Application of Nanotechnology

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Contents

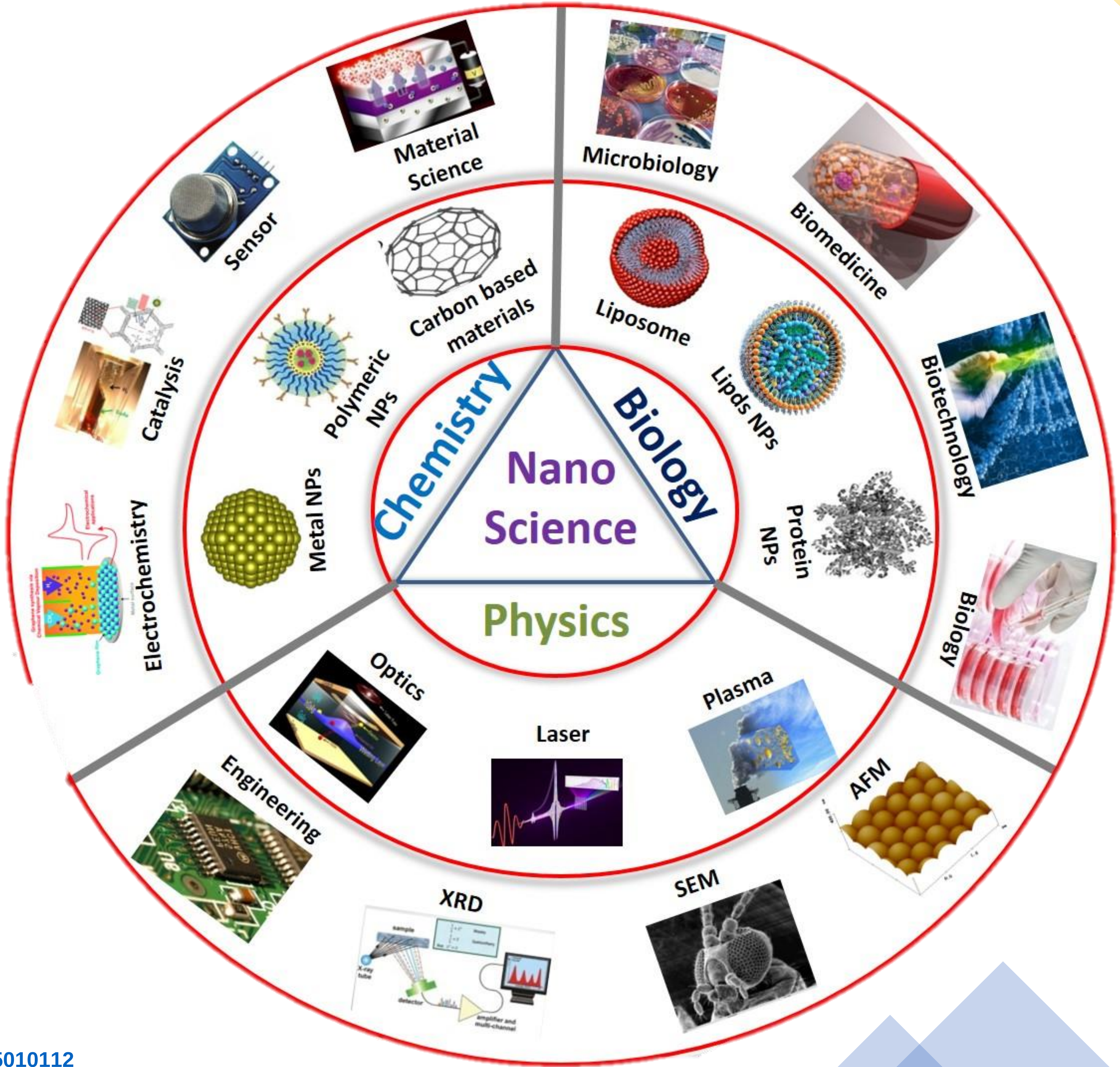
What is Nanoscience and Nanotechnology?

Nanoscience

- **Nanoscience** is about studying how materials behave at a very small scale (at the Nanoscale level).

