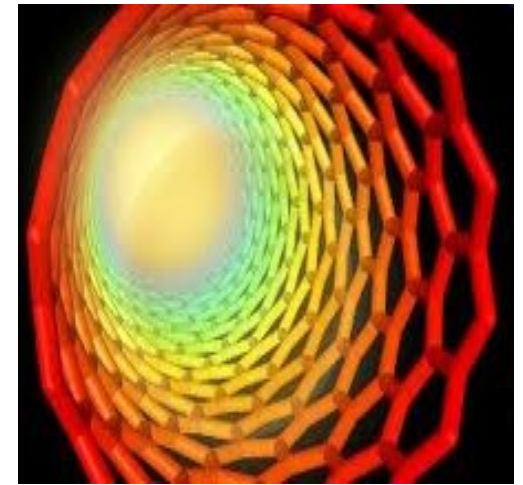
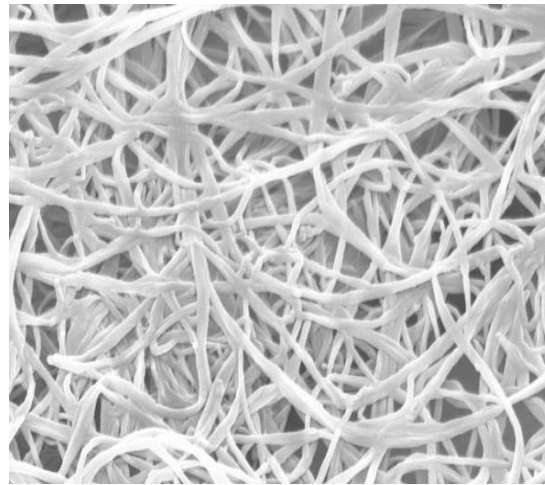
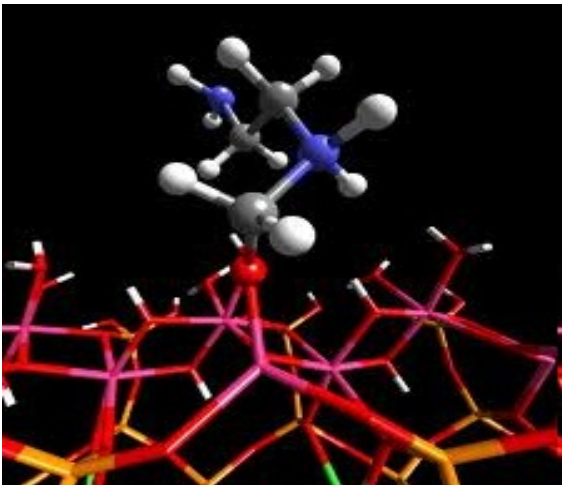


# Nanocomposite materials

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**Department of Physics**  
**Periyar University**  
**Salem. Tamilnadu**  
**India**



# *Outline*

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- Introduction
- Definitions
- Synthesis of nanomaterials
- Challenges
- Nanocomposites
- General features
- Advantages and Limitations
- Conclusion

# Nanotechnology

## What is nanotechnology?

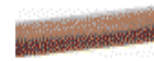
- Technology that deals with materials/particles in nano-size
- Nano =  $10^{-9}$  m
- 1 nm = 1 / 1 000 000 m
  - Human hair 60-80 000 nm thickness
  - red blood corpuscle 2-500 nm in width



