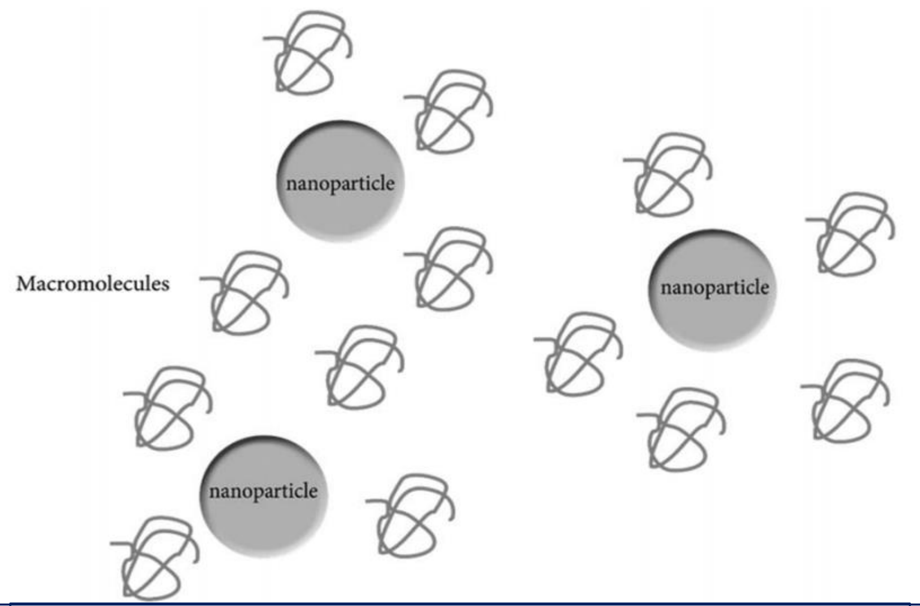
Nanoparticle Behavior of Colloid Solution



A curve that describes the total potential energy between two particles as a function of the distance between them in the case of a, a stable colloid solution, b, unstable colloid solution under aggregation process.



Schematic illustration of steric stabilized nanoparticles in colloid solution.

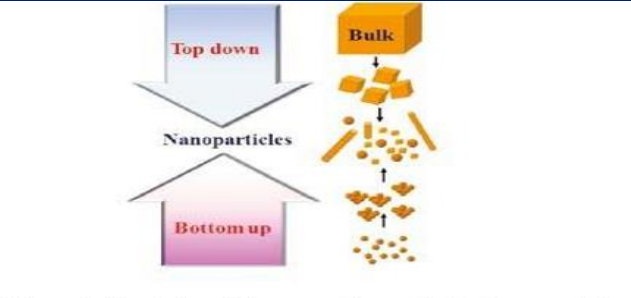


Schematic illustration of depletion stabilization of nanoparticles in colloid solution.

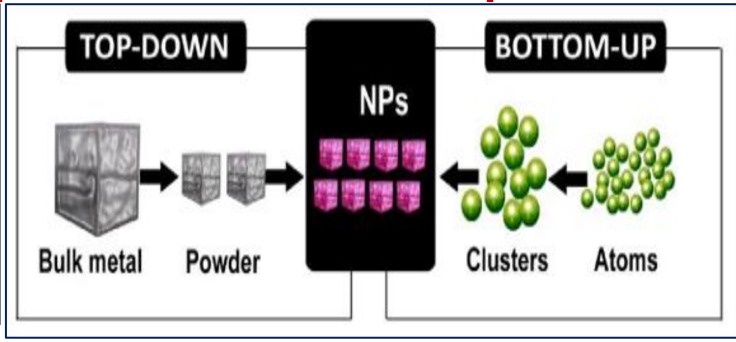
Nanomaterials- Synthesis and Processing

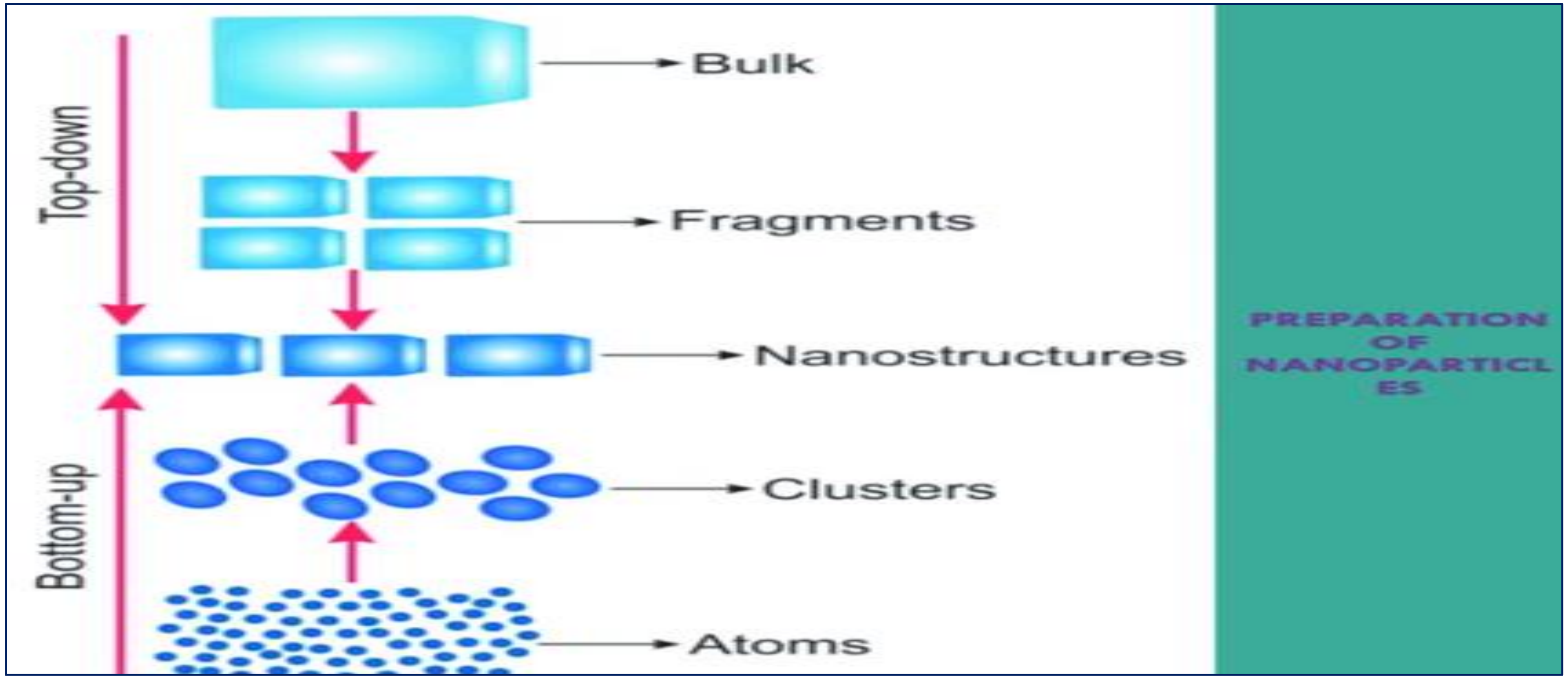
Scientists are conducting research to develop novel materials with better properties, more functionality and lower cost than the existing one. Several physical, chemical methods have been developed to enhance the performance of nanomaterials displaying improved properties with the aim to have a better control over the particle size, distribution methods to synthesis of nanomaterials. In general, top-down and bottom-up are the two main approaches for nanomaterials synthesis.

- **Top-down- size reduction from bulk materials**
- **Bottom-up- material synthesis from atomic level**



Schematic illustration of the preparative methods of nanoparticles.





Nanomaterials- Synthesis and Processing-Top-down Approach

This approaches are included in the typical solid –state processing of the materials. This route is based with the bulk material and makes it smaller, thus breaking up larger particles by the use of physical processes like crushing, milling or grinding. Usually, this route is not suitable for preparing uniformly shaped materials, and it is very difficult to realize very small particles even with high energy consumption. The biggest problem with top-down approach is the imperfection of the surface structure. Such imperfection would have a significant impact on physical properties and surface chemistry of nanostructures and nanomaterials.