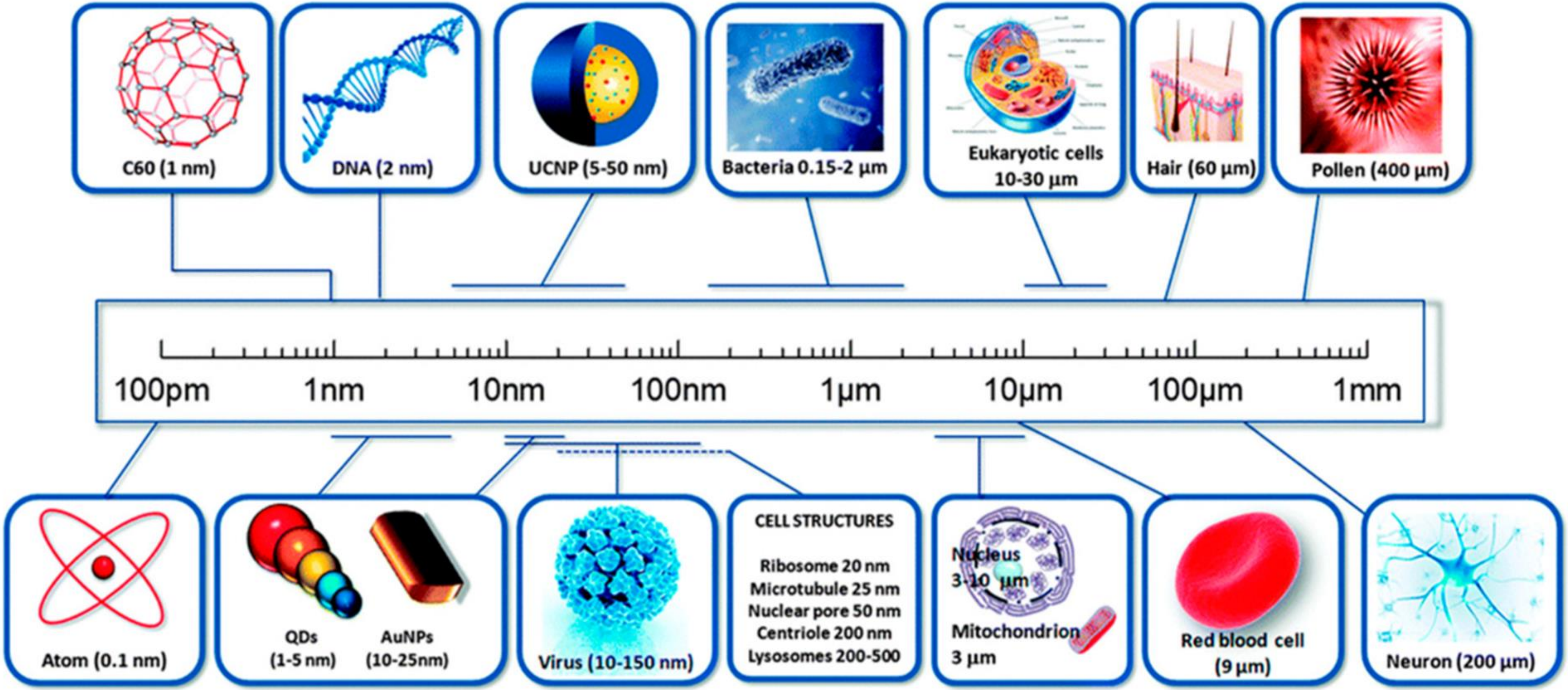
- A **Nanometer** is one millionth of a millimeter. One millimeter is the smallest measurement visible on a 30 cm ruler. Nanoscience works on a scale 1000 times smaller than anything that can be seen with an optical microscope.

- It is not just one science, but a platform that includes *biology*, *chemistry*, *physics*, *medicine*, *materials science and engineering*.



