University School of Automation and Robotics
GURU GOBIND SINGH INDRAPRASTHA UNIVERSITY
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Engineering Chemistry-II (BS-104)

Nanotechnology

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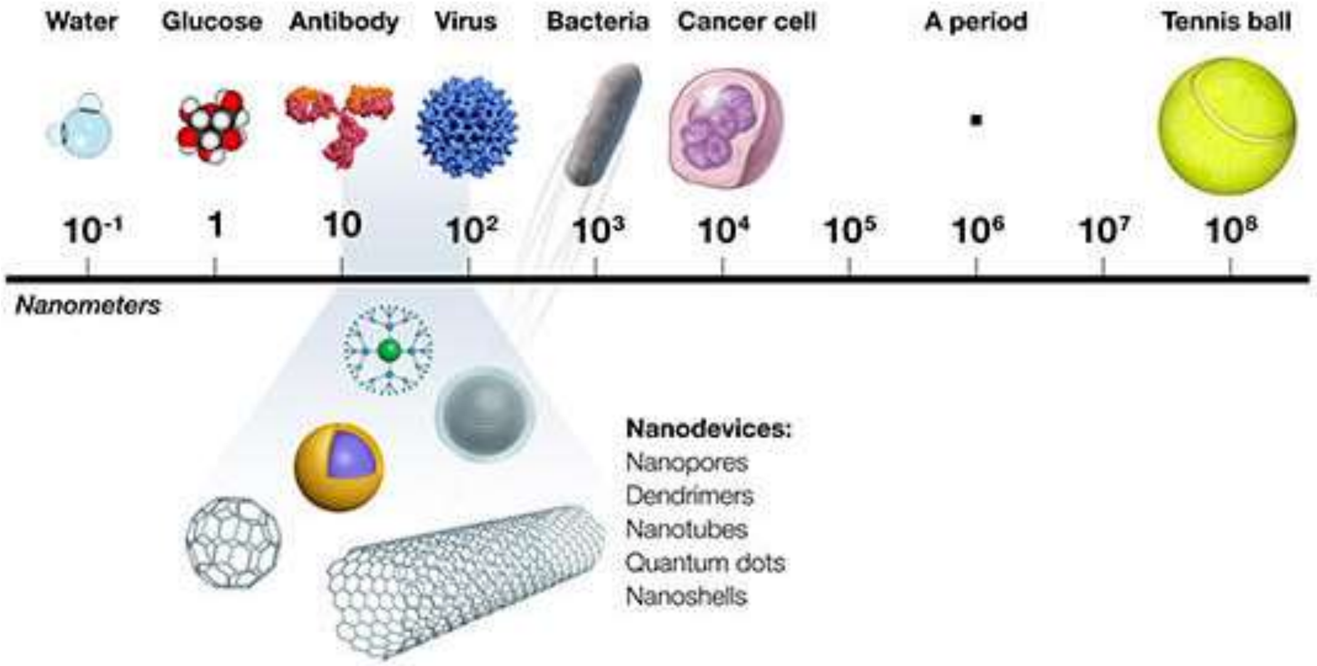
- **Nanotechnology** is defined as the design and fabrication of materials, devices and systems with control at nanometer dimensions.
- The essence of nanotechnology is therefore **size and control**.
- The nanometer, 10^{-9} m, i.e. one millionth of a millimeter
- In 1959, the physicist Richard Feynman, Nobel Prize winner for Physics in 1965, came up with the brilliant concept of the nano when he said **“there is plenty of room at the bottom”** during a conference of the American Physical Society.
- The term nanotechnology was first used in 1974 by Norio Taniguchi (University of Tokyo)



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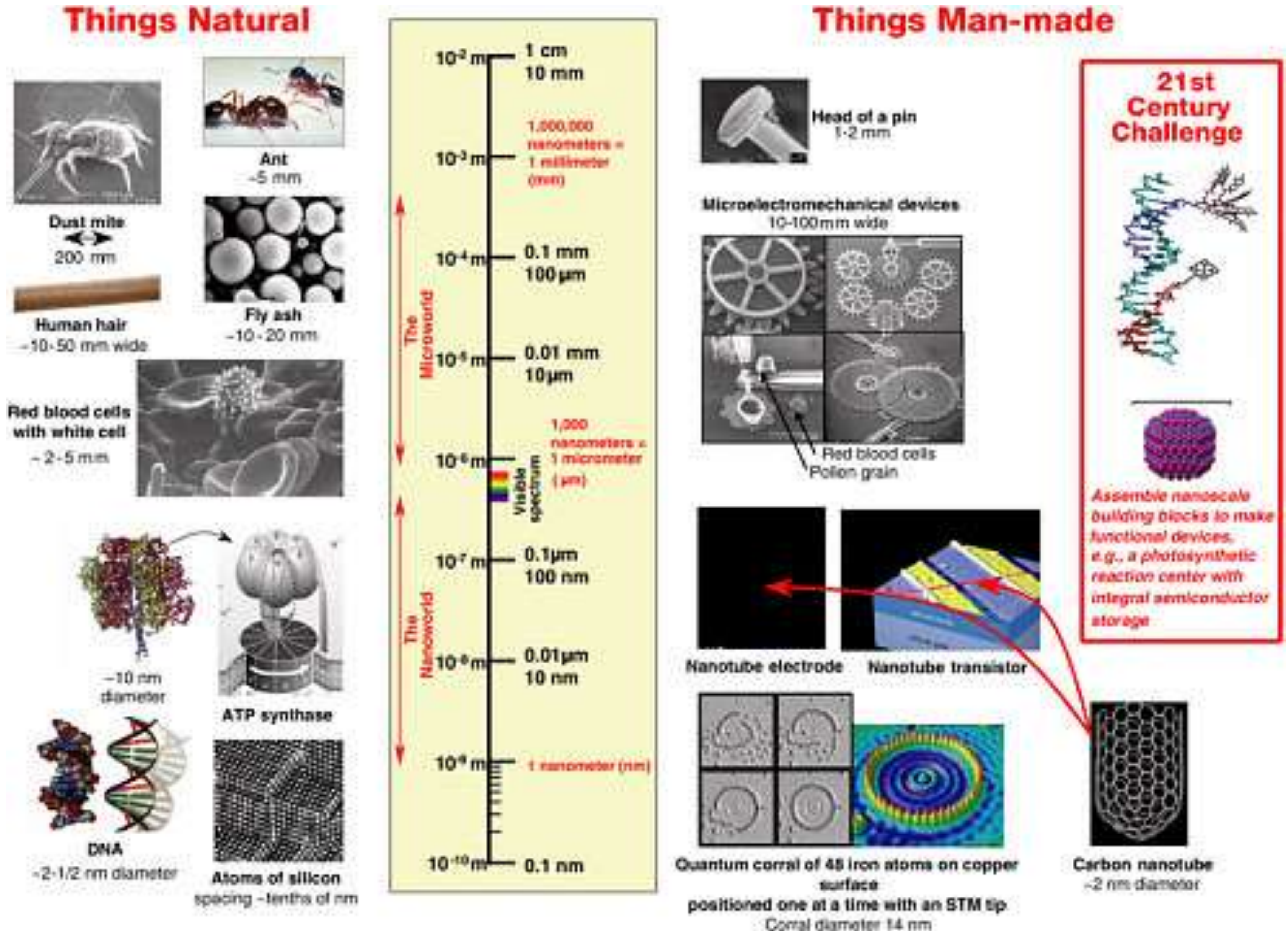
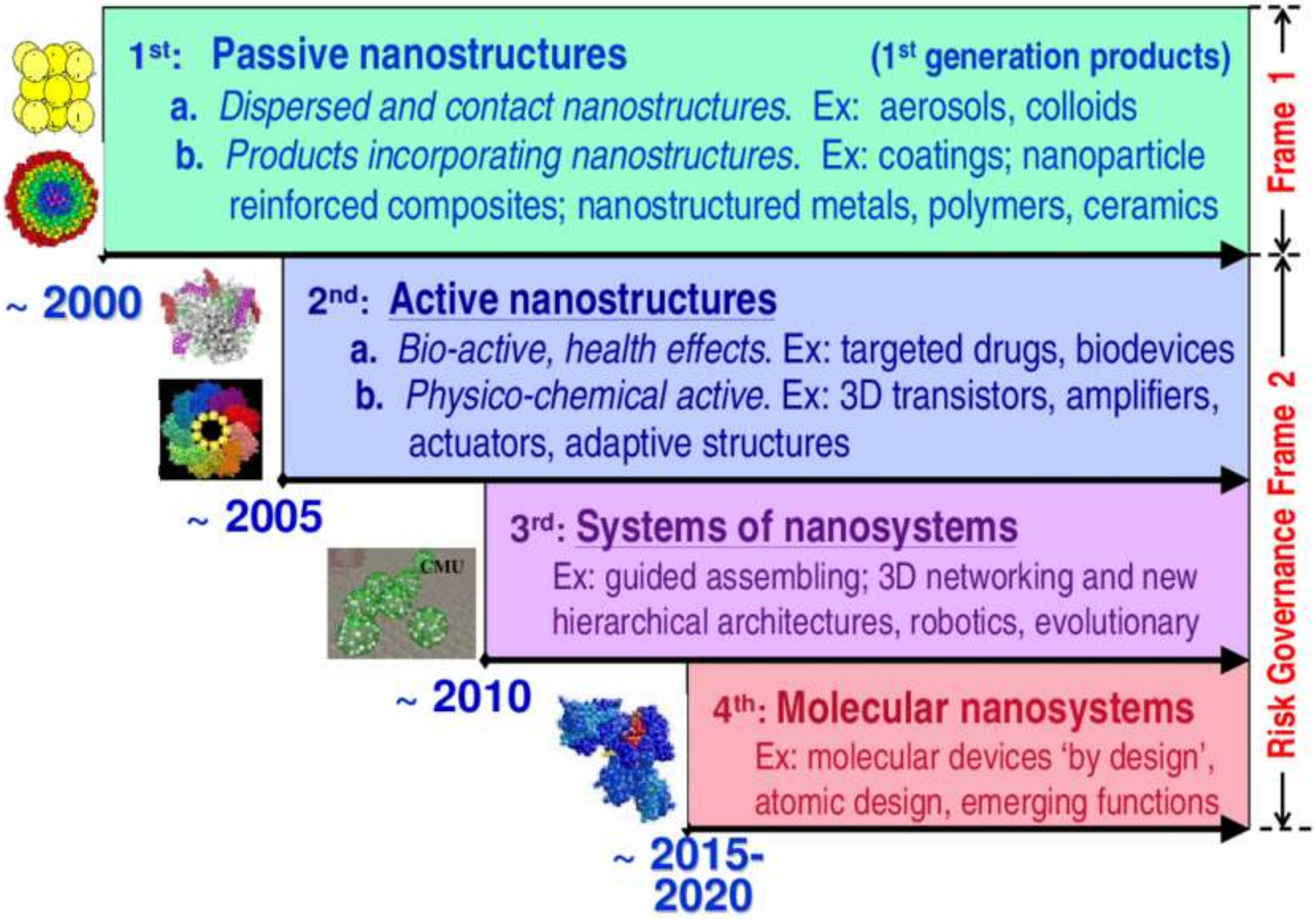