It is well known that the conventional top-down technique can cause significant crystallographic damage to the processed patterns. In Top-down techniques, the starting material is solid state

Top-down approaches

- Lithography-photolithography, electron beam lithography
- Laser ablation
- Sputtering deposition
- Pulse electrochemical etching
- Vapor deposition

Top-down approaches used to produce-

- optical (semiconductor industry)
- electron (master production, research)
- scanning probe (mainly research)

Advantages

- Large scale production: deposition over a large substrate is possible
- Chemical purification is not required

Disadvantages

- Broad size distribution (10-1000 nm)
- Varied particle shapes or geometry
- Control over deposition parameters is difficult to
- achieve
- Impurities: stresses, defects and imperfections get introduced
- Expensive technique

Nanomaterials- Synthesis and Processing- Bottom-up Approach

This approach refers to the build-up of a material from the bottom: atom-by-atom, molecule by-molecule or cluster-by-cluster. This route is more often used for preparing most of the nano-scale materials with the ability to generate a uniform size, shape and distribution. It effectively covers chemical synthesis and precisely controlled the reaction to inhibit further particle growth. Although the bottom-up approach is nothing new, it plays an important role in the fabrication and processing of nanostructures and nanomaterials. Bottom – Up used to produced supramolecular level. All the Bottom-up techniques, the starting material is either gaseous state or liquid state of matter

Physical Techniques

Physical Vapor Deposition (PVD): involves condensation of vapor phase species –

- Evaporation (Thermal , e-beam)
- Sputtering
- Plasma Arcing
- Laser ablation

Chemical techniques CVD

- Deposition of vapor phase of reaction species- PECVD(RF-PECVD,MPECVD)
- Self-assembled Monolayer

Electrolytic deposition

Sol-gel method

Micro emulsion route

Pyrolysis

Advantages

- Ultra-fine nanoparticles
- Nano shells, nanotubes can be prepared
- Deposition parameters can be controlled
- Narrow size distribution is possible (1-20 nm)
- Cheaper technique

Disadvantages

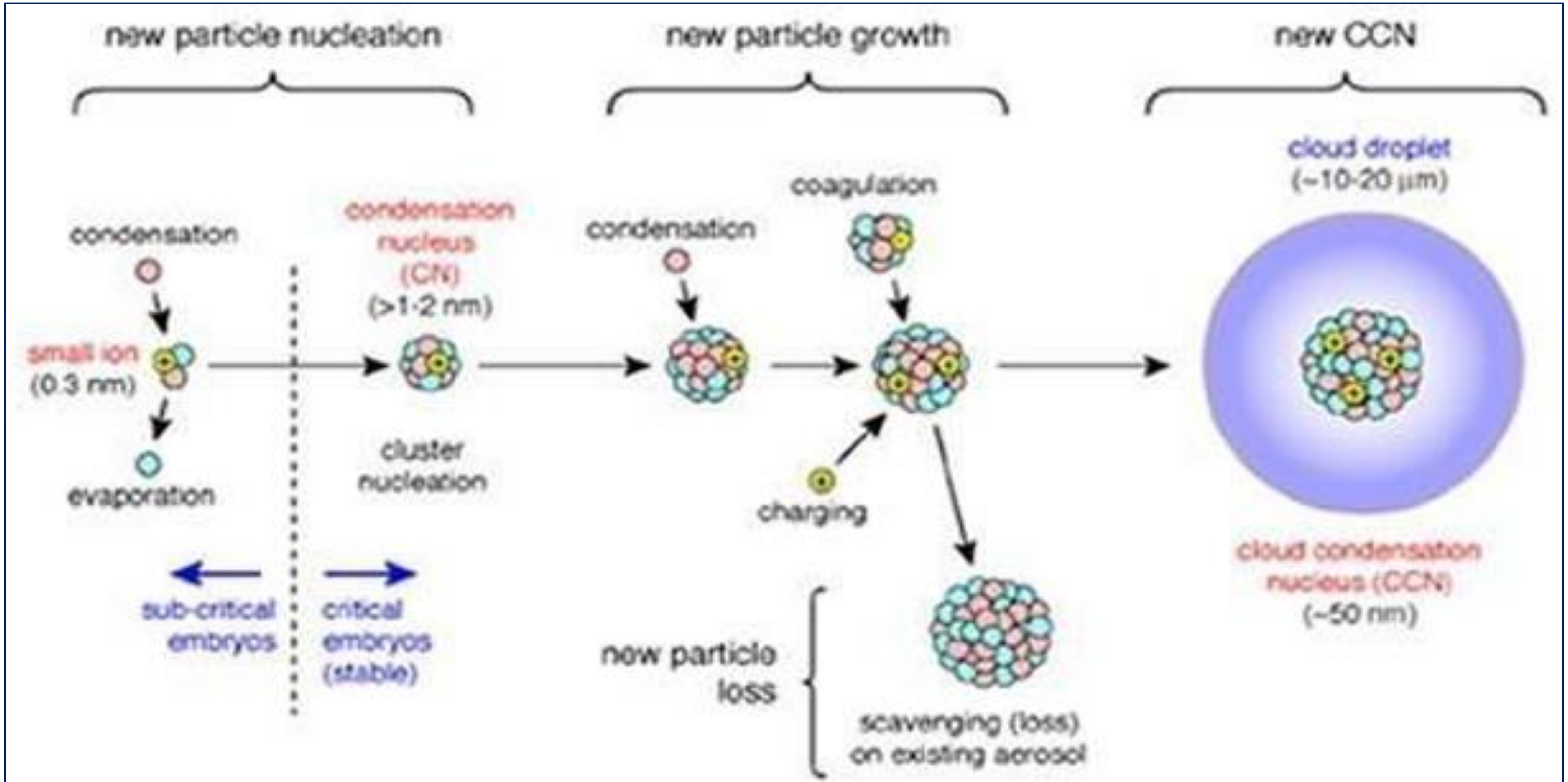
- Large scale production is difficult
- Chemical purification of nanoparticles is required

Growth Kinetics: Nucleation and Growth processes

Synthesis of nanoparticles is a combination of two stage process, nucleation and growth.

Most phase transformations begin with the formation of numerous small particles (clusters) of the new phase that increase in size until the transformation is complete.

Nucleation is the process whereby nuclei (seeds) act as templates for crystal growth. Nucleation is the first step in the formation of either a new thermodynamic phase or a new structure via self-assembly or self-organization.

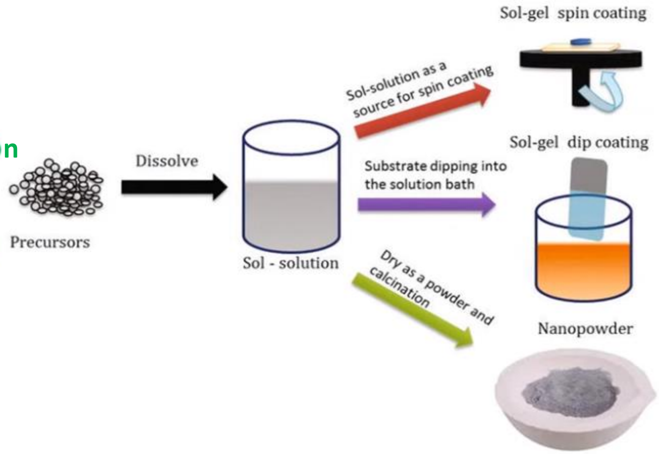


There are two different categories of Nucleation:
- **Heterogeneous**
- **Homogenous**

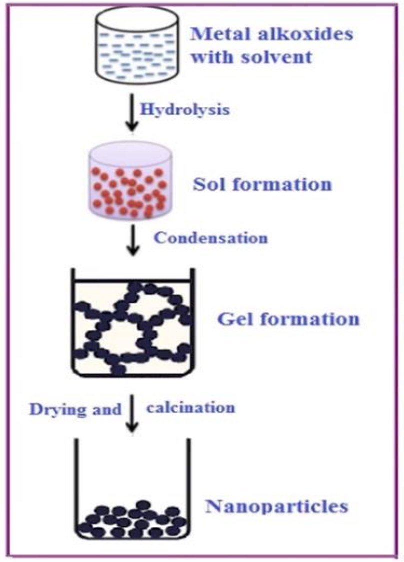
Nanomaterials- Synthesis and Processing

The **sol–gel process** is a **wet chemical technique.**
Also known as **chemical solution deposition.**
Involves several steps, in the following chronological order:

Hydrolysis
Polycondensation
Gelation
Aging & Drying
Densification
Crystallization.



SOL-GEL PROCESS (A BOTTOM TO TOP APPROACH)



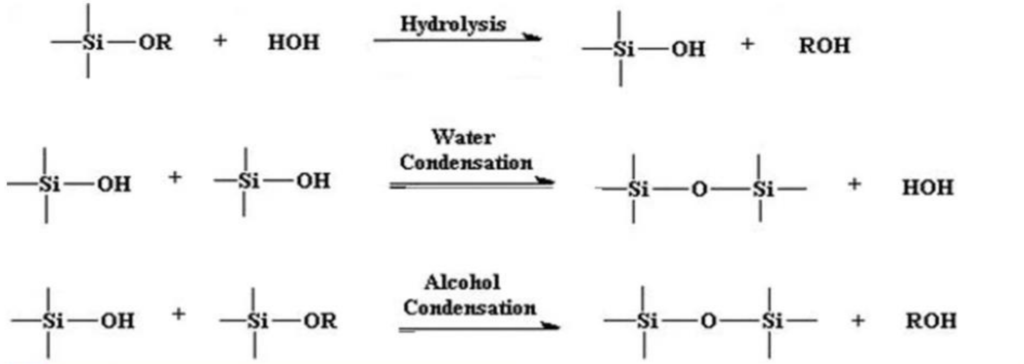
➢The sol-gel process, as the name implies, the transition of a liquid colloidal solution (sol) to a solid three-dimensional network (gel).