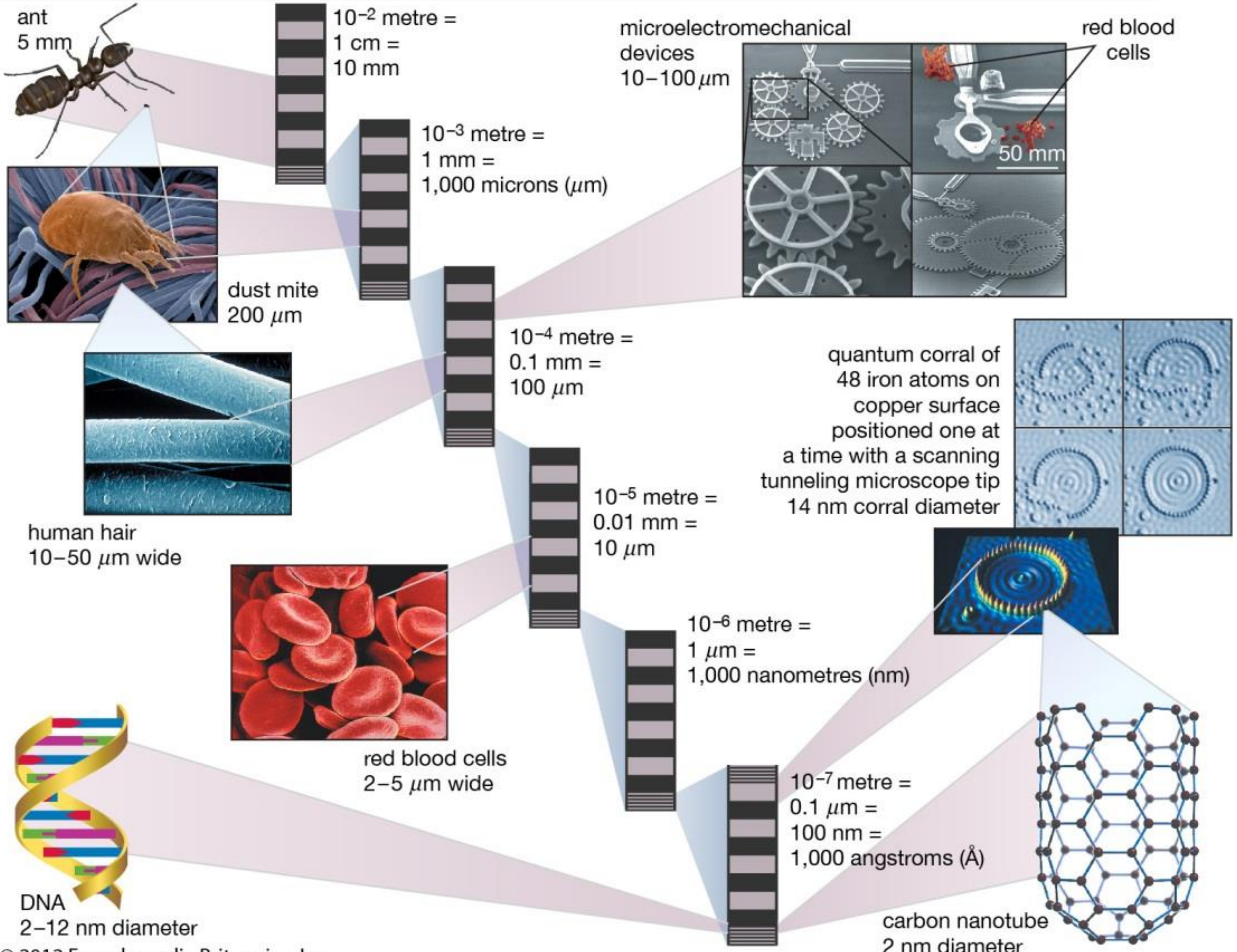
Source: doi.org/10.3390/molecules25010112

Scale of nanomaterial sizes representing the region for dimensions of Microelectromechanica systems (MEMS)