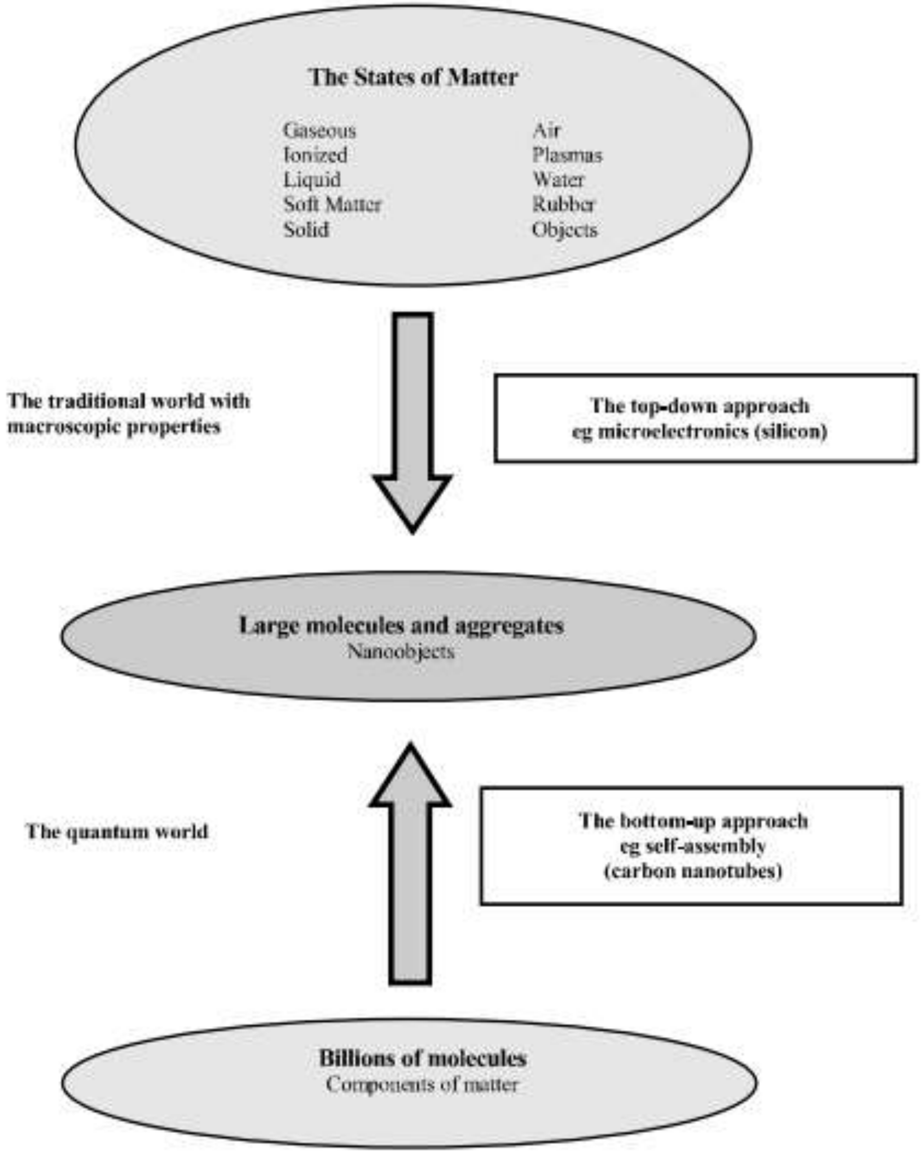
- **Nanotechnology Timeline:**



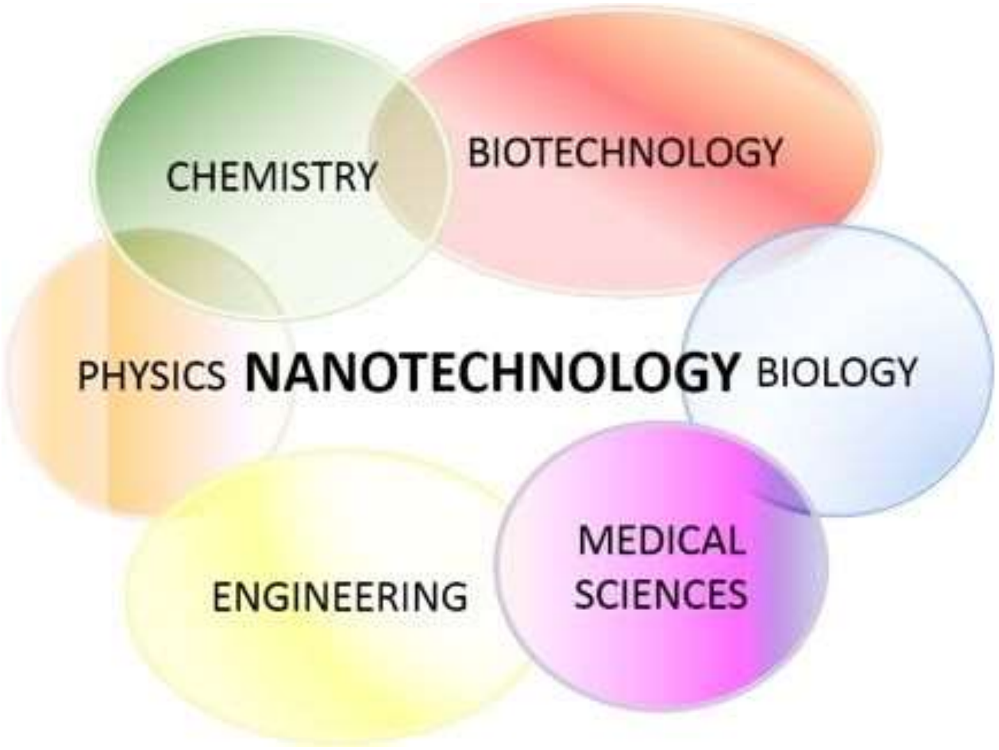
- **Two technological approaches to the nanoworld:**

(i). **Top-down:** which enables us to control the manufacture of smaller, more complex objects, as illustrated by micro and nanoelectronics;

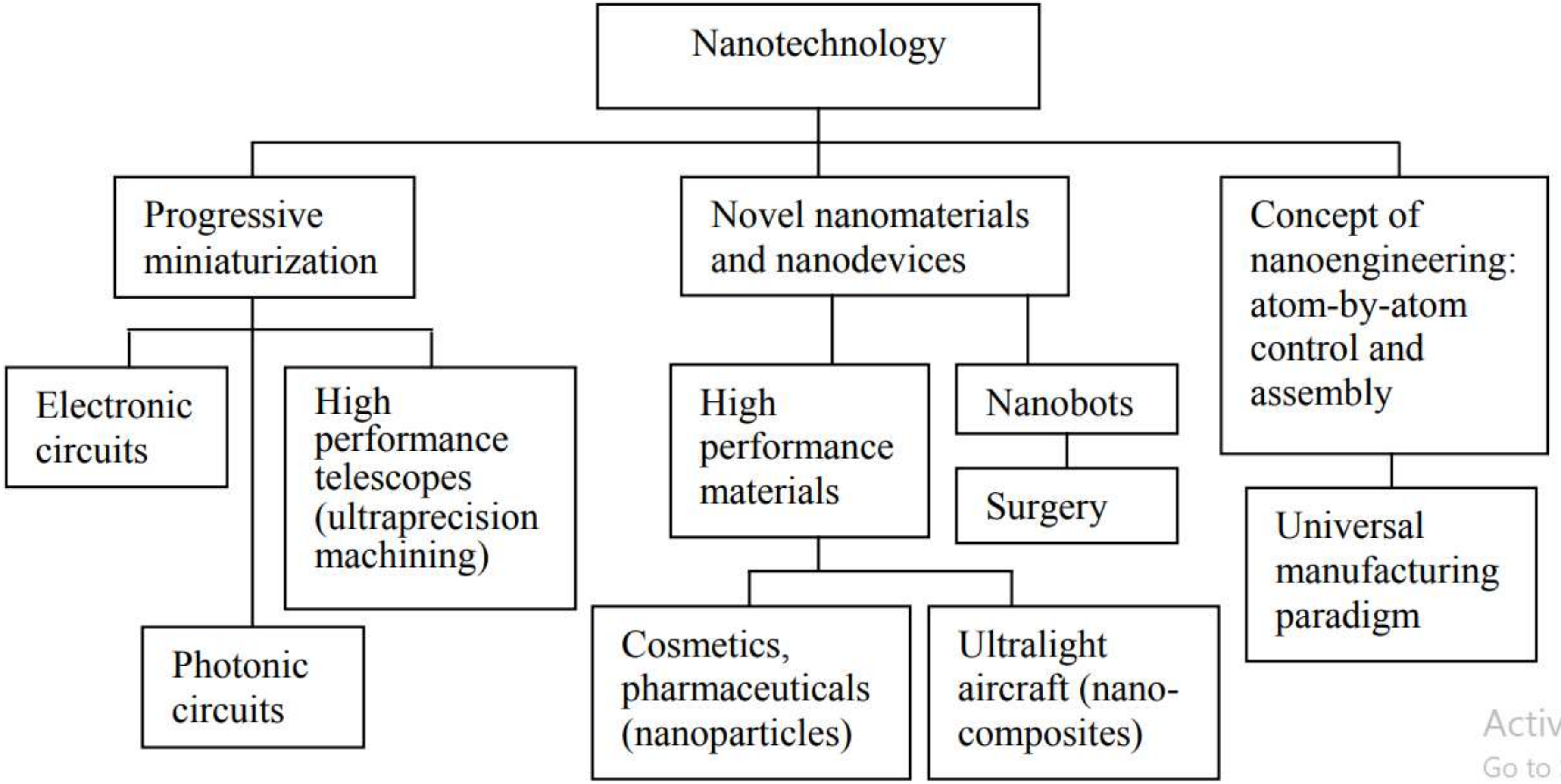
(ii) **Bottom-up:** which enables us to control the manufacture of atoms and molecules, as illustrated by supramolecular chemistry.



- **Nanotechnology: An Interdisciplinary field**
- Nanoscience and nanotechnology could be defined via the convergence of chemistry, biology, physics and engineering.
- Physics, chemistry and biology strongly overlap with nanoscience (defined as the study of matter at the molecular scale), but differ essentially from nanotechnology, which seeks to impose control over materials and devices at that scale.
- Quantum mechanics affects the performance of devices at the lower end of the size range of nano-objects.

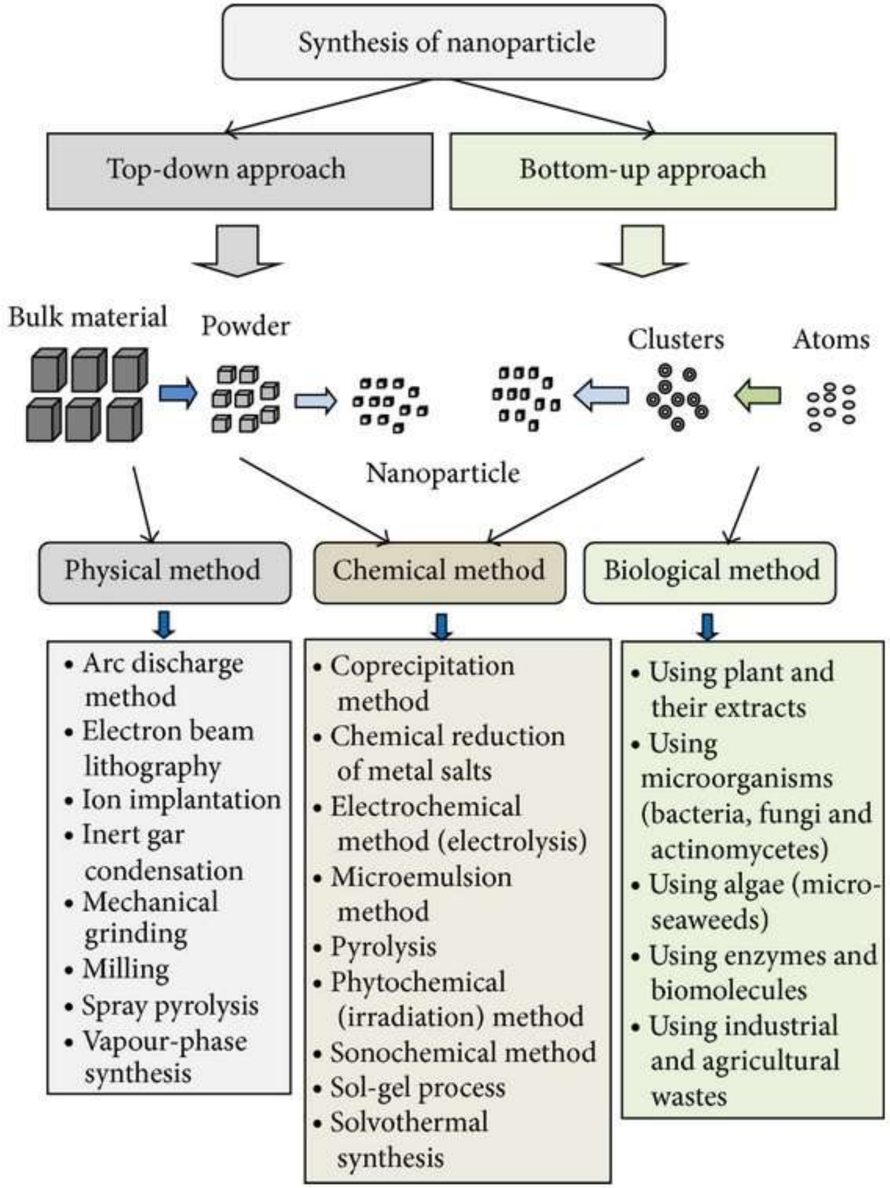


- **What can nanotechnology do for us?**



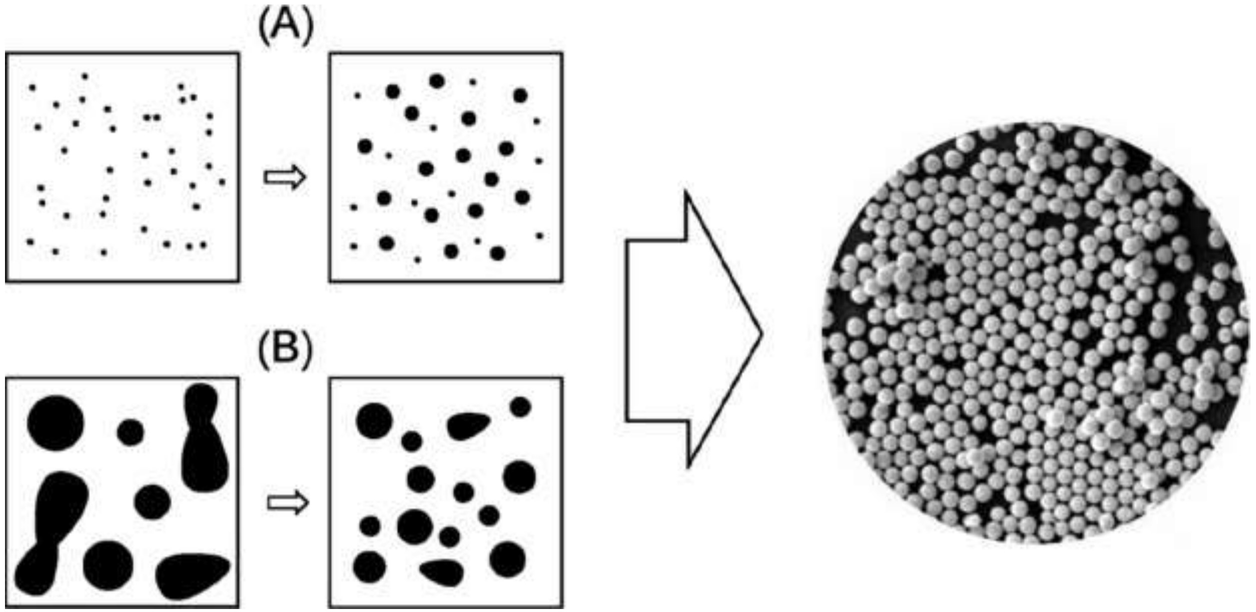
- **Nanoparticles (NPs):** are wide class of materials that include particulate substances, which have one dimension less than 100 nm at least.
- The different groups include fullerenes, metal NPs, ceramic NPs, and polymeric NPs.
- They can be classified into different classes based on their properties, shapes or sizes.
- NPs possess unique physical and chemical properties due to their high surface area and nanoscale size.
- Their optical properties are reported to be dependent on the size, which imparts different colors due to absorption in the visible region.
- Their reactivity, toughness and other properties are also dependent on their unique size, shape and structure.
- Due to these characteristics, they are suitable candidates for various commercial and domestic applications, which include catalysis, imaging, medical applications, energy-based research, and environmental applications.