➢It involves several steps, such as: hydrolysis and polycondensations, gelation, aging, drying, calcination.

•A **sol** is a type of colloid in which very small solid ionic particles are suspended in a liquid. (1nm to 1micro meter)

•A **gel** is a semi rigid mass which is obtained after polycondensations of particles present in the sol.

•During this process the ions present in the sol, arranged in continuous 3-D network in gel.

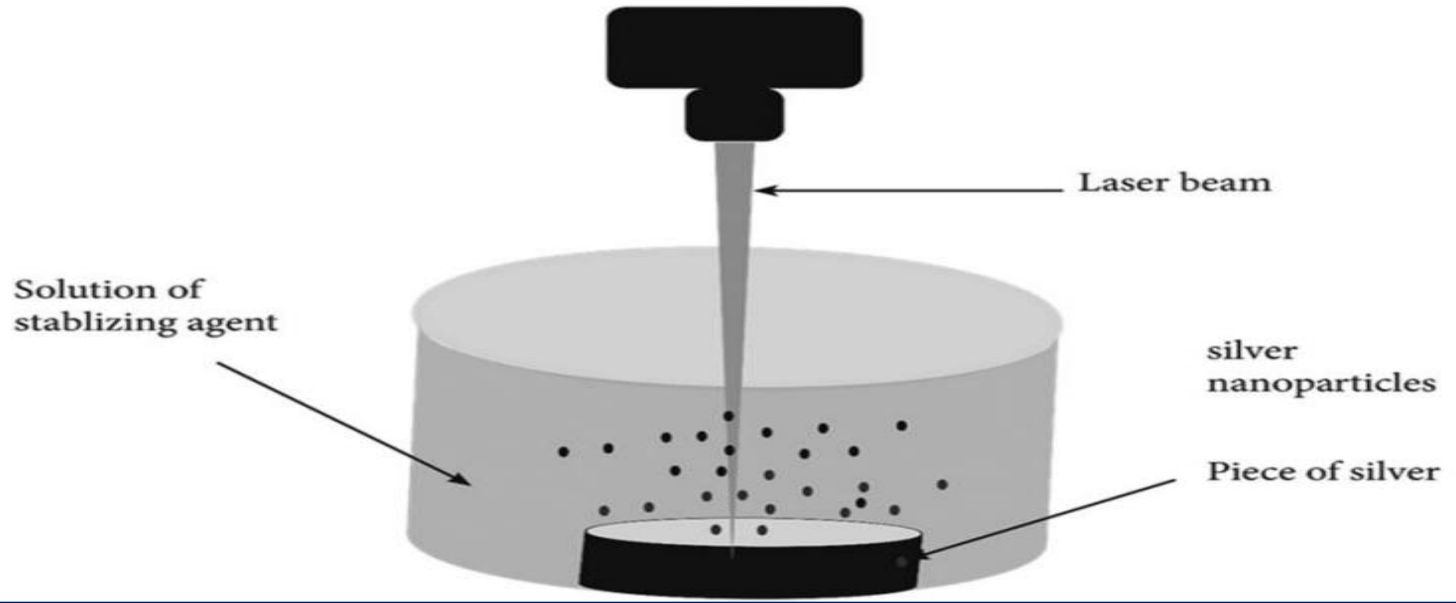


Process:

•**Metal alkoxide or metal chlorides are generally taken as precursors.**

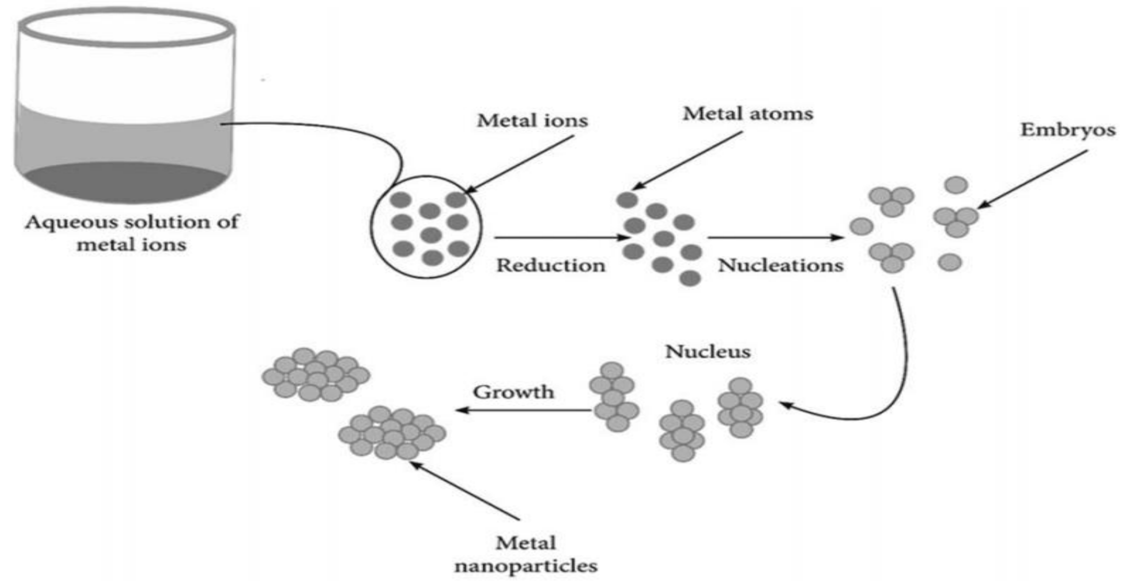
•**They undergo hydrolysis to form sol and followed by condensation to form gel.**

•**These are subjected to drying process for evaporating solvent present in the gel and followed by calcination and it results nano particle powders.**