Ant  
~ 5 mm

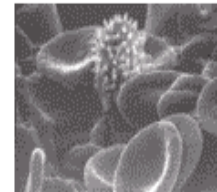


Dust mite  
200  $\mu$ m

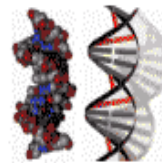


Human hair  
~ 10-50  $\mu$ m wide

Red blood cells with white cell



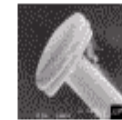
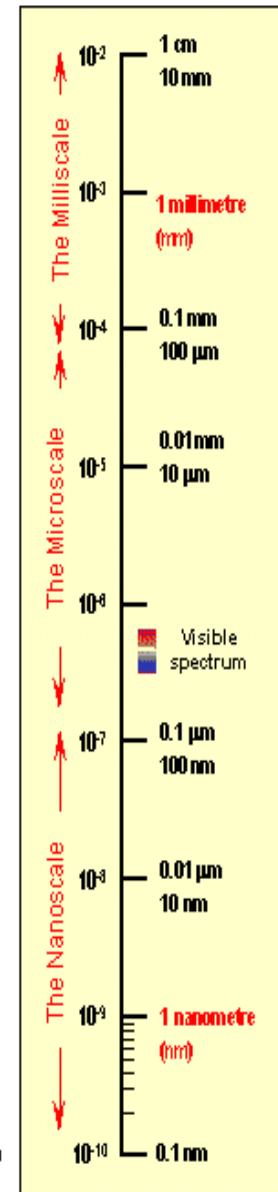
~ 2-5  $\mu$ m



DNA  
~ 2-1/2 nm



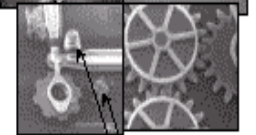
5 Atoms of silicon  
1 nm



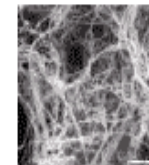
Head of a pin  
1-2 mm

Micro Electro Mechanical Devices

10 -100  $\mu$ m wide



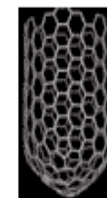
Pollen grain  
Red blood cells



Cellulose nanofibrils  
20-100nm wide



Stacks of clay mineral platelets, each platelet with ~ 1nm thickness

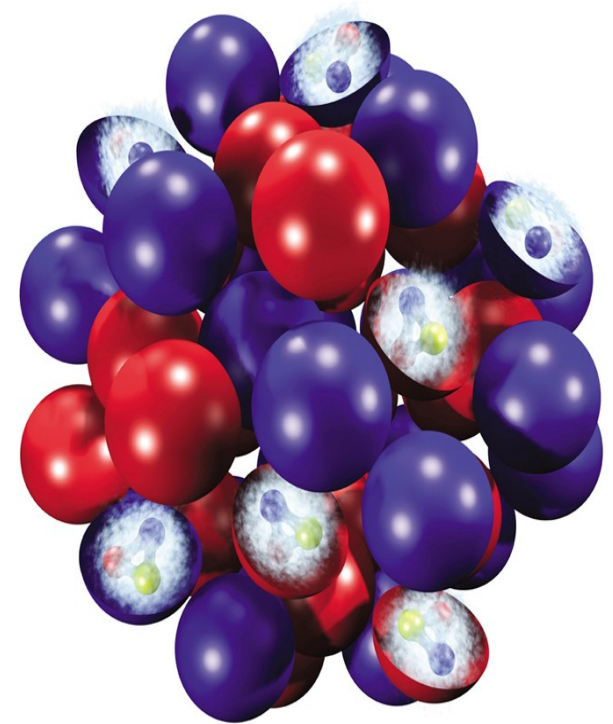


Carbon nanotube  
~ 2 nm diameter

# Continued....

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- Nano-size means atom level
- Percent surface area in proportion to total volume is changed compared to materials in bulk
- Use
  - Cars/motors, aircrafts, energy, electronic equipment, paint, cosmetics, medicine, packaging etc.



# Different definitions for 'NANO'

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## Nanocluster

A collection of units (atoms or reactive molecules) of up to about 50 units

## Nanocolloids

A stable liquid phase containing particles in the 1-1000 nm range.  
A colloid particle is one such 1-1000 nm particle.