- **Synthesis of nanoparticles:** Synthesis methods play a very important role to control the size and surface area of nanomaterials. The techniques applied in synthesizing nanoparticles greatly influence their morphology, size, structure, and performance. The synthesis methods for nanoparticles are broadly divided into top-down and bottom-up approaches.



1) **Top-down approach:** Top-down method is a destructive method that breaks down large molecules into smaller parts before converting into the relevant nanoparticles. This approach involves some decomposition strategies like chemical vapor deposition (CVD), milling process, and physical vapor deposition (PVD).

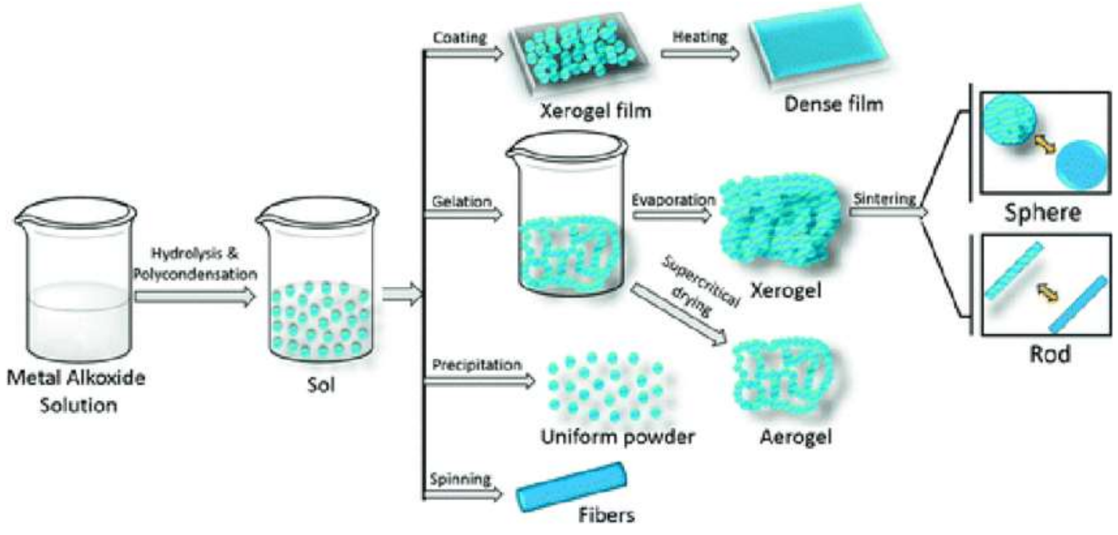
2) **Bottom-up approach:** This approach involves the formation of nanoparticles from simple materials in a build-up manner. It is environmentally friendly, less poisonous, feasible, and of low cost. The materials used are usually Reduction and sedimentation processes like green synthesis, bio-chemical, spin coating, sol–gel etc. adopt this approach.



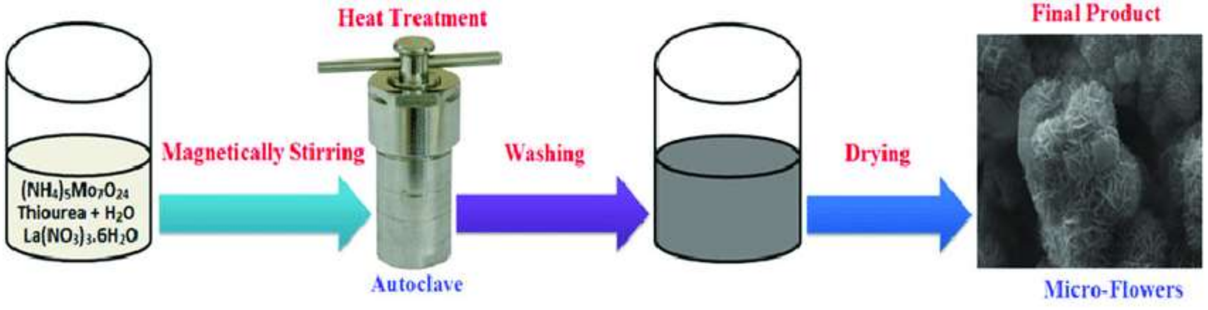
Scheme: (A) Bottom-up approach: A molecular precursor is disintegrated to simpler metal atoms that grow into colloids. (B) Top-down approach: Large drops of a metal broken into smaller drops

1) **Chemical methods:** Some chemical methods adopted in synthesizing nanoparticles include sol gel, precipitation, hydrothermal, thermal decomposition, solvothermal, vapor synthesis etc

- **Sol–gel method** is an easy means of producing nanostructures by homogenously mixing precursors in a solvent to form a gel material which is then heated to produce the required nanoparticle. E.g. TiO_2 nanoparticles
- **Hydrothermal method** utilizes high pressure and temperature to power heterogeneous reactions under aqueous solvents like water. The kind of pressure, pH, and temperature applied affects the features of the synthesized nanoparticles. Such nanoparticles are suitable for biotechnological use because of their hydrophilic surface nature. E.g. Fe_2O_3 nanoparticles

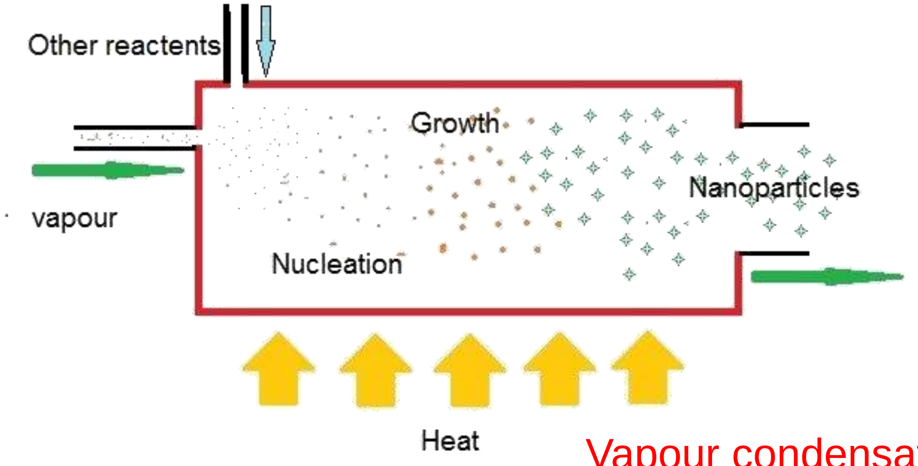


Sol-gel synthesis method

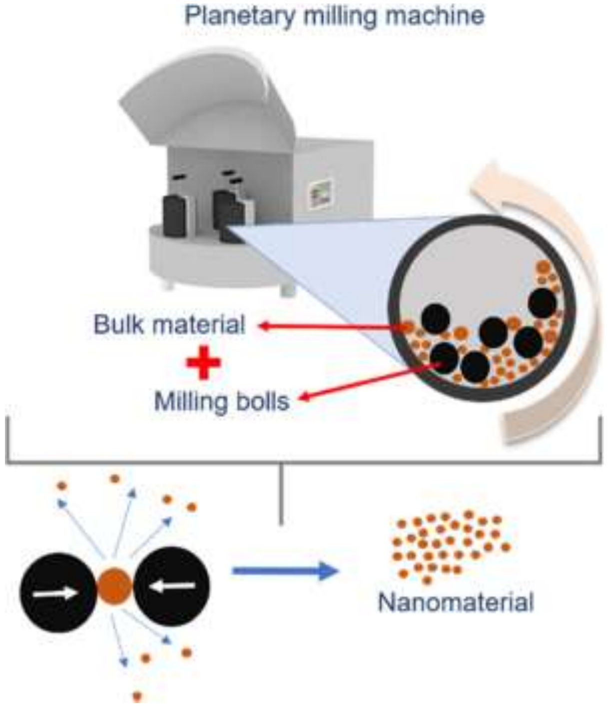


Hydrothermal method

- In **vapor synthesis**, gaseous molecules chemically react to produce a phase which condenses and leads to particle growth. The higher the temperature, the faster the particles are formed.
- **Chemical reduction** method involves the reduction of metal salt precursor in presence of a reducing agents and a capping agent e.g. AgNPs, AuNPs