Top-down laser ablation synthesis of metal nanoparticles

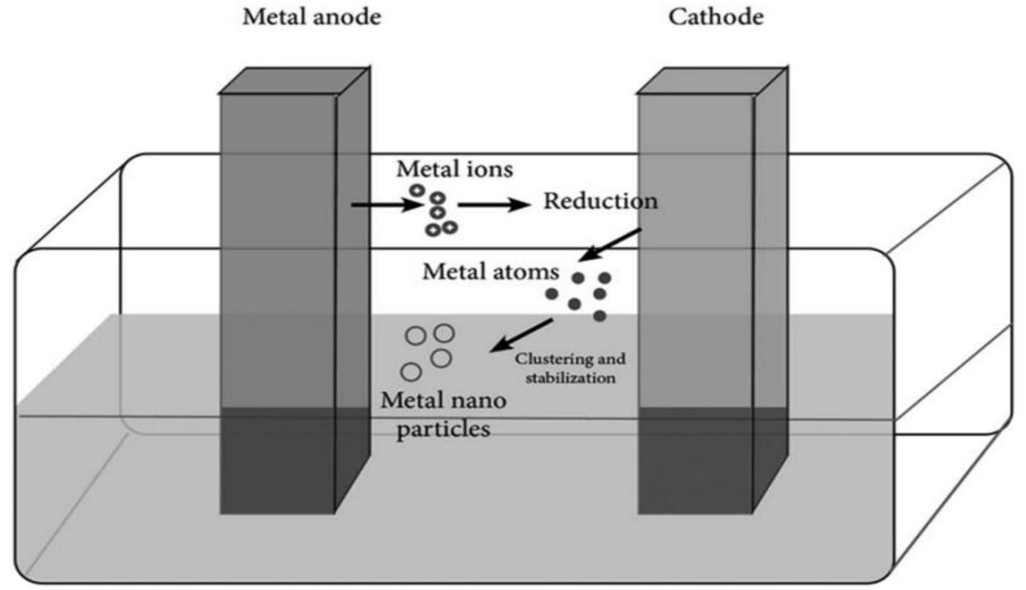
Nanomaterials- Synthesis and Processing



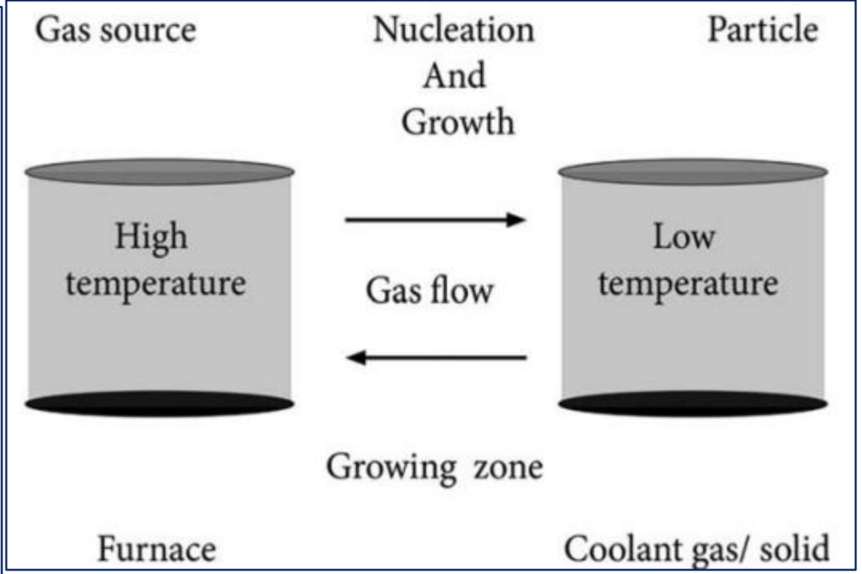
Mechanism of producing metal nanoparticles by reduction method.

Reducing agents, and reaction conditions for the reduction of various metal ions.

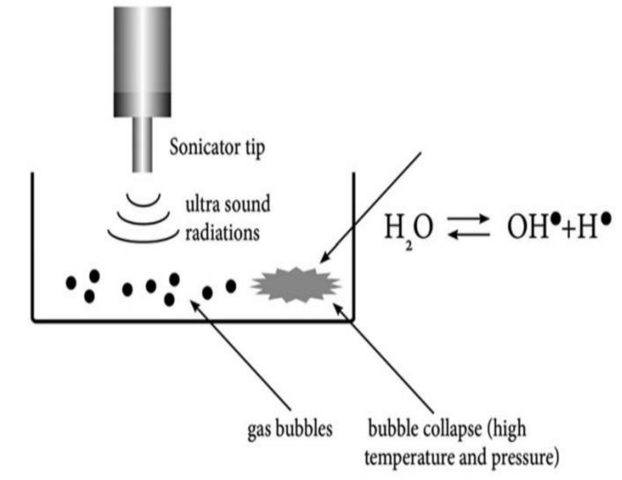
Metal ions	Reducer	Reaction conditions	Rate of reaction
Au^{3+}, Pt^{4+}, Pt^{2+}, $Pd^{2+2\backslash}$	Organic acids, alcohols	$\geq 70\ ^{\circ}C$	Slow
Ag^{+}, Rh^{3+}, Hg^{2+}, Ir^{3+}	Sugars, hydrazine, H_2SO_3, $NaBH_4$	Ambient	Fast
Cu^{2+}, Re^{3+}, Ru^{3+}	Polyols	$>120\ ^{\circ}C$	Slow
	Aldehydes, sugars	70–100 °C	Slow
	$NaBH_4$	Ambient	Fast
Cd^{2+}, Co^{2+}, Ni^{2+}, Fe^{2+}, In^{3+}, Sn^{2+}	Polyols	$>180\ ^{\circ}C$	Fast
	$NaBH_4$	Ambient	Slow
Cr^{3+}, Mn^{2+}, Ta^{5+}	$NaBH_4$	Ambient	Slow
	Radicals	Ambient	Fast



Electrochemical method for the preparation of metal nanoparticles.



Gas phase preparation of nanoparticles.

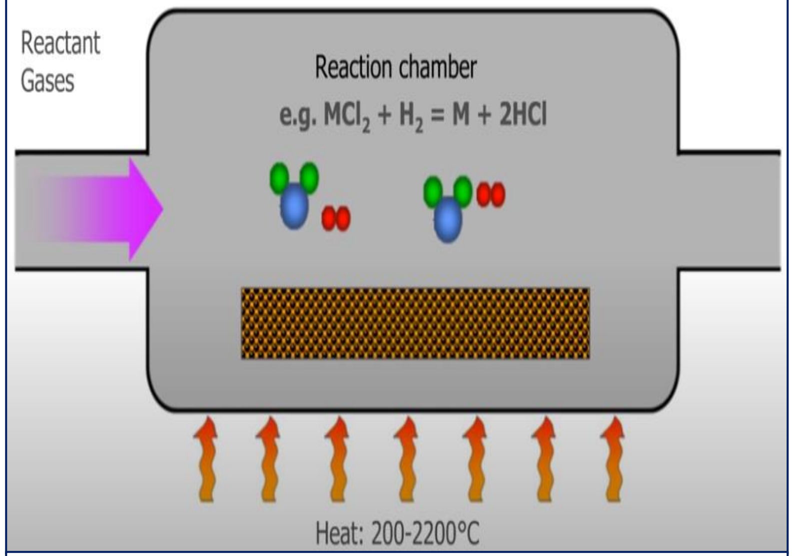


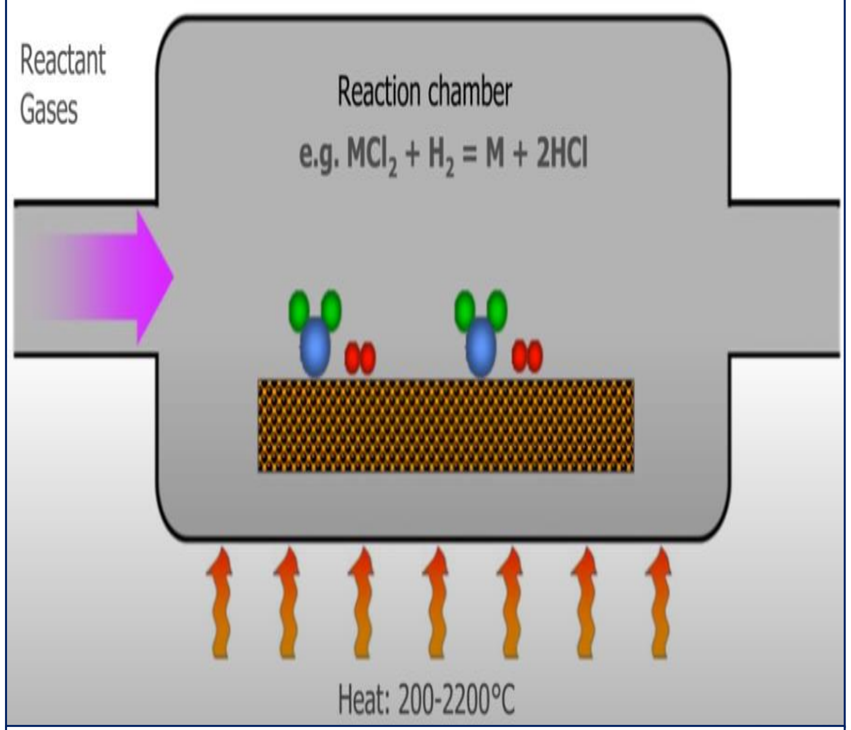
Sonochemical reaction system (reactions under ultrasound irradiation).