## Nanoparticle

A solid particle in the 1-100 nm range that could be noncrystalline, an aggregate of crystallites or a single crystallite

## Nanocrystal

A solid particle that is a single crystal in the nanometer range

# Some Nanotech inventions –

## Nano is not new!

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- Nanowires of silicon, and other materials, have remarkable optical, electronic and magnetic properties.
- People use nanoparticles of soot in tires since 1900 to make them black, and nano bits of gold and silver have been added to color pigments in stained glass since the 10<sup>th</sup> century! Color depends on the size of these particles.
- You can't avoid nanoparticles-or you'd have to stop drinking milk, which is full of nano-sized particles of casein. The sugar molecule is about 1nm is diameter.
- Humans are living proof of Nanotechnology

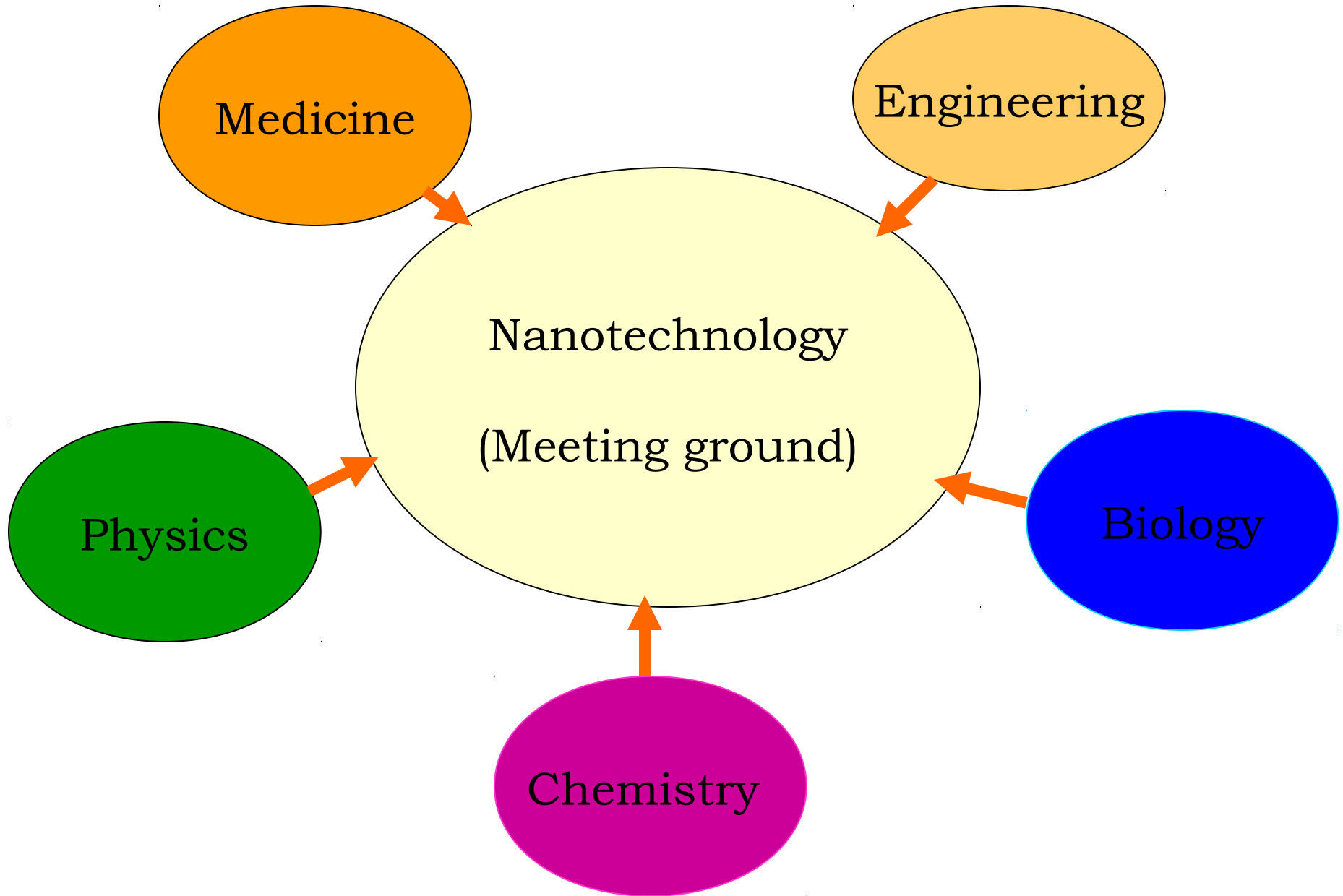
# Why nanoparticles are different from bulk materials?