Vapour condensation method

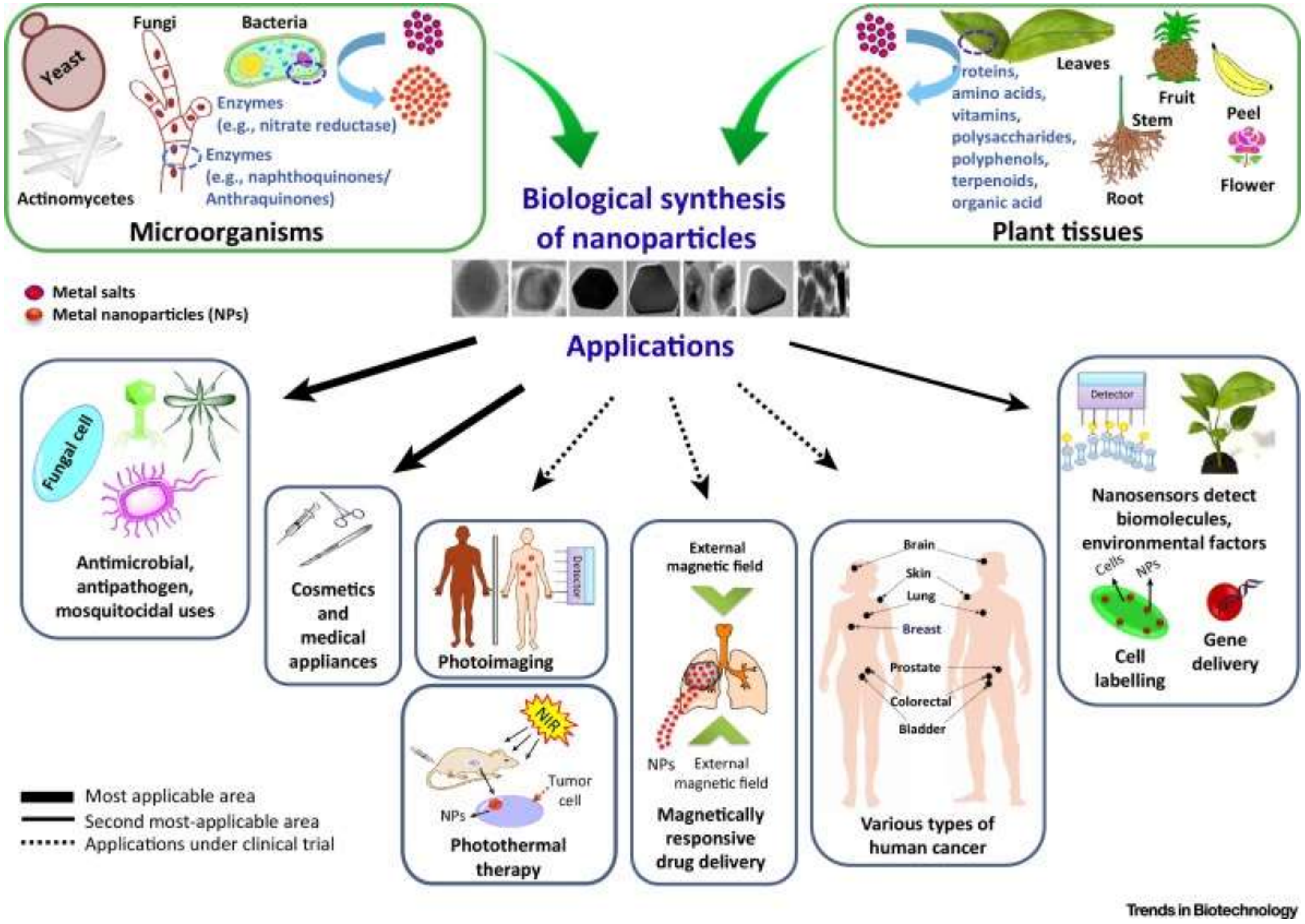


Milling method

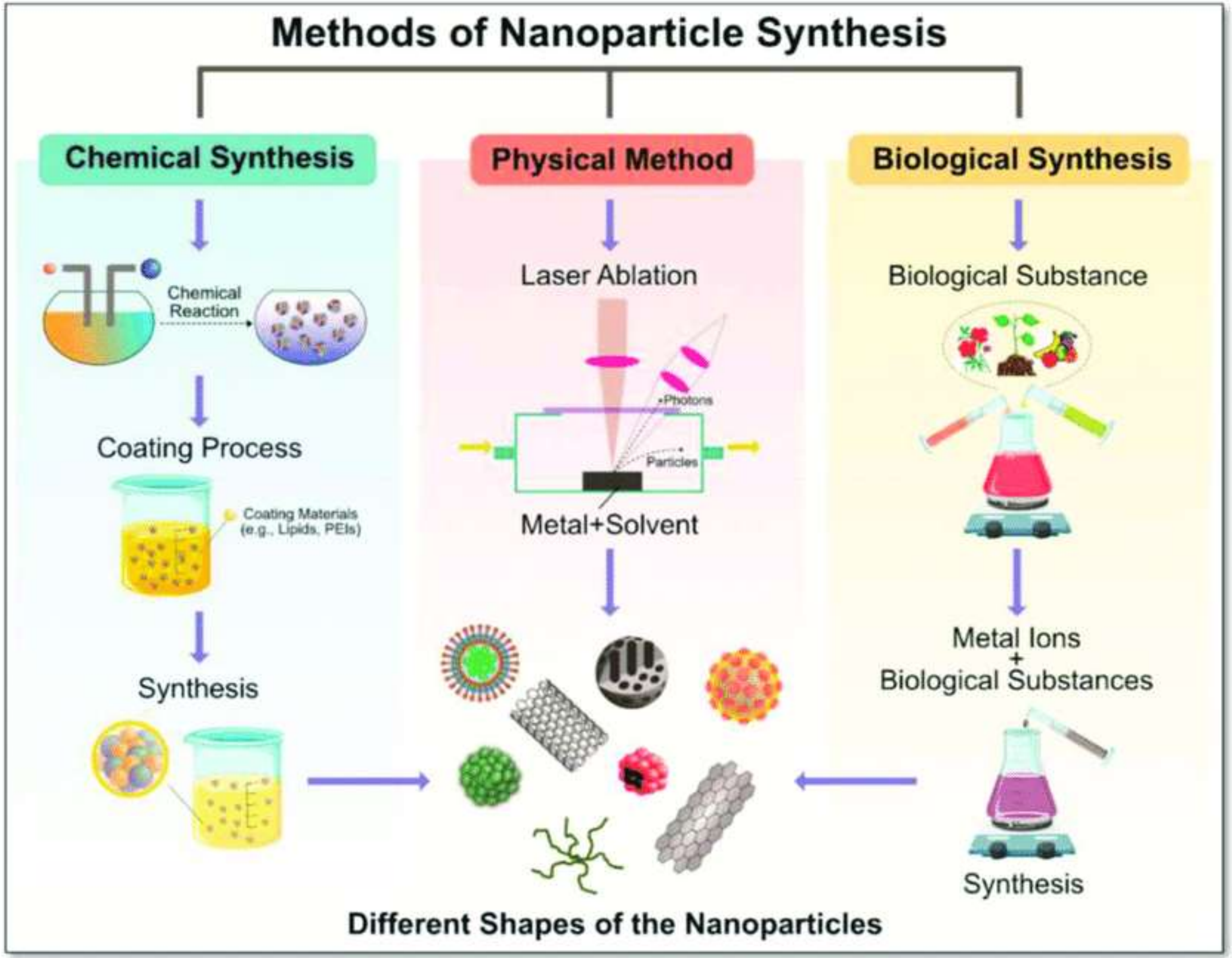
2. Physical methods: Nanoparticles can also be synthesized by mechanical methods like mechanical alloying, milling, and mechanochemical processes.

- Milling method regenerates interfacial chemical operations at low temperatures. Mechanochemical technique involves continuous welding operations that adequately select milling materials and minimize agglomerations. Nanoparticles of oxides, iron, nickel, silver, cobalt can be synthesized using these methods.

3). Biological methods: ological or biosynthesis of nanoparticles is an environmentally-friendly, green, and non-toxic method involving microorganisms. Nanoparticles of iron oxide, silver, nickel oxide, copper oxide, zinc ferrite have been synthesized using this method. Biogenic means of producing nanoparticles are green and cheap; with the involvement of fungi, waste materials, and bacteria. Phytonanotechnology is compatible with biological systems, available source materials, high stability, and entails synthesizing nanoparticles from plants.

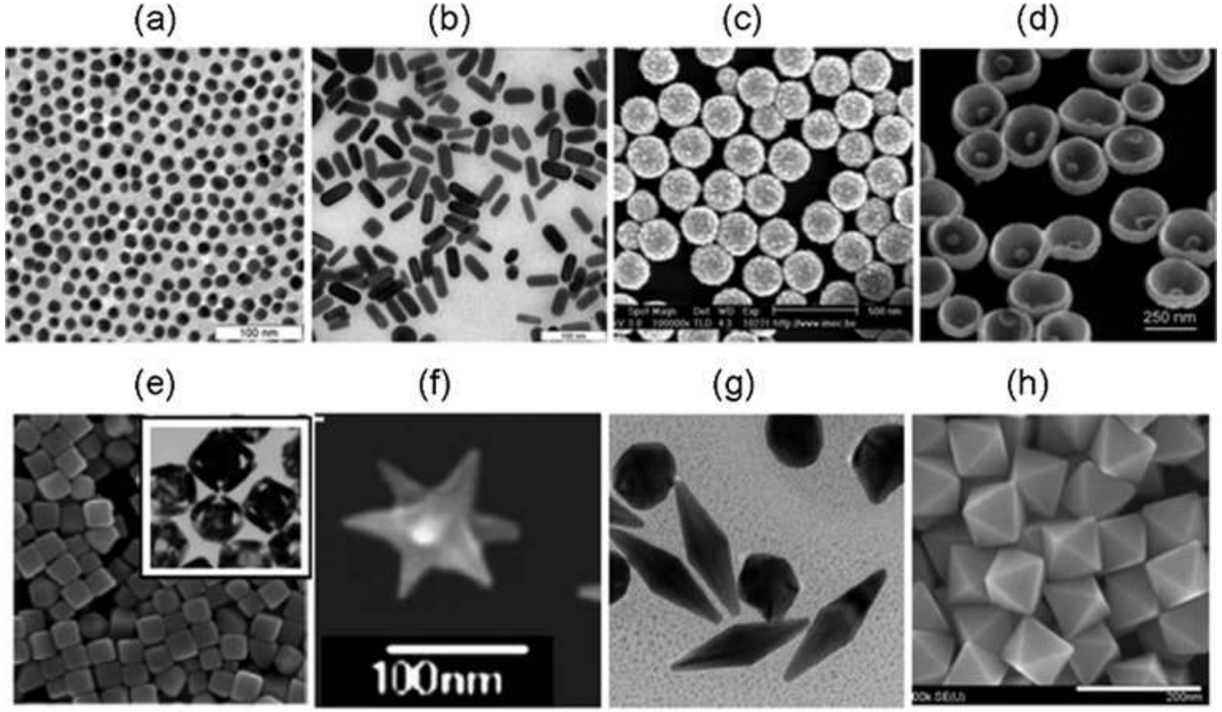


Diverse bio-development synthesis of nanoparticles and their application areas


Methods of Nanoparticle Synthesis
Chemical Synthesis
Physical Method
Biological Synthesis
Chemical Reaction
Coating Process
Coating Materials (e.g., Lipids, PEIs)
Synthesis
Laser Ablation
Photons
Particles
Metal+Solvent
Biological Substance
Metal Ions
+
Biological Substances
Synthesis
Different Shapes of the Nanoparticles

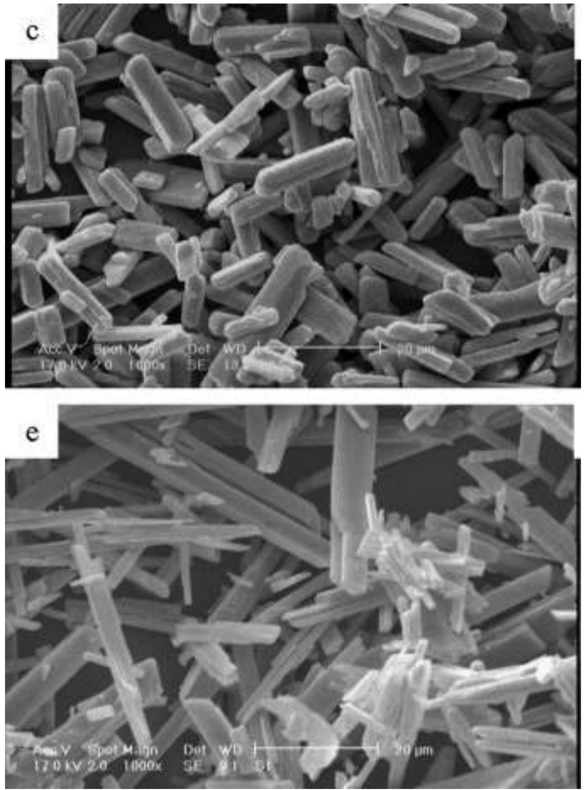
- **Characterization of nanoparticles:** Properties of nanoparticles like shape, size, surface morphology, crystalline nature, light absorption etc. need to be completely described using relevant characterization techniques.

1) **Morphological features:** The morphology of nanoparticles greatly influence the properties exhibited by nanoparticles. Microscopy methods applied on nanoparticles are usually electron microscopy or scanning probe microscopy. Scanning electron microscope (SEM) gives nanoscale and surface information of the dispersion and morphology of nanoparticles. Transmission electron microscopy (TEM) uses transmittance of electrons to provide bulk information at high and low magnifications.



TEM images of different form of gold NPs, synthesized by different techniques

SEM images of ZnO



2) Optical studies: Optical methods reveal reflectance, transmittance, photochemical, and luminescence features of nanoparticles. Spectroscopy uses the interaction of particles with electromagnetic radiation to determine the shape, concentration, and size of nanoparticles. Spectroscopic techniques like infrared, ultraviolet–visible, photoluminescence (PL), UV/vis-diffuse reflectance spectrometer (DRS), and magnetic resonance methods are applied to nanoparticles. The sizes of nanoparticles affect their optical features and make it useful in bioimaging devices.

3) **Structural analysis:** The structure of nanoparticles gives details about the kind of bond existing between the atoms and the features of the bulk material. Some of the structural techniques used on nanoparticles include BET, X-ray diffractometry (XRD), IR etc. XRD describes the phase, particle size, type of NP, and crystal nature of the nanoparticles.

4) **Elemental analysis:** The elemental composition of nanoparticles can be determined using energy dispersive X-ray spectroscopy (EDX), XPS, Raman, FT-IR etc. EDX details the elemental components of bulk particles. XPS is a very sensitive spectroscopic method used to obtain the exact compositional ratio of the elements, their bonding nature, depth profile analysis. Raman and FTIR techniques use vibrational methods to show functionalized peaks and particle information.

5) **Size analysis:** Sizes of nanoparticles can be estimated using scanning electron microscope, transmission electron microscope, X-ray diffractometer, atomic force microscope etc. The sizes of the nanoparticles are obtained using size distribution profiles and give more precise results when used alongside digital models.