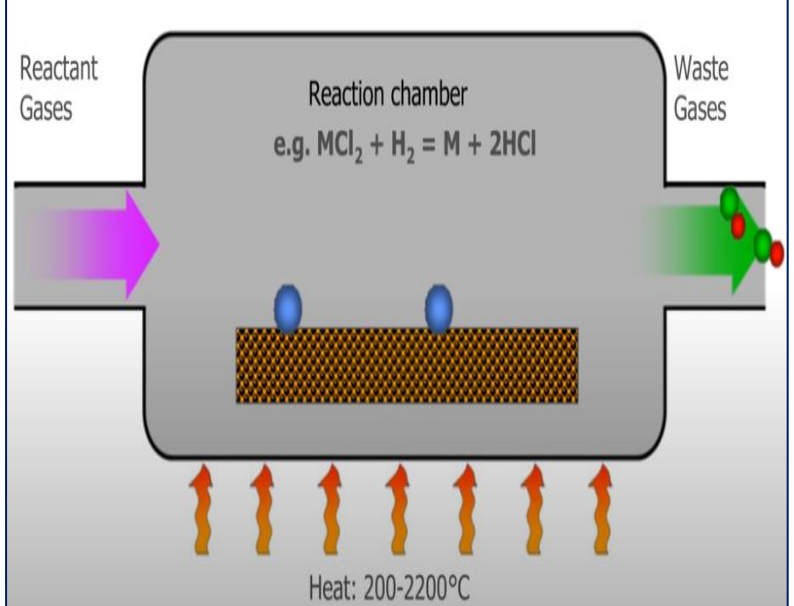
Nanomaterials- Synthesis and Processing

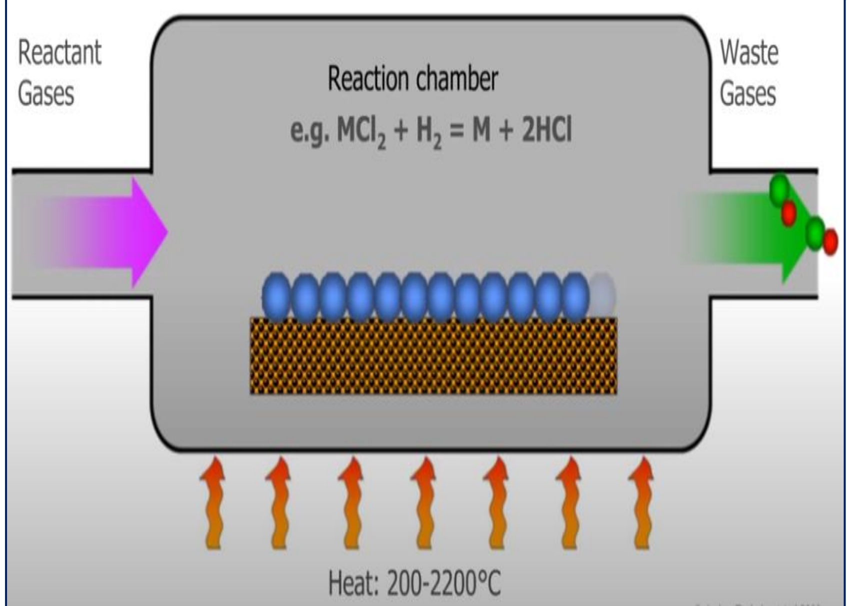
What is CVD?

"CVD is a process where gaseous precursors react to form a solid coating on a heated substrate"

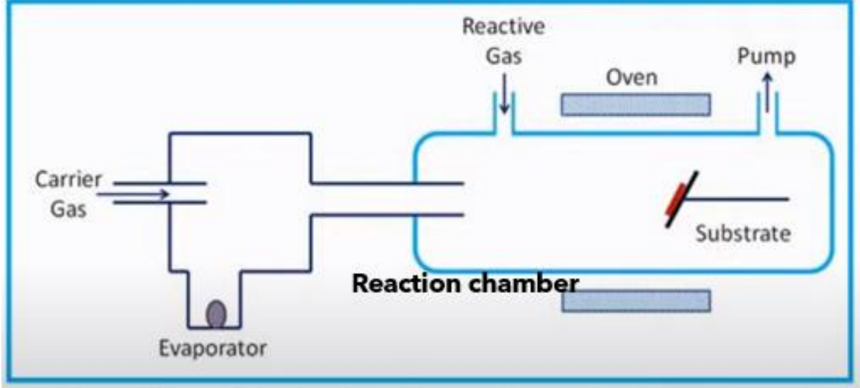








Chemical Vapour Deposition Method



- To avoid undesired chemical reactions, the substrate surface temperature, deposition time, pressure and type of surface is carefully selected.

- Bottom up Approach
- Substrate is exposed to one or more volatile precursors (chemicals) which react and/or decompose on the substrate surface to produce desired compound.
- By-products are removed by carrier gas flow through the reaction chamber.
- CVD is used to produce high purity, high performance solid materials.

Characterization techniques of nanomaterials

S. No.	Techniques	Information acquired
1.	Scanning Electron Microscopy (SEM) with Energy-dispersive X-ray spectroscopy	Surface topography (up to 10nm) and composition
2.	Transmission Electron Microscopy (TEM)	Surface morphology (up to 0.2nm)
3.	Atomic Force Microscopy	Identification of individual surface atoms
4.	Particle Size Analyzer	Particle Size distribution
5.	FT-Raman Spectra	Distinguish single walled carbon nanotubes and multi walled carbon nanotubes
6.	Photoluminescence Spectra	CNT chirality or Asymmetry determination
7.	X-ray photoelectron spectroscopy	Electronic state of the element

Nanomaterials-Nanowires

Nanowires are cylindrical solid wires structures with one of the dimensions smaller than 100 nm and length few micrometers. Nanowires are quantum mechanically one dimensional structures when their diameter is comparable to the electron’s de Broglie wavelength in the plane perpendicular to the growth direction.

One dimensional confinement of electrons in nanowires causes the change in density of states and allowed energy levels in nanowires. Quantum confinement in nanowires also allows the study of other unique phenomena such as ballistic transport, coulomb blockade and phonon confinement.

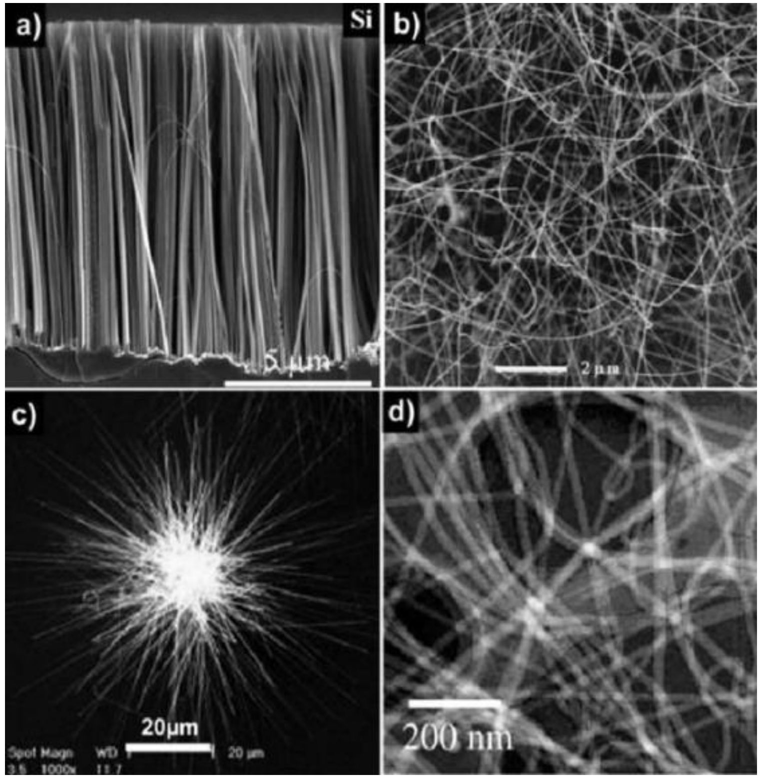
One interesting phenomena observed in nanowires is that we can easily play with the band gap which is an important parameter in fabricating devices for specific applications.

Since the band gap increases with the decrease of nanowire diameter, nanowire can emit visible light with high efficiency. Nanowire band gap is also affected by the surface chemistry because of the high surface area to volume ratio. Depending on the passivant on the nanowire surface the band gap can also be increased or decreased accordingly.

A well accepted mechanism for the growth of nanowires through gas phase reaction is vapor liquid-solid process. To grow any nanowire, the material used must be soluble in the catalyst nanoparticles. For example-

To grow silicon nanowire gold nanoparticles are used because silicon vapor is soluble in gold nanoparticles.

To grow gallium nitride nanowire iron nano particles are used because the reactants gallium and nitrogen are soluble in iron nanoparticles.