- Nanoparticles are different from bulk materials and isolated molecules because of their unique physical and chemical properties.

Properties	Examples
Catalytic	Better catalytic efficiency through higher surface-to-volume ratio
Electrical	Increased electrical conductivity in ceramics and magnetic nanocomposites, increased electric resistance in metals
Magnetic	Increased magnetic coercivity up to a critical grain size, superparamagnetic behaviour
Mechanical	Improved hardness and toughness of metals and alloys, ductility and superplasticity of ceramic
Optical	Spectral shift of optical absorption and fluorescence properties, increased quantum efficiency of semiconductor crystals
Sterical	Increased selectivity, hollow spheres for specific drug transportation and controlled release
Biological	Increased permeability through biological barriers (membranes, blood-brain barrier, etc.), improved biocompatibility

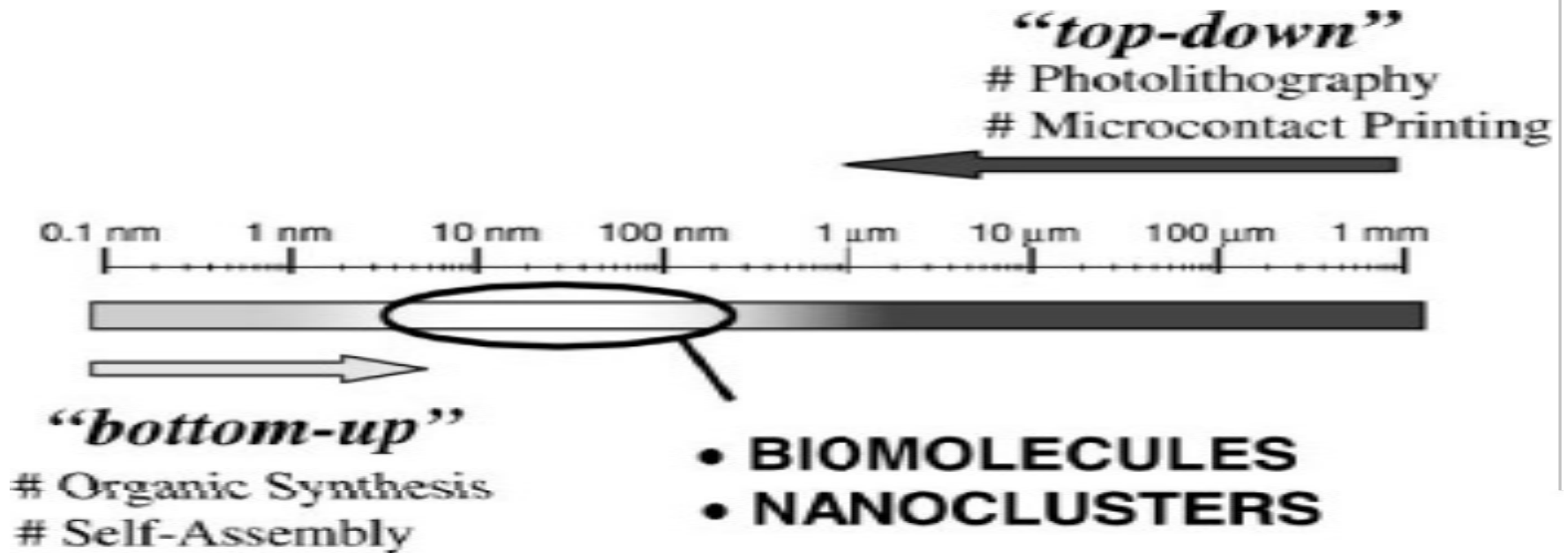
# Interdisciplinary technology

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# Two basic synthetic approaches



A gap currently exists in the engineering of small-scale devices. Whereas conventional top-down processes hardly allow the production of structures smaller than about  $200 \pm 100$  nm, the limits of regular bottom-up processes are in the range of about  $2 \pm 5$  nm.