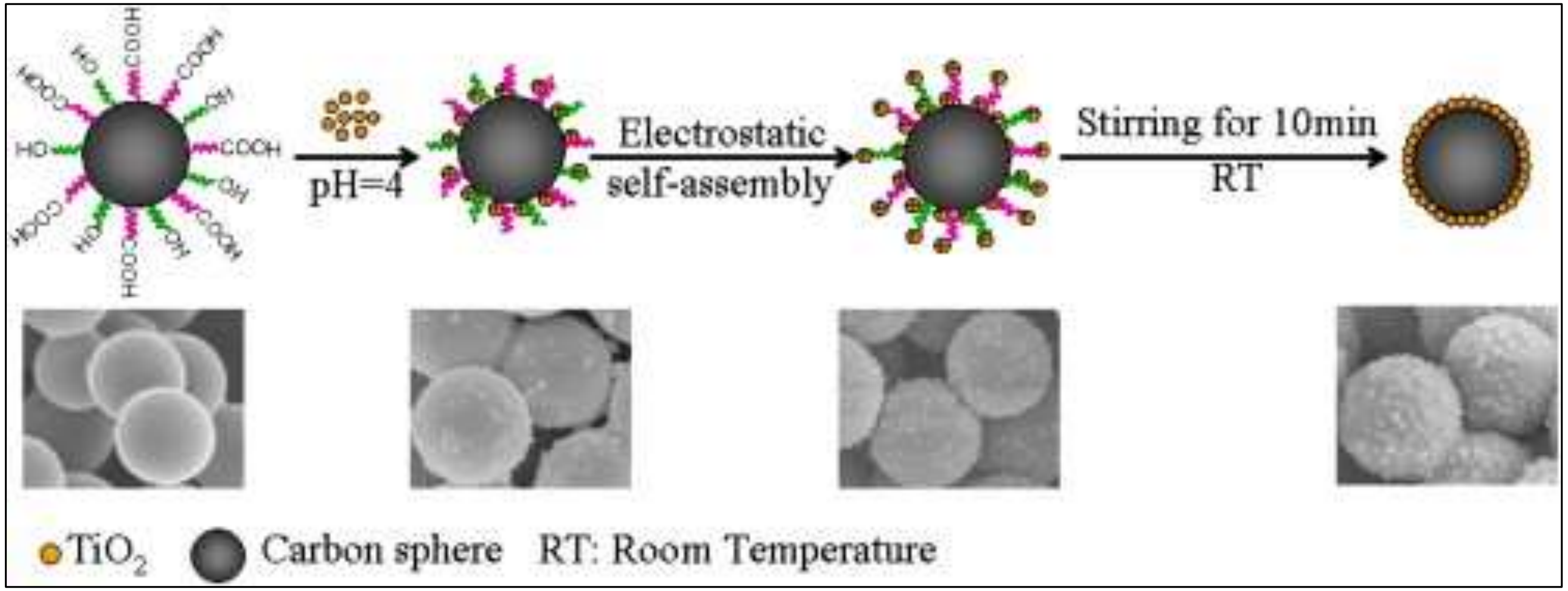
6) Physicomechanical properties: Mechanical properties, optical activity, surface area, and chemical reactions of nanoparticles are physiochemical characteristics obtainable from nanoparticles. Free surface electrons on nanoparticles are very mobile and are not scattered upon light illumination. The magnetic features of NPs are manifested at small nanoscales due to their uneven distribution, influenced by the synthesis technique adopted, and find vast application in biomedicine, resonance imaging, and catalytic devices. Mechanical characteristics of nanoparticles like stress, surface coatings, hardness, strain, friction, adhesiveness etc. aid an understanding of NPs and greatly affect the quality of the surface. Nanoparticles have great conduction to heat especially on the surface.

Table: Characterization methods and analysed properties

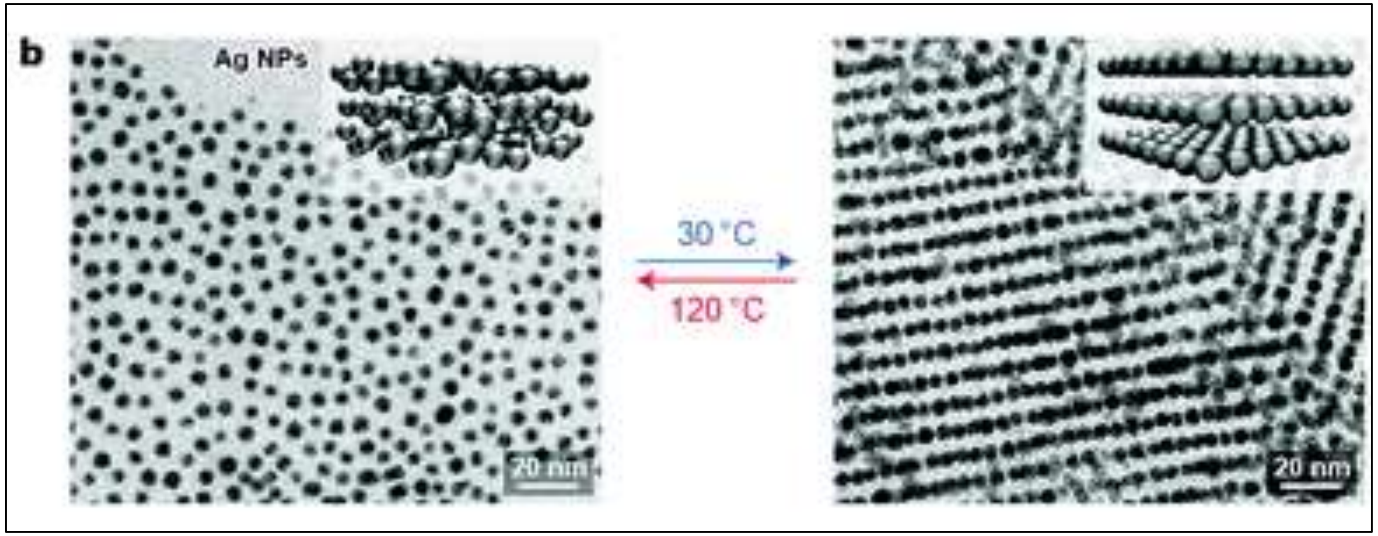
Characterization Method	Information obtained
Dynamic light scattering (DLS)	• Size and size distribution of MNPs in solution
UV-Vis spectrum	• Formation of colloidal MNPs (Plasmon band)
X-ray diffraction (XRD)	• Crystal structure and size, chemical composition
Nuclear magnetic resonance (NMR)	• Molecular physics, crystals and non-crystalline materials
X-ray photoelectron spectroscopy (XPS)	• Surface composition of supported MNPs
Transmission electron microscopy (TEM) Scanning electron microscopy (SEM)	• Size and Morphology of MNPs
Energy Dispersive X-Ray (EDX)	• Element and distribution of MNPs
Scanning tunneling microscope	• Size and structure of MNPs

Method	Properties to be Analyzed
SEM/TEM	Particle shape, size and morphology.
XRD	Extent of Crystallization of the sample.
BET	Accessible surface area
FT-IR	Vibrational stretch frequency of metal-oxygen bonds.
UV-VIS spectra	UV absorption of the amorphous gels and crystalline ceramic samples heated at different temperatures.
TG-DTA	Weight loss and thermal effect during the conversion of precursors to final method oxides in the heat-treatment process
SLS	Particle size distribution.
HRTEM	Crystallographic structure of a sample at an atomic scale.
EELS	Loss of energy, change in momentum and ionization potential of a atom
EDS/EDX	Chemical characterization, investigation of a sample through interactions between light and matter and analyzing X-rays in its particular case.

- **Self assembly of nanomaterials:**
- Molecular self-assembly is an autonomous process whereby disordered building blocks gradually form larger, well-organized patterns, driven by mutual interactions of the building blocks toward reducing the system free energy.
- It occurs under kinetic and thermodynamic conditions that allow local and specific molecular interactions such us electrostatic or hydrophobic interactions, π-π interactions, hydrogen bonding, and Van der Waals forces to keep molecules at a stable state, achieving minimal energy in the system.
- The self-assembly of micro-/nanoparticles, among various kinds of building blocks, has generated intense interest because the self-assembled patterns commonly possess unique physical properties and find various applications in the fields of nanophotonics, solar cells, catalysts, data storage.
- Self-assembly of nanostructured materials holds promise as a low-cost, high-yield technique with a wide range of scientific and technological applications.



Electrostatic self-assembly of TiO2 nanoparticles particles onto carbon spheres



Temperature-induced transition between isotropic (left) and lamellar (right) phases of Ag NPs

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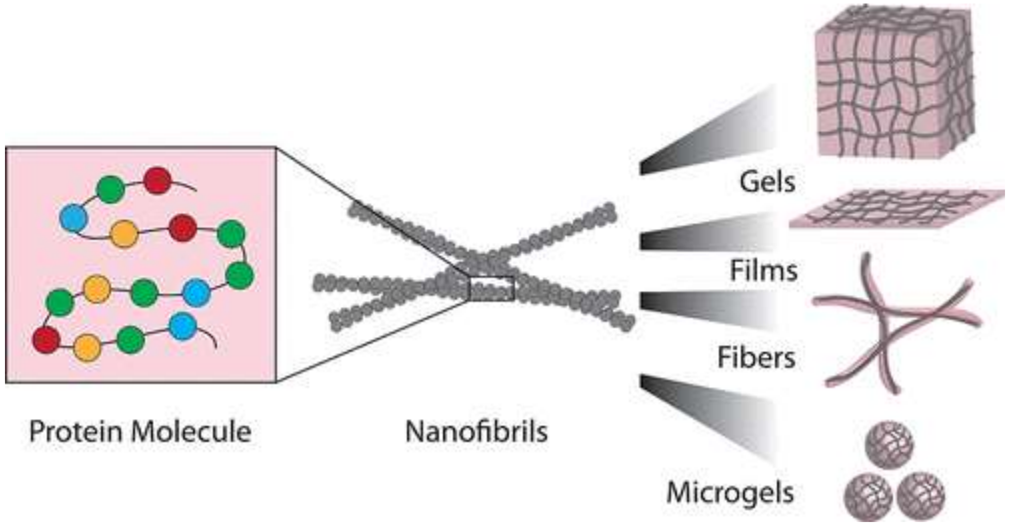
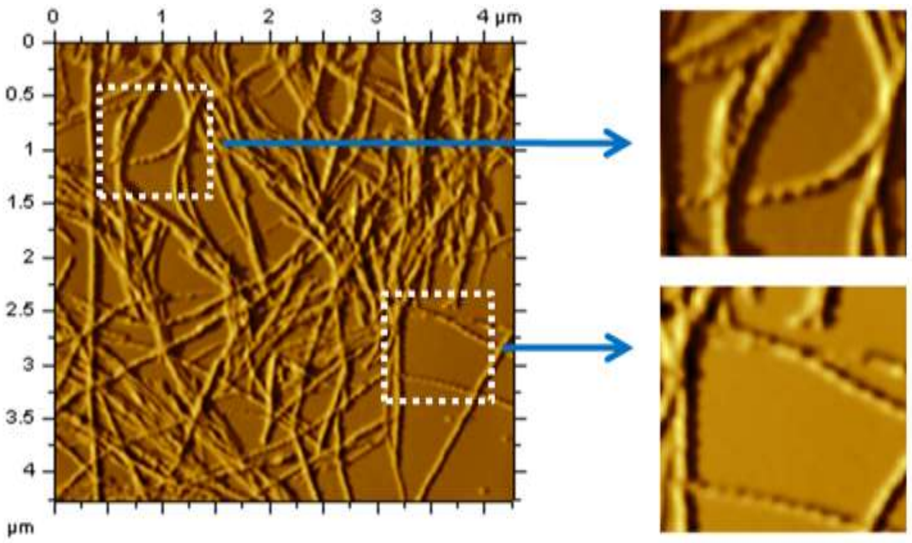
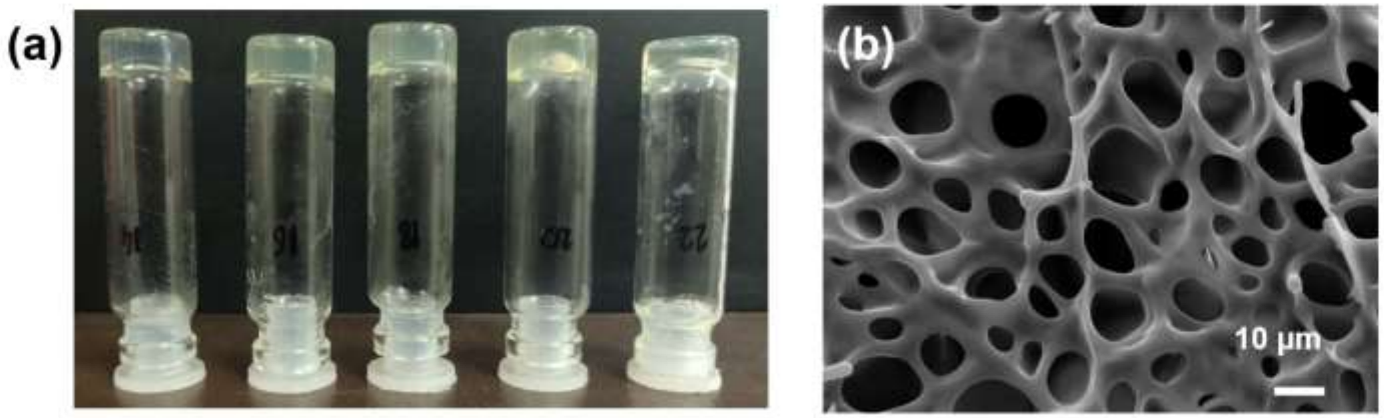