Source: Chem. Soc. Rev. 2015, 44, 1561–1584

Scale of nanomaterials

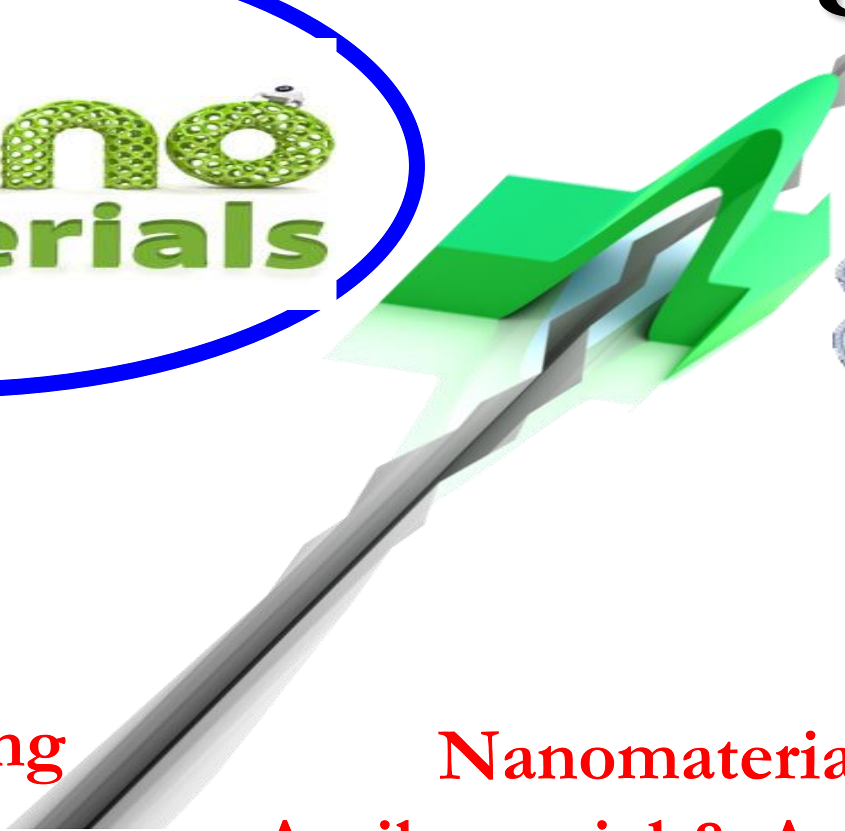


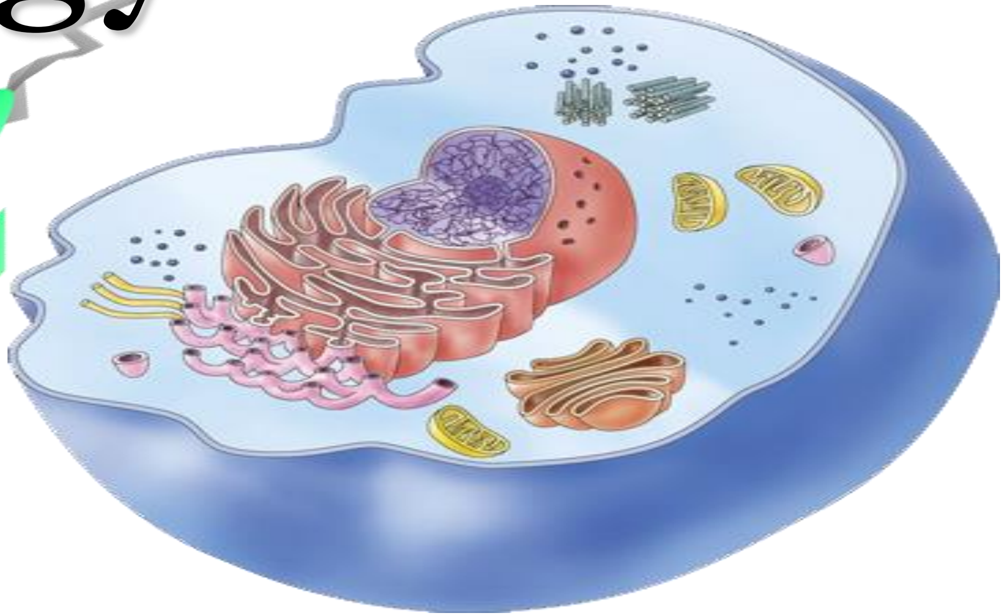
Nanotechnology

- **Nanotechnology** is the manufacture and development of materials, devices and structures by applying an understanding of how materials behave at the Nanoscale.

- Nanotechnology is now applied widely in the ICT (Information and Communications Technology) industry in the manufacture of smaller integrated circuits (computer 'chips') and more efficient data storage mechanisms. It is also used in the medical devices industry to make smaller products. Nanotechnology will impact virtually every industry in the near future.