# Nanoparticles

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- ❖ Nanoparticles are of different types viz.,
- ❖ Pure Metal Nanocolloids (Ag, Au, Cu, Fe, Ni, Co, etc.)
- ❖ Bimetallic Colloids (Pt –Ru, Pt –Ni, Co –Mo, Pd –Fe/Ru)
- ❖ Metal oxides ( $\text{TiO}_2$ , ZnO,  $\text{Fe}_2\text{O}_3$ ,  $\text{CrO}_2$  Meallates, etc.)
- ❖ Metal chalcogenides PbS, CdS, ZnS, ZnSe, CdSe, CdTe, HgS, CuInSe, etc.,
- ❖ Ferromagnetic Shape Memory Alloys
- ❖ Conducting Polymer –Metal Nanoparticles-Composites,  
etc.

# Synthesis of Nanoparticles

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- Chemical Reduction
- Reverse micellar synthesis
- Sol-gel process
- Aero-gel Process
- Microemulsion
- Co-precipitation
- Decomposition of Organometallic Compounds
- Hydrothermal routes
- Solution evaporation process,
- Sonochemical Ultrasonication
- Encapsulation in hosts (Zeolites, clays, buseritesbuserites, etc.)
- $\gamma$ - Ray irradiation in presence of redox mediators, etc.

# Challenges in nanotechnology

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For the fabrication and processing of nanomaterial and nanostructures, the following challenges must be met:

- ❖ Overcome the huge surface energy, a result of enormous surface area or large surface to volume ratio
- ❖ Ensure all nanomaterials with desired size, uniform size distribution, morphology, crystallinity, chemical composition and microstructure that altogether result in desired physical properties.
- ❖ Prevent nanomaterials and nanostructures from concerning through either Ostwald ripening or agglomeration
- ❖ Morphology control

# Nanocomposites

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## Definitions:

- ✓ Nanocomposites are broad range of materials consisting of two or more components, with at least one component having dimensions in the nm regime (i.e. between 1 and 100 nm)
- ✓ Nanocomposites consist of two phases (i.e nanocrystalline phase + matrix phase)  
Phase may be inorganic-inorganic, inorganic-organic or organic-organic
- ✓ Nanocomposite means nanosized particles (i.e metals, semiconductors, dielectric materials, etc) embedded in different matrix materials (ceramics, glass, polymers, etc).

# General features of nanocomposites

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Nanocomposites differ from traditional composites in the smaller size of the particles in the matrix materials.

Small size may cause

- a) Physical sensitivity of bulk materials to physical or mechanical energy
- b) Higher chemical reactivity of grain boundaries

## Physical sensitivity

- Small size effect
- Quantum confinement effect

## Chemical reactivity

- Higher gas absorption
- Increased nonstoichiometry
- Regrowth
- Rotation and orientation
- Sub graining
- Assembly

# Physical sensitivity

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## Small size effect:

When the particle sizes in composite materials approach lengths of physical interaction with energy, such as light wave, electromagnetic waves, the periodic boundary conditions of coupling interaction with energy would behave different from its microscopic counterparts, which results in unusual properties

## Quantum confinement effect:

When electrons are confined to a small domain, such as a nanoparticles, the electrons behave like “particles in a box” and their resulting new energy levels are determined by quantum confinement effect. These new energy levels give rise to the modification of optoelectronic properties such as “blue shift” light emitting diode

# Chemical reactivity

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## **Higher gas absorption:**

large specific area of nanoparticles can easily absorb gaseous species

## **Increased nonstoichiometry phases:**

Nanomaterials easily form chemically unsaturated bonds and nonstoichiometry compounds

## **Regrowth:**

Nanomaterials are probably easier to recrystallise and regrow in processing and service conditions than traditional materials

## **Rotation and orientation:**

Crystallographic rotation and orientation of nanoparticles have been found in processing of nanocomposites

## **Sub-grain:**

Nanoparticles enveloped into larger particles act as dispersed pinholes to divide the large particles into several parts.