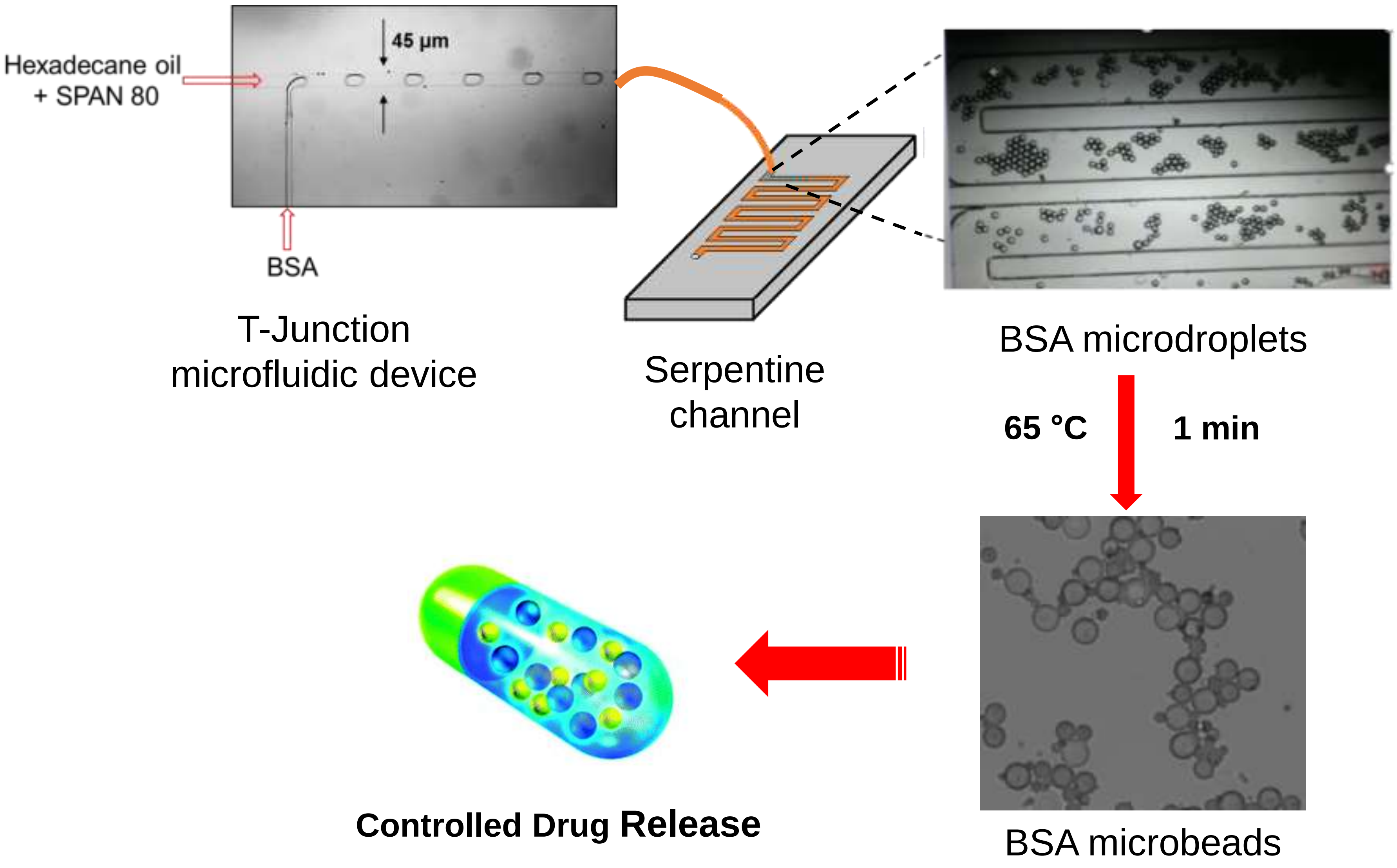
Different self-assemblies in proteins



AFM image of aggregated Bovine Insulin fiber



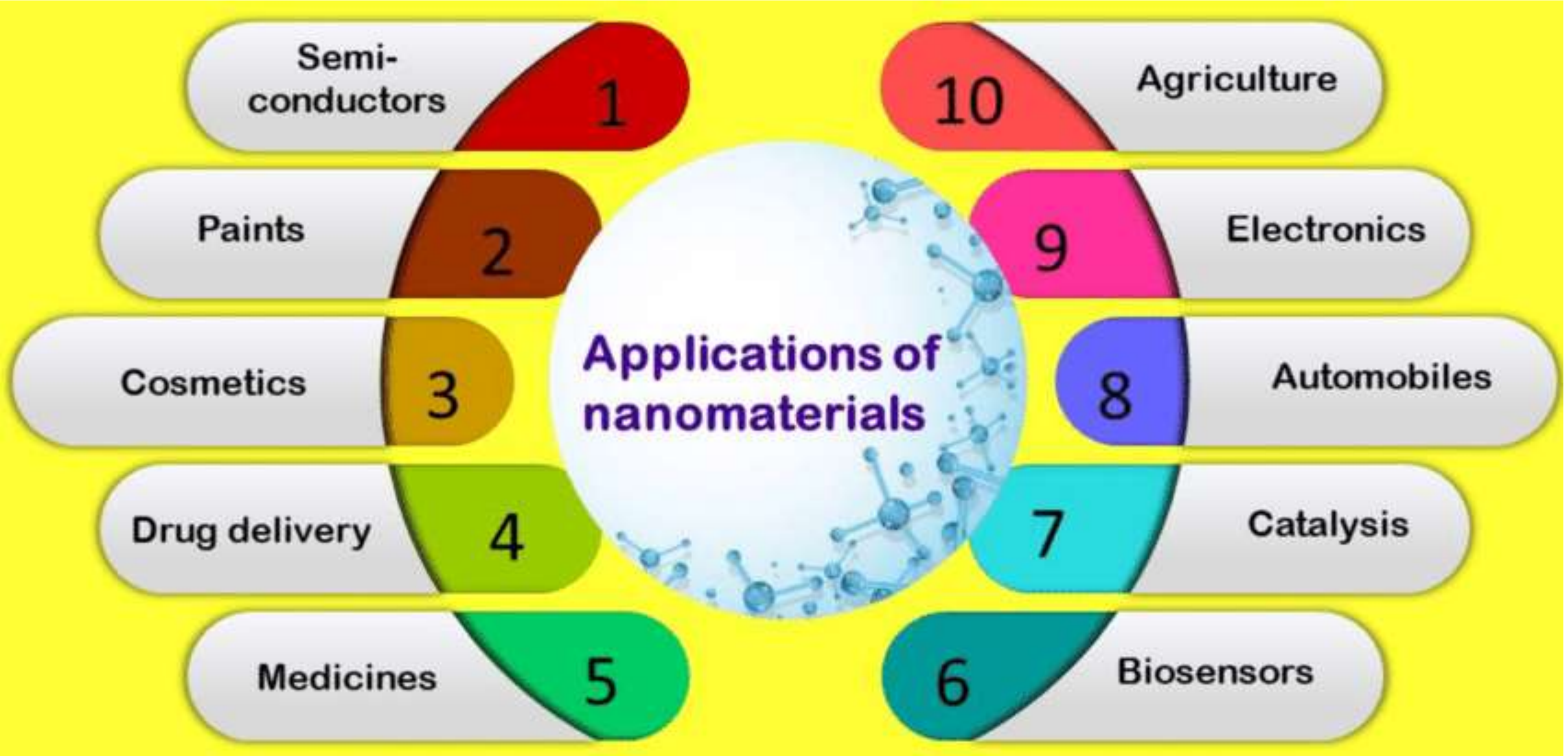
(a) Hydrogels of Bovine serum albumin (BSA), (b) porous structure of BSA hydrogel



Hexadecane oil
+ SPAN 80
45 µm
BSA
T-Junction
microfluidic device
Serpentine
channel
BSA microdroplets
65 °C
1 min
BSA microbeads
Controlled Drug Release

Building-Blocks			Supramolecular Assemblies	Applications
Synthetic	Polymers	Linear (e.g. block-co-polymers) AB ABA ABC	Micelles Vesicles Tubes	Nanoreactors; artificial organelles; nanocarriers drug delivery[21, 22]
		Branched (e.g. dendrimers) Dendrons	Nanoparticles Nanofibers	Nanocarriers for drug and gene delivery[23–25]
	Surfactants	Anionic Cationic Neutral	Micelles Vesicles	Drug and gene delivery systems; antimicrobial and antifungal activity[26, 27]
	Others	Porphyrin Rotaxane Graphene	Nanotubes Toroids Carbon nanotubes	Nanomedicine; drug delivery; hydrogels[8, 28, 29]
Biological	Viruses	CPMV λ phage hHPBV	Aligned phage film Fibrils Particles	Biomaterials; cell culture substrates[30–33]
	Nucleic acids	RNA DNA	DNA origami	Therapeutics (vehicles for drug delivery); diagnostics (biosensing)[11, 34, 35]
	Lipids	Fatty acid Phospholipid Cholesterol	Lipid bilayer Vesicles Films	Nanoreactors; artificial organelles; controled drug delivery[19, 36–37]
	Saccharides	Amylose (helical) Cyclodextrin (cyclic)	Double helix Nanotube Spherical micelle	Drug delivery; biosensors[38,39]
	Peptides	VSYK EACQ	Random coil β-sheet α-helix Helix protein	Hydrogel biomaterials; drug delivery; tissue engineering; 3D cell culture[40–48]

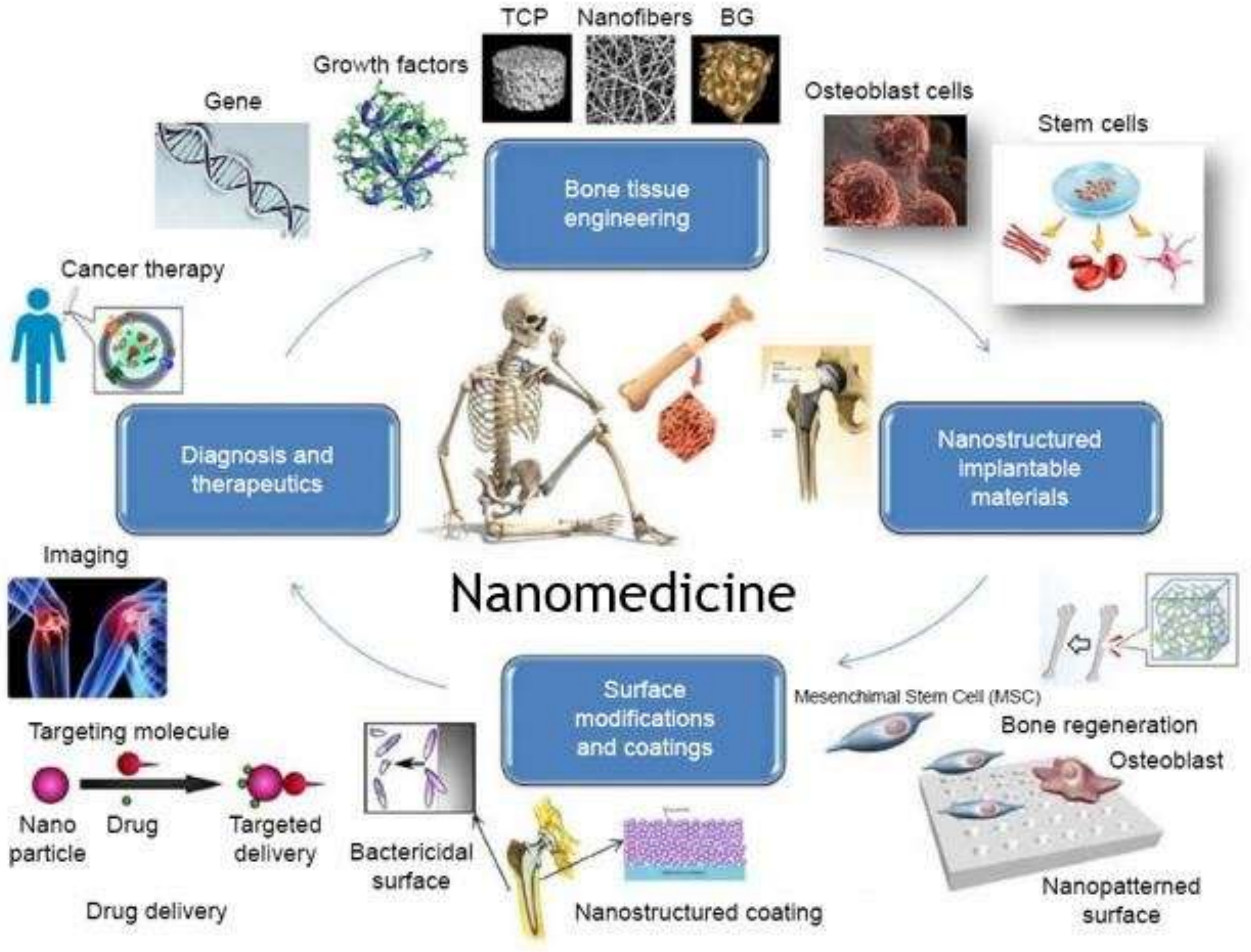
- **Applications of nanoscale materials:**



I. Applications of nanomaterials in medicine:

- **Drug Delivery** - Nanotechnology uses nanoparticles for delivering drugs to body parts. Drug delivery means the drug is delivered to the required location of the body in specified quantities. The use of nanoparticles ensures that the drug reaches only the specified location and its side effects are reduced considerably.
- **Diagnostic Techniques** - Nanotechnology is making rapid progress in diagnosing diseases with the help of nanoparticles. Methods are developed/being developed for early detection of diseases like: Cancer, Parkinson's disease, Alzheimer's disease, Kidney Damage, Flu viruses, etc. Present methods of detecting diseases like cancer are uncomfortable for the patients and are time-consuming. These methods are invasive also. However, these issues can be removed with the help of nanosensors. These nanosensors use the application of nanotubes, cantilevers, nanowires or atomic force microscopy for early detection of diseases. The most important aspect of these nanosensors is that they improve sensitivity.
- **Medical Imaging** - Since nanoparticles have varied chemical composition, they are fast becoming drivers of developing newer imaging techniques. There is a need for fast and detailed imaging of tissue microstructures and lesion characterization. This kind of imaging requires non-toxic contrast agents which can circulate for a longer duration, and nanotechnology fulfills that requirement. It provides nanoparticles based contrast agents which can be used in most of the imaging methods.