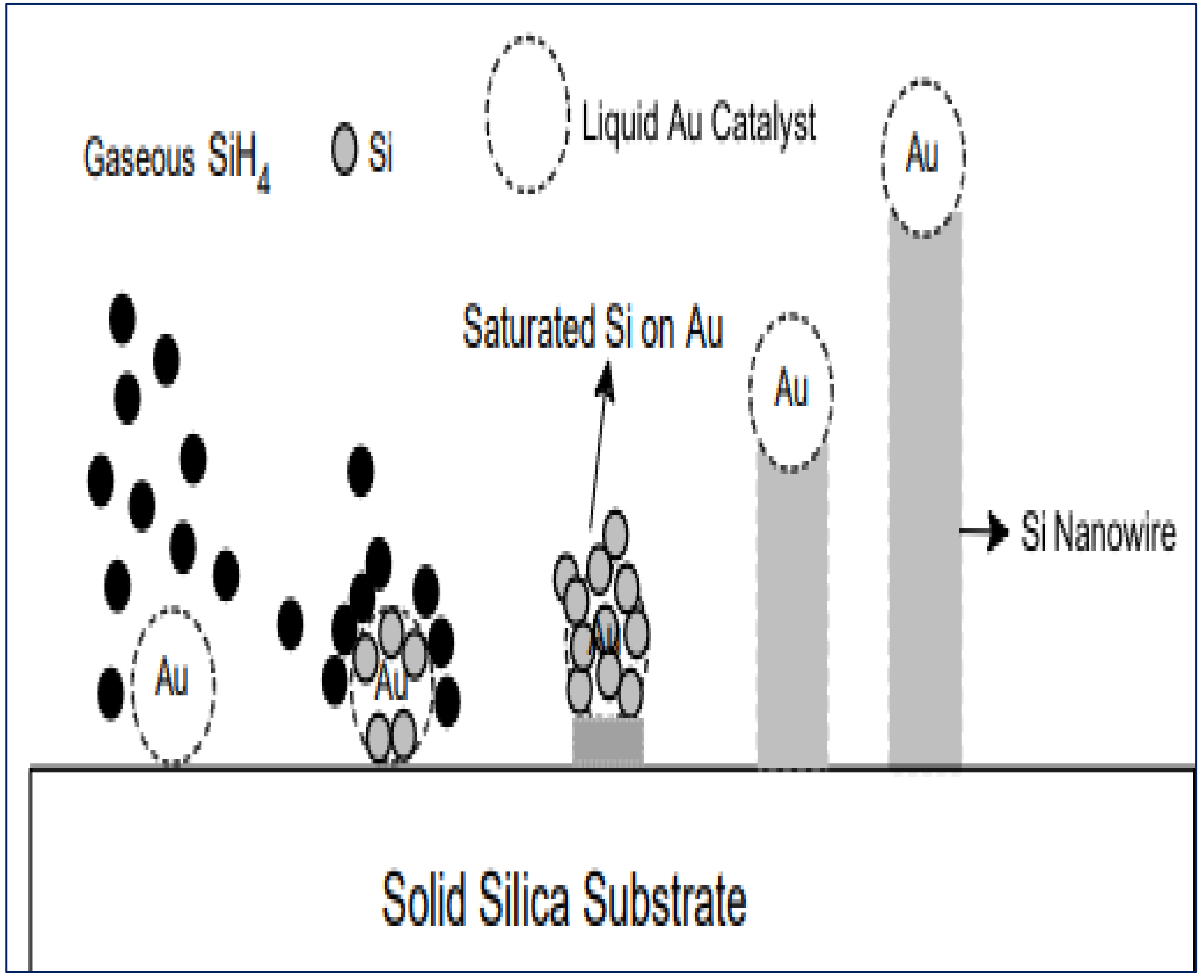


SEM Image of Si nanowires

Nanomaterials-Nanowires

Synthesis of Silicon nanowires (Vapor-Liquid-Solid Mechanism)

- In the first step, diffusion of vapor phase (SiH_4 reactants) takes place into the gold liquid phase (catalyst nanoparticles).
- In the second step, super saturation of Si reactants occur in the gold liquid phase which causes thethe precipitation of Si solid phase (nanowire).



Applications of Nanowires

- Nanowires are used in electron devices like field effect transistors, light emitting diodes, bio sensors, optical switches, solar cells and photo detectors.
- Nanowires replace copper in computers and in electronics.
- Self-assembled nanowires (NWs) have strong flexibility of tailoring their chemistry which makes them the building blocks for the nano-sized devices, e.g. in communication systems by miniaturization of light sources and development of nanotechnologies and biosensors.

Nanomaterials-Carbon Nanotube

In 1991, Sumio Iijima presented transmission electron microscopy observations of elongated and concentric layered microtubules made of carbon atoms. This propelled the research related to one of the most actively investigated structures of the last century – nowadays called the carbon nanotubes (CNTs). Following Iijima's ground-breaking discovery of multiwall carbon nanotubes (MWCNTs), carbon nanostructures – and in particular carbon nanotubes – have been at the forefront of scientific research in physics, chemistry, materials science, and so on. The discovery of single-wall carbon nanotubes (SWCNTs) in 1993 set yet another milestone in an exponentially growing field. Conceptually, these new nano forms of carbon allotropes with cylindrical geometry belong to the versatile family of fullerenes. Fullerenes were discovered by Harry Kroto, Robert Curl and Richard Smalley in 1985. This nanometer scale structure was named fullerene due to its resemblance to the highly symmetric domes designed by the architect Richard Buckminster Fuller. Buckminster fullerenes or fullerenes are the third allotrope of carbon and consist of a family of spheroidal or cylindrical molecules with all the carbon atoms sp^2 hybridized. C60 was the first fullerene to be discovered. Called the bucky ball, it is a soccer ball (icosahedral) shaped molecule with 60 carbon atoms bonded together in pentagons and hexagons. The carbon atoms are sp^2 hybridized, but unlike graphite, they are not arranged in a plane and is made up of 12 pentagons and 20 hexagons arranged in a spherical shape. The tubular form of the fullerenes are called carbon nanotubes.

Types of Carbon Nanotubes A carbon nanotube is a tube-shaped material, made of carbon, having a diameter measuring on the nanometer scale. To understand the structure of a carbon nanotube it can be first imagined as a rolled up sheet of graphene, which is a planar-hexagonal arrangement of carbon atoms distributed in a honeycomb lattice. A single layer of graphite sheet is called graphene. Carbon Nanotubes have many structures, differing in length, thickness, and in the type of helicity and number of layers. As a group, CNTs typically have diameters ranging from <1 nm up to 50 nm. Their lengths are usually several microns, but recent advancements have made the nanotubes much longer, and measured in centimeters.

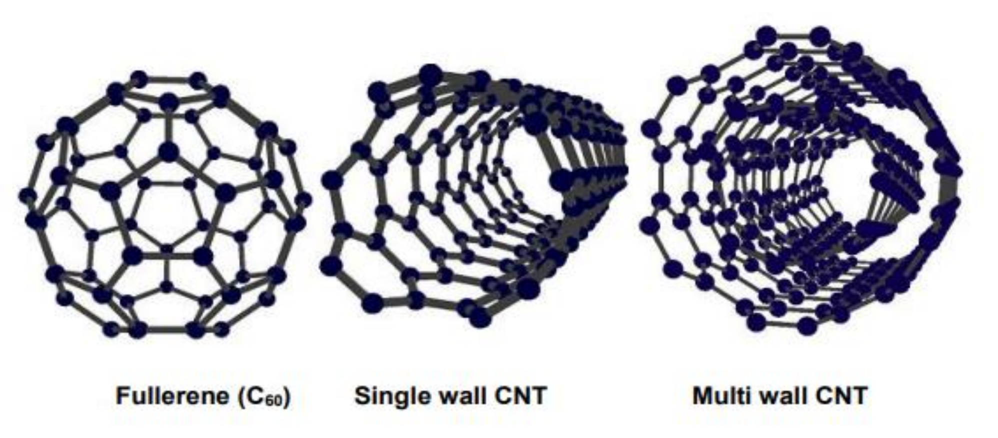
Nanomaterials-Carbon Nanotube

Single wall carbon nanotubes (SWCNT)