## **Assembly**

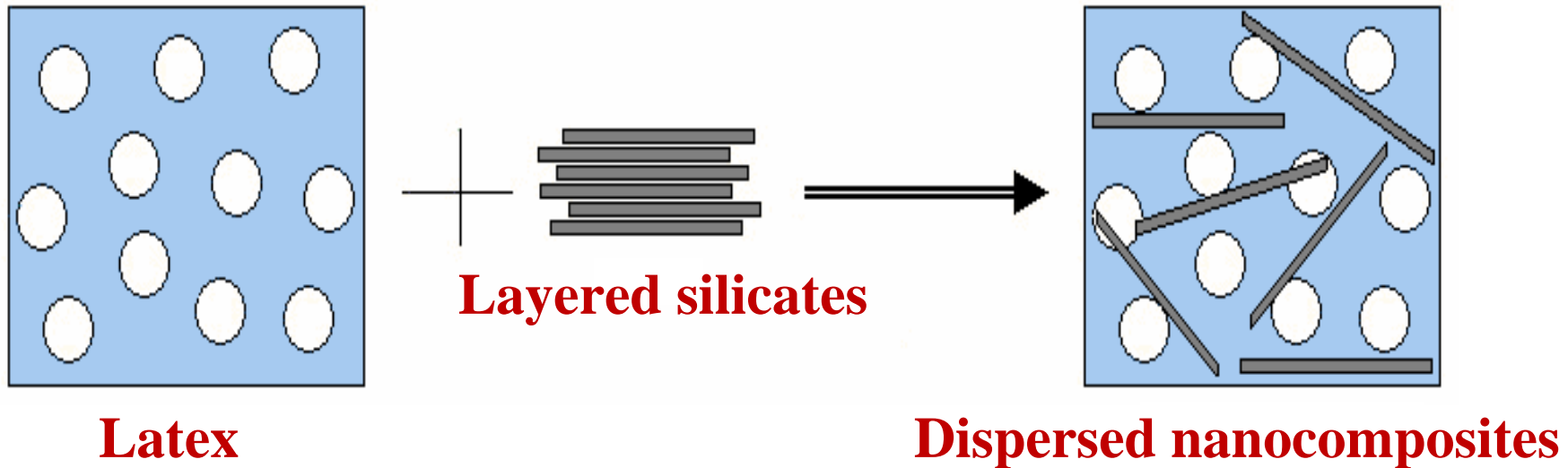
Nanoparticles are easy to aggregate and assemble in liquid or gaseous media



# Nanocomposites materials

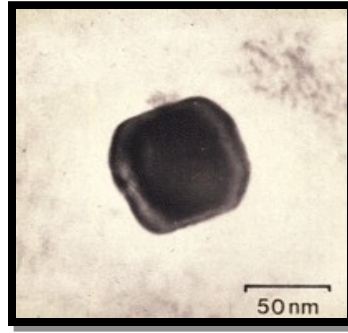
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Nanocomposites can be formed by blending inorganic nanoclusters, fullerenes, clays, metals, oxides or semiconductors with numerous organic polymers or organic and organometallic compounds, biological molecules, enzymes, and sol-gel derived polymers



# Continued...

- Resulting nanocomposite may exhibit drastically different (often *enhanced*) properties than the individual components
  - Electrical, magnetic, electrochemical, catalytic, optical, structural, and mechanical properties



***Lycurgus Cup***



Lycurgus Cup is made of glass. Roman ~400 AD, *Myth of King Lycurgus*

Appears green in reflected light and red in transmitted light

# Classification of nanocomposites

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## Ceramic based nanocomposites