I. Applications of nanomaterials in medicine:

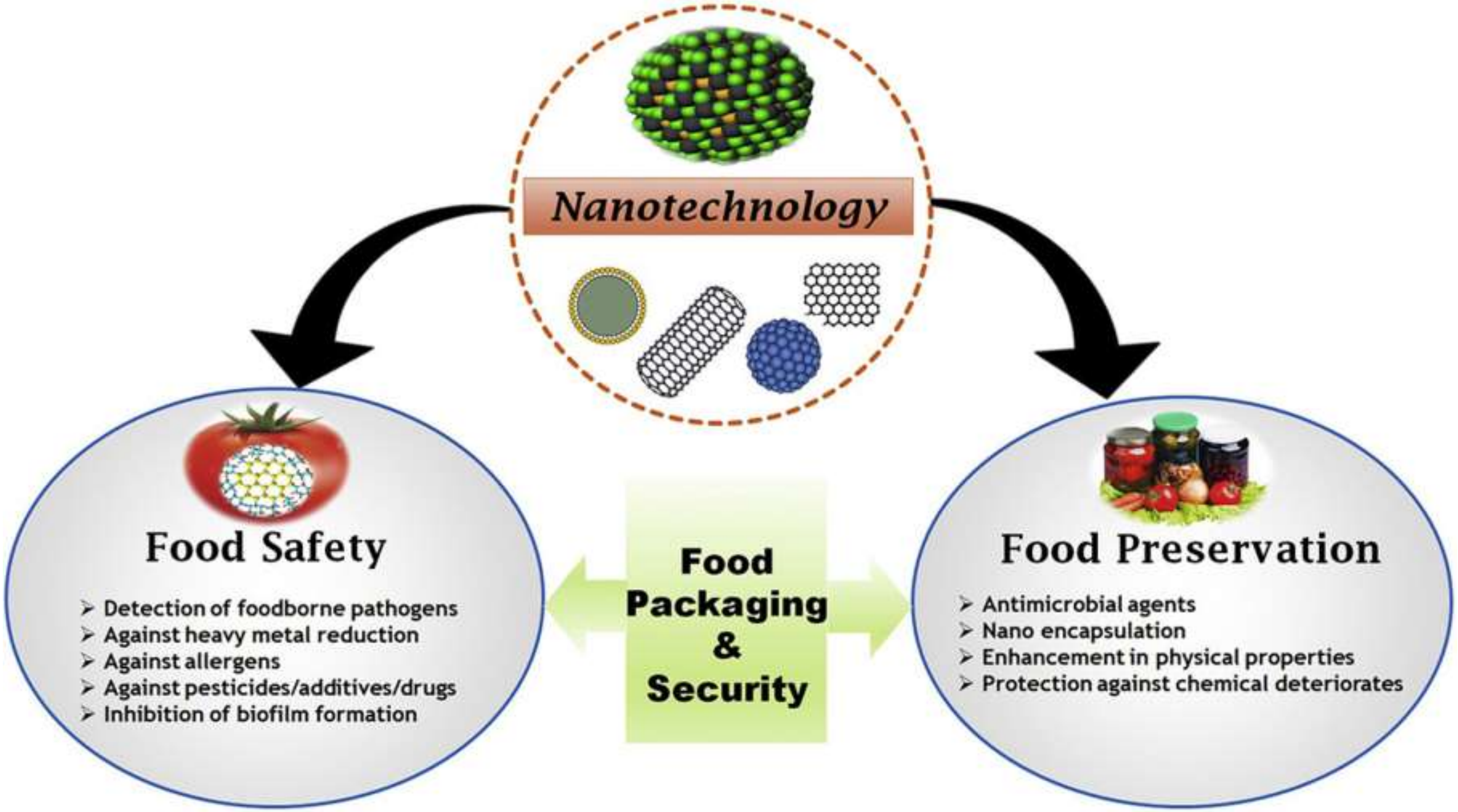


Structure type	Composition	Properties
Quantum dots	CdTe nanocrystal core, stabilizing ligand: 3-thiopropionic acid, bound ligand: lectin	High fluorescence efficiency, stable fluorescence, selective binding to cells
Mesoporous silica nanoparticles	Spherical porous nanoparticles (diameter approx. 100 nm), containing surfactant-dispersed doxorubicin)	pH-dependent release of drug substance, cancer cell penetration capacity
Silver nanoparticles	Ampicillin-modified surface area of silver nanoparticles	Synergic antibacterial activity of silver nanoparticles and the antibiotic
Graphene, graphene derivatives	Surface area of graphene and its derivatives modified with enzymes, antibodies and polymers	Formations (electrodes) sensitive to concentrations of various substrates
Dendrimers	Synthetic polyamidamine polymers with branched chains and common central core	Nucleic acid binding capacity
Iron-cobalt nanoparticles	Spherical FeCo nanoparticles, coated with graphite, functionalized with polyoxyethylene glycol and biocompatible phospholipide	Capacity to penetrate the cell and interact with the exterior magnetic field
Carbon nanotubes	Single-walled carbon nanotubes, functionalized with folic acid	Capacity to absorb near-infrared radiation (NIR)

II. Applications of nanomaterials in consumer products:

- **Cosmetics** - Nanotechnology is being used in the skincare products and the products protecting us from harmful sunlight. This keeps our skin youthful and glowing. The applications of nanoparticles in consumer products also include moisturizers and hair care products. Nanotechnology uses them as ultraviolet filters. They also act as delivery agents. The cosmetic industry uses Liposomes for this purpose.
- **Food -** Nanotechnology can be used in various aspects of food. These include production, processing, packaging and even safety of food. As the concerns about the quality of foods and their nutritional value and benefits grow, the need to find ways to enhance the quality of foods without disturbing their nutritional value is also growing. The food industry is also seeing a growth in the demand for nanomaterials in the food as they are found to be non-toxic. Apart from this, they are also stable at high temperatures. Thus, nanoparticles have a great role and use in all aspects of the food industry including manufacturing, processing, and packaging.
- **Glass -** Nanoparticles are being used to make glass photocatalytic and hydrophilic. In a photocatalytic glass, nanoparticles are energized when ultraviolet rays fall on it and start loosening the dirt particles on the glass. Similarly, hydrophilic glass has a property that makes water spread evenly on the surface, making it easy to clean. These glasses are being used to manufacture scratchproof eyeglasses. This system is also being used to manufacture self-cleaning windows.

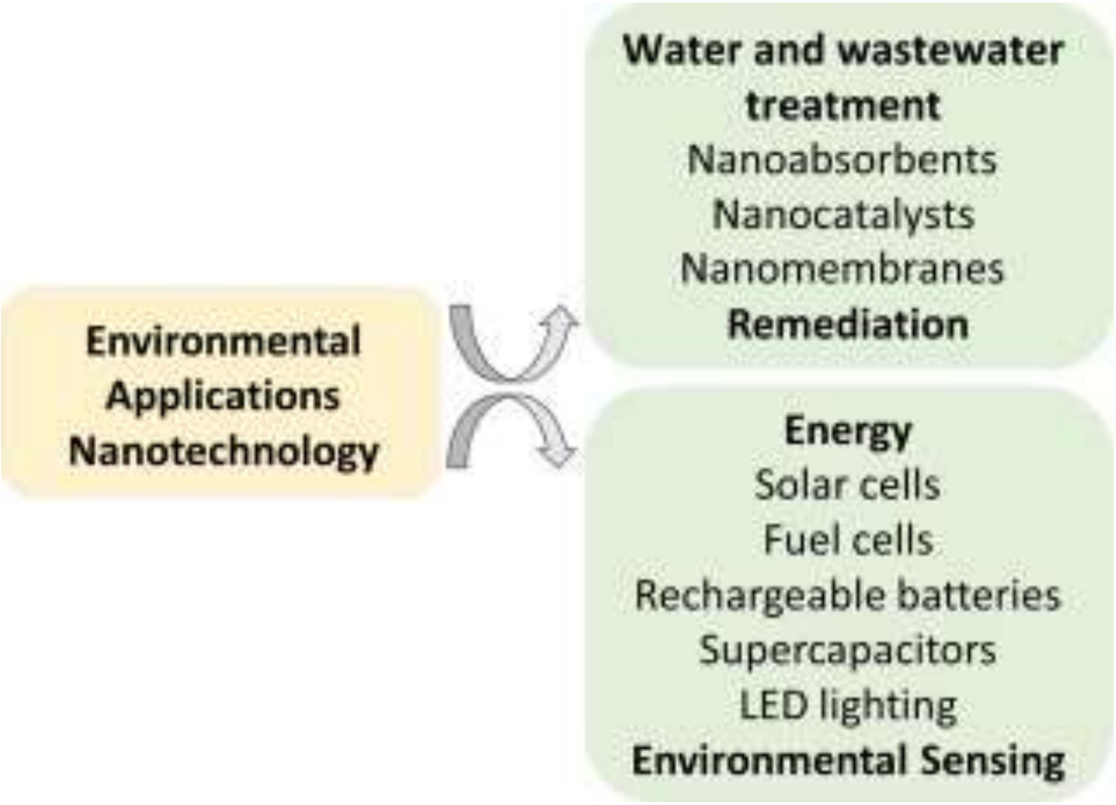
II. Applications of nanomaterials in food industry:



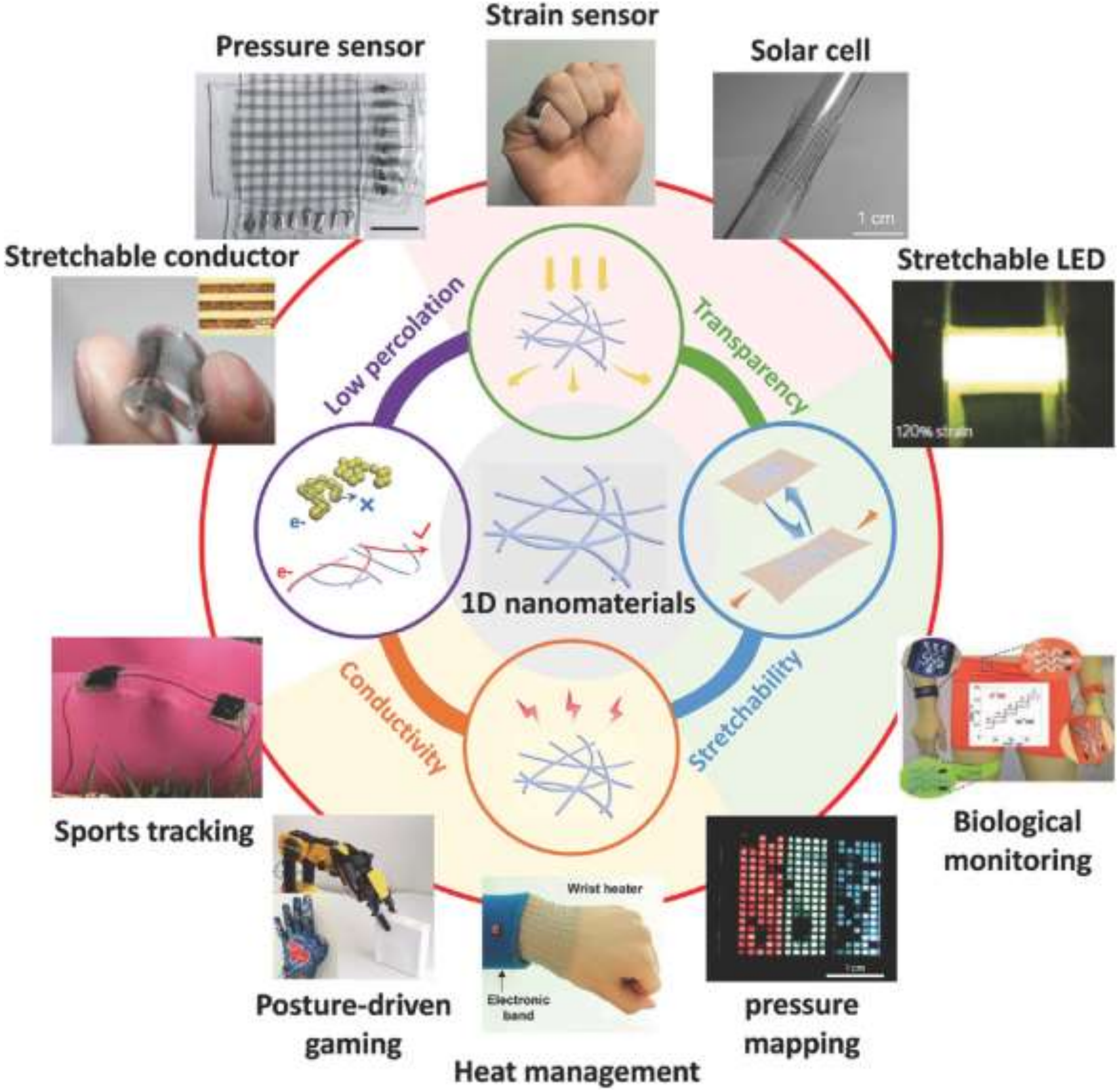
III. Applications of nanomaterials in environment and energy:

- Two of the gravest challenges being faced by the world today are the environmental pollution and shortage of energy. The evolution of nanotechnology has helped in the discovery and creation of newer nanomaterials. And these nanomaterials are acting as stimulators for various environmental applications thus improving upon environmental sustainability.
- Some examples are:
  - The process of manufacturing propylene oxide has many polluting byproducts. It has been established in research that if nanoclusters are used as catalysts, these polluting byproducts are considerably reduced. This propylene oxide is used to manufacture various plastics, paints, detergents, etc.
  - Nanoparticles are being used for treating groundwater. It is done when iron nanoparticles spread all through the water body and clean up the organic solvents present in the groundwater.
  - Nanoparticles can be used in cleaning oil spills. They are in a grid that provides more surface area for the reaction which is useful in cleaning the oil spills.