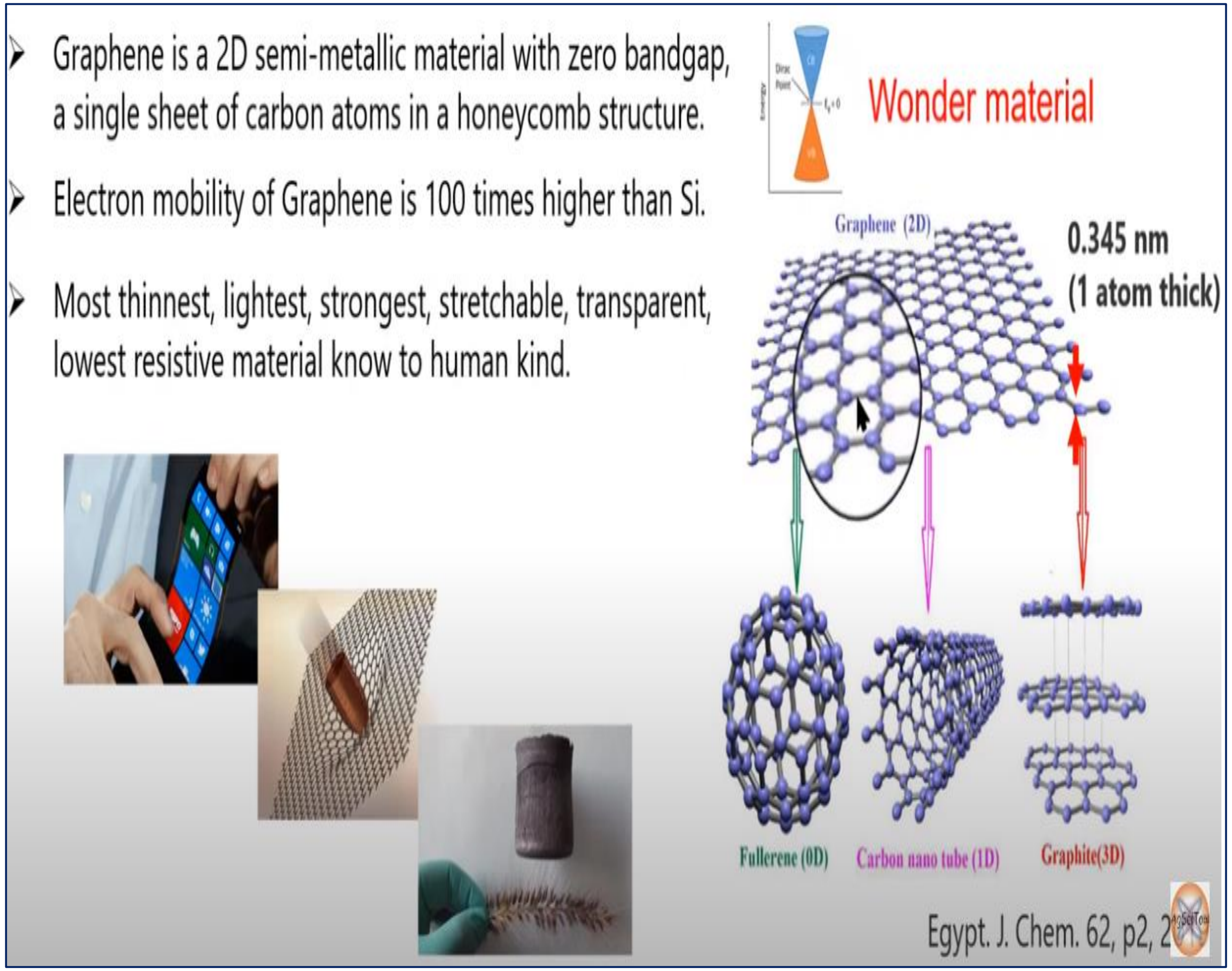
Single-wall nanotubes (SWNT) are tubes of graphite that are normally capped at the ends. They have a single cylindrical wall. The structure of a SWNT can be visualized as a layer of graphite, a single atom thick, called graphene, which is rolled into a seamless cylinder. Most SWNT typically have a diameter of close to 1 nm. The tube length, however, can be many thousands of times longer. SWNT are more pliable yet harder to make than MWNT. They can be twisted, flattened, and bent into small circles or around sharp bends without breaking.

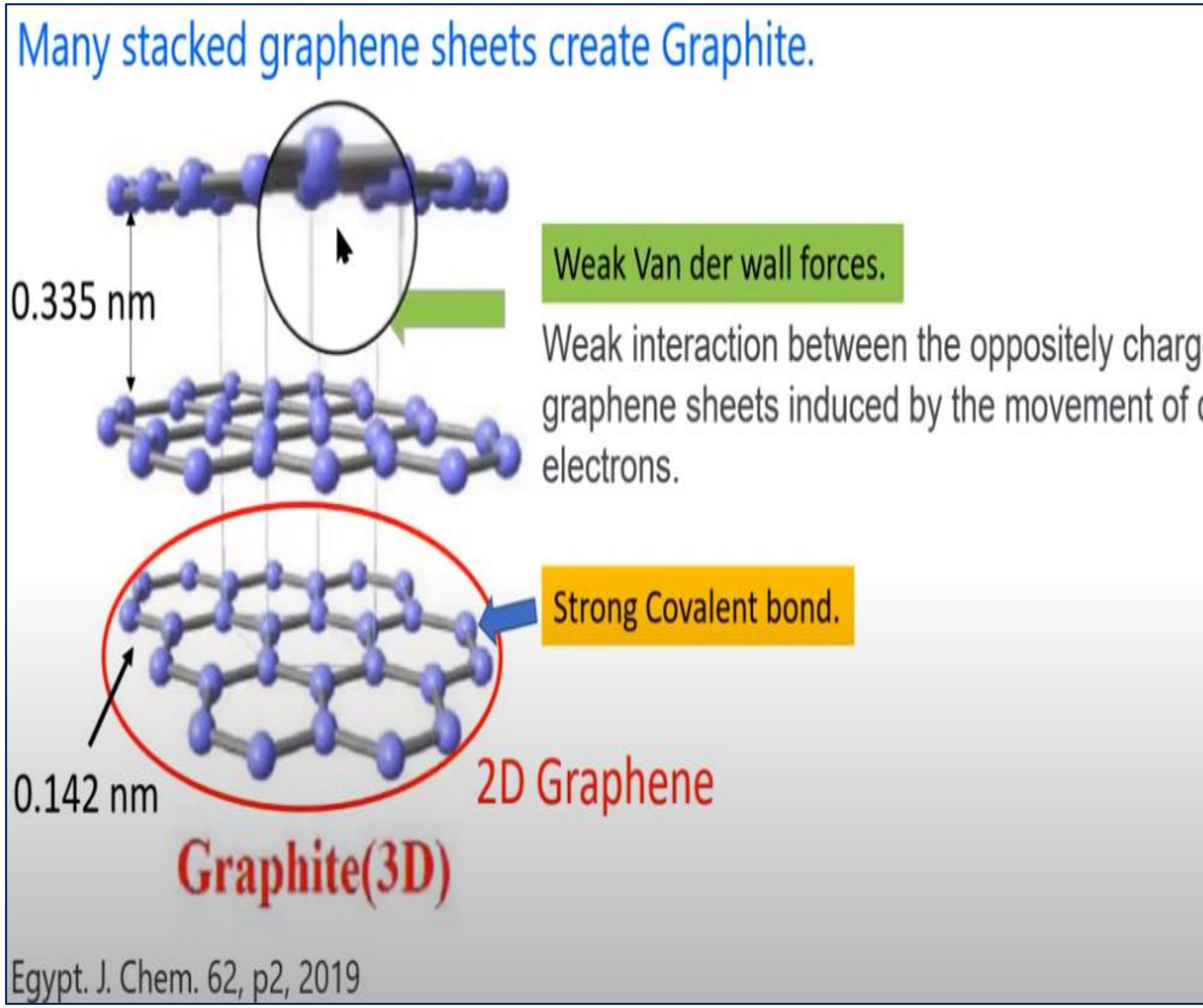
Multi wall carbon nanotubes (MWCNT)

There are two structural models of multi wall nanotubes. In the Russian Doll model, a carbon nanotube contains another nanotube inside it (the inner nanotube has a smaller diameter than the outer nanotube). In the Parchment model, a single graphene sheet is rolled around itself multiple times, resembling a rolled up scroll of paper. The simplest representative of a MWNT is a double walled carbon nanotube (DWNT). Multi wall carbon nanotubes have similar properties to single wall nanotubes, yet the outer walls on multi wall nanotubes can protect the inner carbon nanotubes from chemical interactions with outside materials. Multi wall nanotubes also have a higher tensile strength than single wall nanotubes. The diameters of MWNT are typically in the range of 5 nm to 50 nm. The interlayer distance in MWNT is close to the distance between graphene layers in graphite, around 3.39 A^{o} . MWNT are easier to produce than SWNT. However, the structure of MWNT is less well understood because of its greater complexity and variety. Regions of structural imperfection may diminish its desirable material properties.



Nanomaterials-Graphene





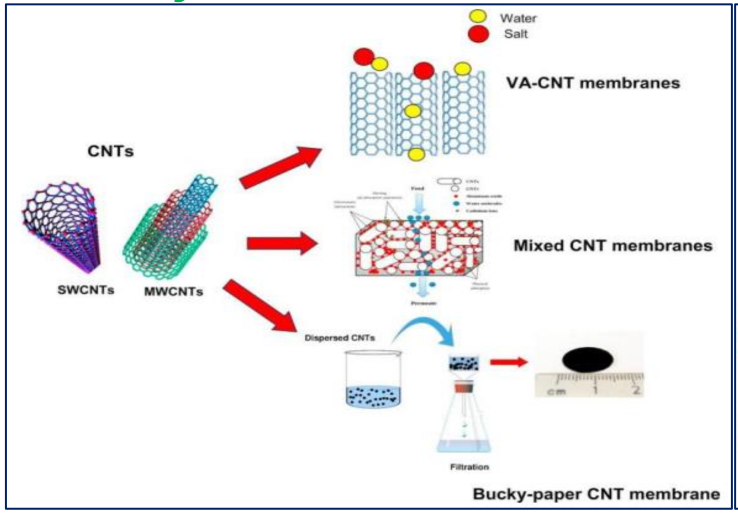
Nanomaterials-Water Purification

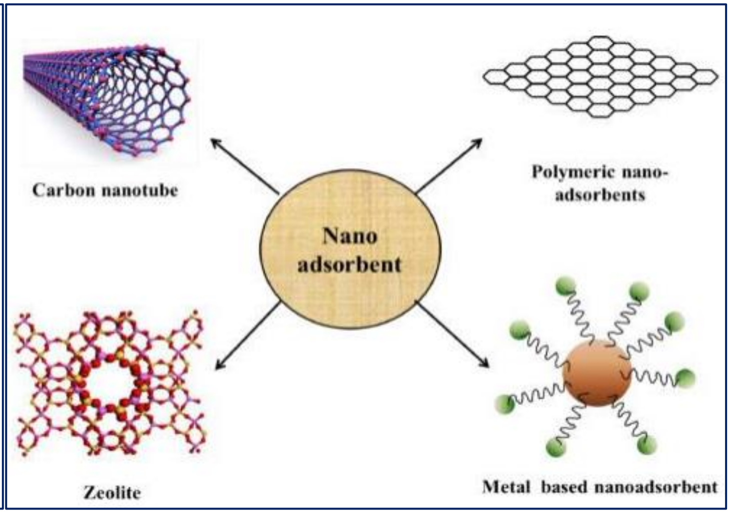
Scientists classified nano scale materials that are being evaluated as functional materials for water purification into four classes-