- Increase in the strength, hardness, and abrasion by refining particle size
- Enhance ductility, toughness, formability, superplasticity by nanophase
- Change electrical conduction and magnetic properties by increasing the disordered grain boundary interface

## Metallic based nanocomposites

- Increased hardness, strength and superplasticity;
- Lowered melting point;
- Increased electrical resistivity due to increased disordered grain surfaces;
- Increased miscibility of the non-equilibrium components in alloying and solid solution;
- Improved magnetic properties such as coercivity, superparamagnetization, saturation magnetization and magnetocaloric properties

## Polymer based nanocomposites.

- electrical, optical, magnetic and catalytic properties arising from the inorganic materials, and enhanced thermal and mechanical stability originating from the polymeric matrix

# Advantages and limitations of ceramic nanocomposite processing methods.

Methods	Advantages	Limitations
Powder process	Simple	Low formation rate, high temperature, agglomeration, poor phase dispersion, formation of secondary phases in the product.
Sol-Gel Process	Simple, low processing temperature; versatile; high chemical homogeneity; rigorous stoichiometry control; high purity products; formation of three dimensional polymers containing metal-oxygen bonds. Single or multiple matrices. Applicable specifically for the production of composite materials with liquids or with viscous fluids that are derived from alkoxides.	Greater shrinkage and lower amount of voids, compared to the mixing method
Polymer Precursor Process	Possibility of preparing finer particles; better reinforcement dispersion	Inhomogeneous and phase-segregated materials due to agglomeration and dispersion of ultra-fine particles

# Advantages and limitations of processing methods for metal-based nanocomposites.

Methods	Advantages	Limitations
Spray Pyrolysis	Effective preparation of ultra fine, spherical and homogeneous powders in multicomponent systems, reproductive size and quality.	High cost associated with producing large quantities of uniform, nanosized particles.
Liquid Infiltration	Short contact times between matrix and reinforcements; moulding into different and near net shapes of different stiffness and enhanced wear resistance; rapid solidification; both lab scale and industrial scale production.	Use of high temperature; segregation of reinforcements; formation of undesired products during processing.
Rapid Solidification Process (RSP)	Simple; effective.	Only metal-metal nanocomposites; induced agglomeration and non-homogeneous distribution of fine particles.
RSP with ultrasonics	Good distribution without agglomeration, even with fine particles.	
High Energy Ball Milling	Homogeneous mixing and uniform distribution.	
Chemical Processes (Sol-Gel, Colloidal)	Simple; low processing temperature; versatile; high chemical homogeneity; rigorous stoichiometry control; high purity products.	Weak bonding, low wear-resistance, high permeability and difficult control of porosity.
CVD/PVD	Capability to produce highly dense and pure materials; uniform thick films; adhesion at high deposition rates; good reproducibility	Optimization of many parameters; cost; relative complexity.

# Advantages and limitations of polymer-based nanocomposite processing methods

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## Methods

Intercalation /  
Prepolymer from  
Solution

In-situ  
Intercalative  
Polymerization

Melt  
Intercalation

Template  
Synthesis

Sol-Gel Process

## Advantages

Synthesis of intercalated nanocomposites based on polymers with low or even no polarity. Preparation of homogeneous dispersions of the filler.

Easy procedure, based on the dispersion of the filler in the polymer precursors.

Environmentally benign; use of polymers not suited for other processes; compatible with industrial polymer processes.

Large scale production; easy procedure.

Simple, low processing temperature; versatile; high chemical homogeneity; rigorous stoichiometry control; high purity products; formation of three dimensional polymers containing metal-oxygen bonds. Single or multiple matrices. Applicable specifically for the production of composite materials with liquids or with viscous fluids that are derived from alkoxides.

## Limitations

Industrial use of large amounts of solvents.

Difficult control of intragallery polymerization. Limited applications.

Limited applications to polyolefins, who represent the majority of used polymers.

Limited applications; based mainly in water soluble polymers, contaminated by side products

Greater shrinkage and lower amount of voids, compared to the mixing method

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Thank you