- Concerns regarding the shortage of energy are being addressed with the following developments:
  - ➢ Stronger and lower weight windmill blades are being manufactured with epoxy made with nanotubes. Windmills using these blades generate more electricity than others.
  - ➢ Nenotatrapods with nanocarbon particles are being used to make low-cost electrodes for fuel cells.
  - ➢ Low-cost and high-efficiency solar cells are being developed using silver nanowires.



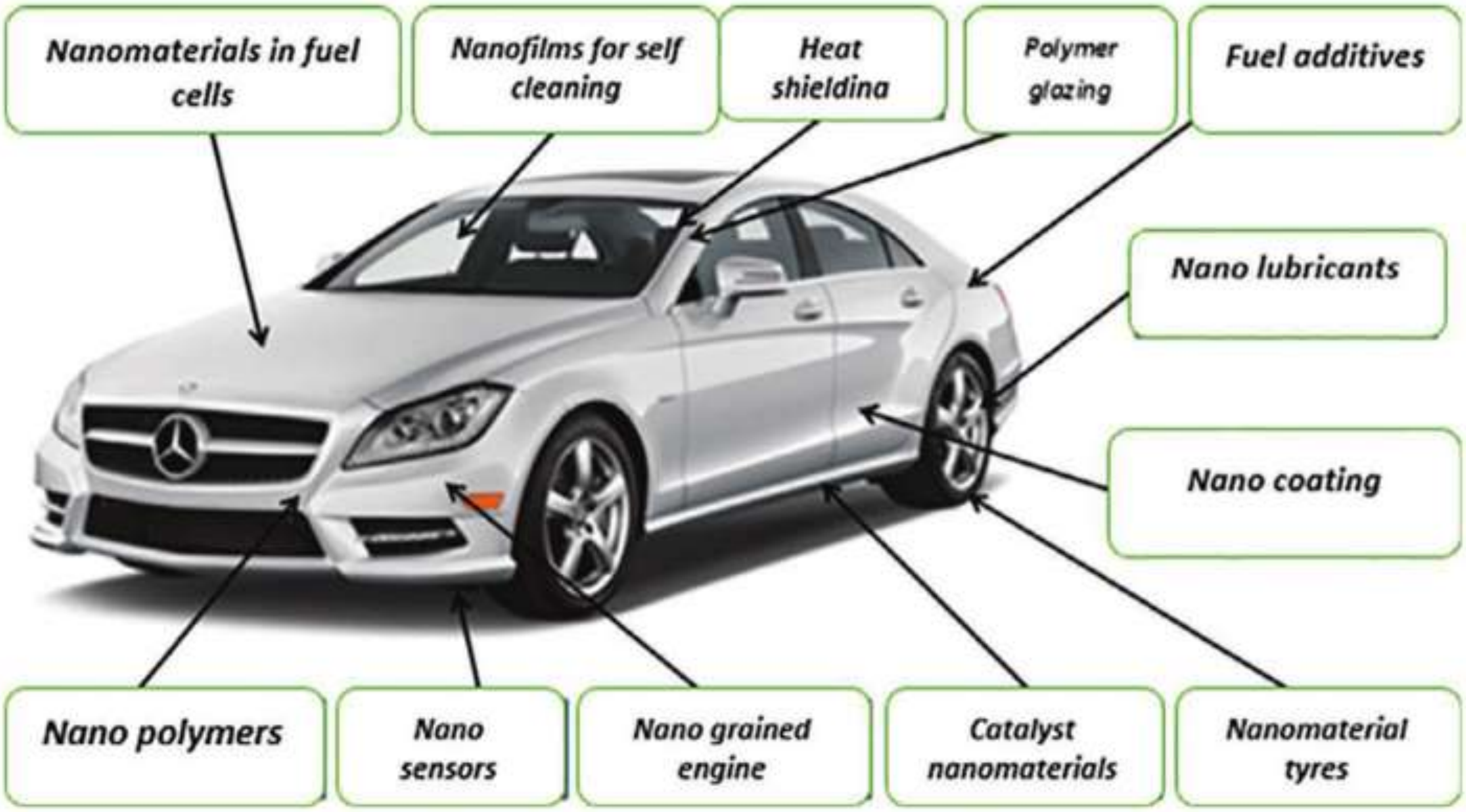
IV. Applications of nanomaterials in electronics:



IV. Applications of nanomaterials in electronics:

- The use of nanotechnology is making a big difference in the manufacture of electronics. Some researches have shown how the capability of an electronic device can be increased while reducing its weight and power consumption at the same time.
  - A method to print prototype circuit boards on standard inkjet printers by using silver nanoparticle ink has been developed by the researchers. This ink forms the conductive lines needed to print circuit boards.
  - Nanomagnets have been used as switches, like transistors in electrical circuits. Using them results in electrical circuits consuming much less power than the transistor-based circuits.
  - Nanoparticles are being used in ultra HD displays of the television as well as in the memory chips.
  - The use of nanowires makes the flat panel display more flexible and thinner than the ones being manufactured currently.

V. Applications of nanomaterials in automobiles:



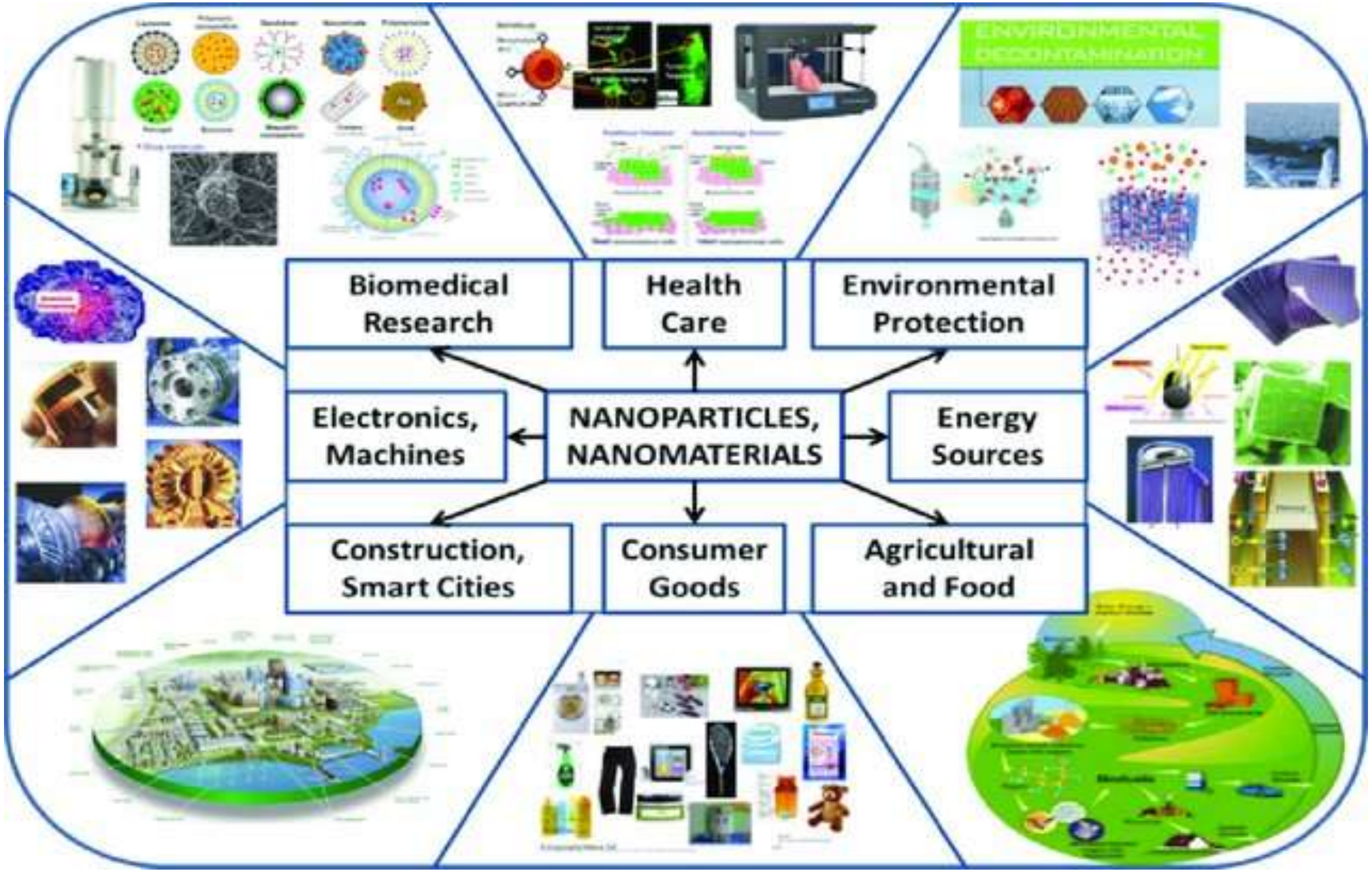
V. Applications of nanomaterials in automobiles:

- Nanotechnology is set to play a major role and is going to be one of the core technologies in the automobile sector in the future. Key areas like fuel consumption, safety, environmental impact, driver information, and comfort are being addressed by the use of nanoparticles. The automobile sector can benefit from nanomaterials by way of lightweight, less wear, and corrosion, and advanced electronics and sensors as also advanced tire technology.
- In cars, nanotechnology offers the following advantages:
    - Lighter materials that are also strong and result in less fuel consumption and increased safety.
    - Hydrogen and fuel cell-powered cars have less effect on the environment.
    - Better electronics systems in smaller sizes.
    - For gasoline-powered cars, improvement in engine efficiency and fuel consumption.
    - Lower component failure resulting in longer life of the car.
- Some major applications of nanotechnology are as under:
    - Traditional metallic chassis parts are being replaced by nonengineered thermoplastic parts which help in a weight reduction of the vehicle up to 40%.
    - Paint adhesion and color durability improve when used on nanostructured surfaces. Along with this, scratch-resistant, dirt-repellant, and UV-repellant paints are being made available.

- A new nanomagnetic material Spintronics is bringing revolutionary changes in the car computing system of the vehicles. This is used in recuperating technologies like reusing the braking energy.
- With the increased insistence on the use of electric cars, makers are trying to find ways to reduce the costs of these cars. One of the major breakthroughs in this area has been the use of Lithium-ion batteries. Nanotechnology has a great scope of improving the life and performance of these batteries. It can also help in reducing the size and weight of batteries while improving their safety and stability at the same time. It will also shorten their recharge time.
- The automobile industry has been using Carbon black as a nanomaterial in tires as a pigment and reinforcing agent. This reinforcing agent provides properties such as better grip, resistance to wear and tear, and abrasion resistance. The addition of nanomaterials in the rubber used for tires improves the safety and durability of tires.
- Driving during the day and the night becomes difficult due to different types of lights. For safer and secure mirrors and windows, an ultra-thin layer of aluminum oxide (thickness less than 100 nm is provided on the glass. This is done to reduce the impact of UV rays during the day and glare of the lights of the vehicles coming from the opposite side during the night. This nanolayer of aluminum oxide makes the glass dirt and water repellant.

VI. Applications of nanomaterials in textile industry:

- **CONCLUSION:**


Biomedical Research
Health Care
Environmental Protection
Electronics, Machines
NANOPARTICLES, NANOMATERIALS
Energy Sources
Construction, Smart Cities
Consumer Goods
Agricultural and Food
ENVIRONMENTAL DECONTAMINATION