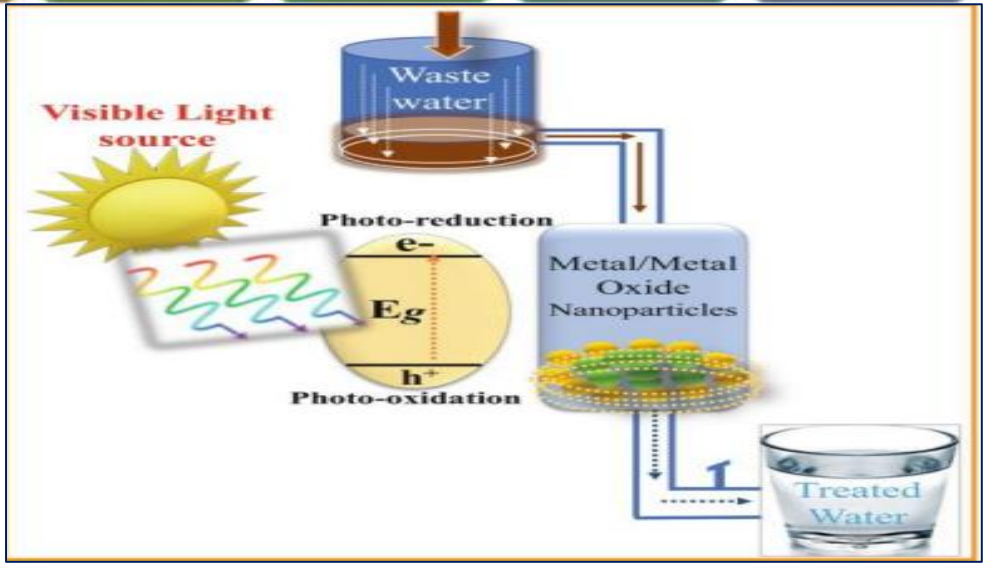
- Dendrimers
- metal-containing nanoparticles
- Zeolites
- carbonaceous nanomaterials

The application of nano technology in the cleaning up of contaminated water would summarize by (smith, 2006).

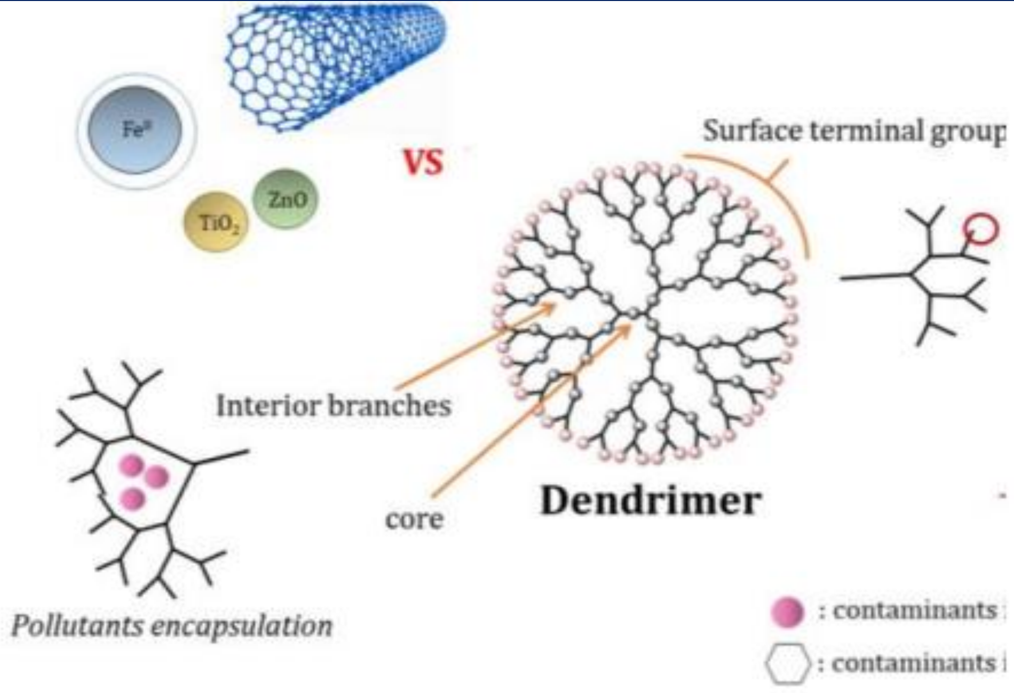
- Nano scale filtration technique
- The adsorption of pollutants on Nano particles
- The breakdown of contaminants by Nano particle
- catalysts.







Nanomaterials-Water Purification



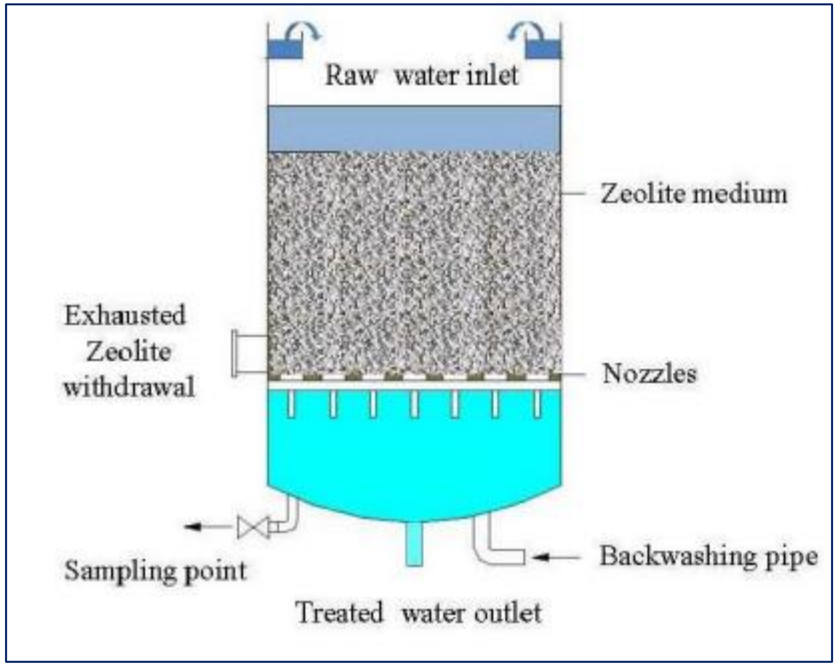


Photo catalysis has emerged as a green technology for the complete mineralization of hazardous organic chemicals to water, carbon dioxide and simple mineral acids (Tang, Z. and Ye J., 2004; Mohapatra D. P.et al., 2013) and occurs at room temperature.

When light radiation falls on the surface of metal, electrons absorb it and get excited. These electrons disperse on the surface of the photo catalyst and react with external substances, causing reductions and oxidations (Pankaj K.et al., 2012

Check List

1. Identify the two properties of nanomaterials.
2. Classify nanomaterials based on dimensions. Give example of each.
3. Classify nanoporous materials with examples.
4. Explain the size dependent properties of nanomaterials.
5. Explain the nanoparticle behavior in colloids.
6. Explain top-down nanofabrication and bottom-up nanofabrication.
7. List the top-down and bottom-up approaches in the synthesis of nanomaterials.
8. Explain schematically the solgel process in the nanomaterial synthesis.
9. Show the mechanism of reduction method and electrochemical method in the production of nanoparticles.
10. What is CVD? Explain that process schematically.
11. List the techniques you may apply to characterize nanomaterials with respective properties.
12. Write about the properties of nanowires and respective applications.
13. Classify CNT and differentiate CNTs based on their structure and properties.
14. Describe the use of nanomaterials in water purification.