Nanochemistry and Biology





Food Safety Testing

Nanomaterial Antibacterial & Antivirus

Nanomaterial Antitumor

History of Nanotechnology

The word Nano is a Greek word meaning dwarf

There's Plenty of Rooms at the Bottom

Richard P. Feynman

Nobel Prize in Physics (1965)

Father of Nanotechnology

There's Plenty of Rooms at the Bottom is the title of a lecture given by physicist Rischard Feynman at the American Physical Society meeting at Caltech on December 29, 1959. In his lecture, Feynman considered the possibility of direct manipulation of individual atoms as a powerful form of synthetic chemistry. His vison of the future inspired Eric Drexler among others and is now referred to as <u>Nanotechnology</u>

Norio Taniguchi was a professor at Tokyo University of Science. He coined the term Nano-technology in **1974** to describe semiconductor processes such as thin film deposition and ion beam milling exhibiting characteristic control on the order of a nanometer: "Nano-technology' mainly consists of the processing of separation, consolidation, and deformation of materials by one atom or one molecule.

Kim Eric Drexler is an American engineer best known for popularizing the potential of molecular nanotechnology (MNT), from the 1970s and 1980s. His 1991 doctoral thesis at Massachusetts Institute of Technology was revised and published as the book Nano systems: Molecular Machinery Manufacturing and Computation (1992), which received the Association of American Publishers award for Best Computer Science Book of 1992. In 1998, the first DNA was manipulated with man made nano-machines. Nano machines was successfully able to “walk” along DNA paths and manipulate structure.

Figure from: The British Museum

Ancient History of Nanotechnology

- **The Lycurgus cup**

The glass appears green in reflected light (A) and red-purple in transmit (B).

- **Stained glass window**

Effect of nanoparticles on the colors of the stained-glass window.

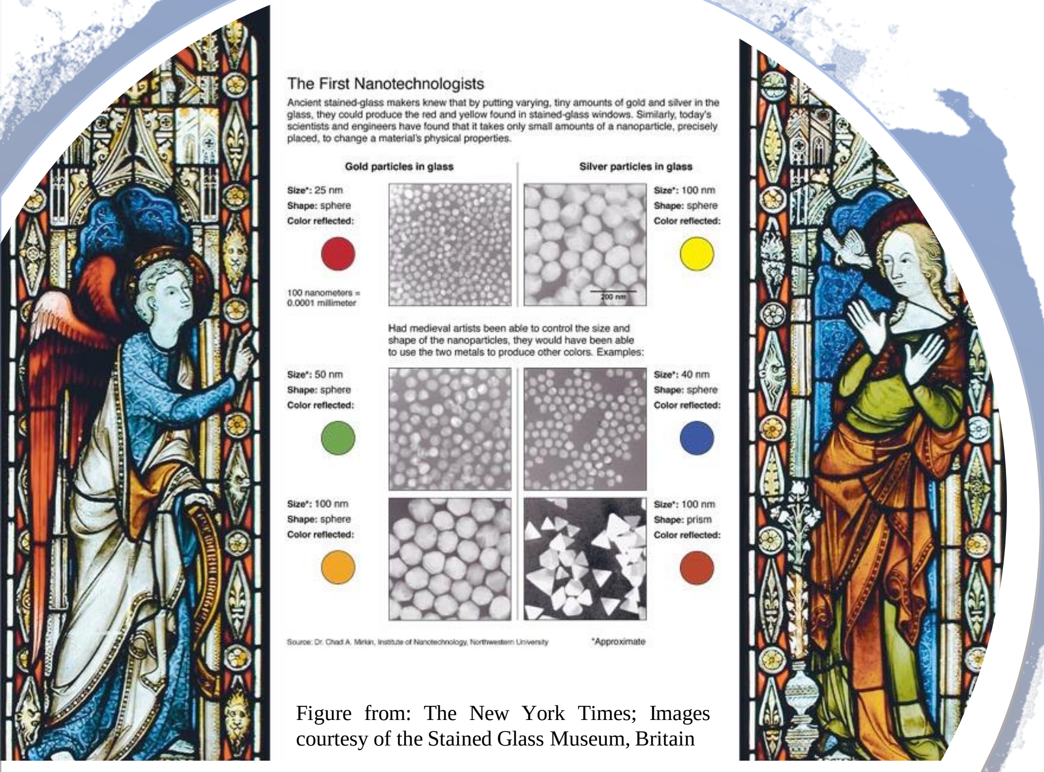


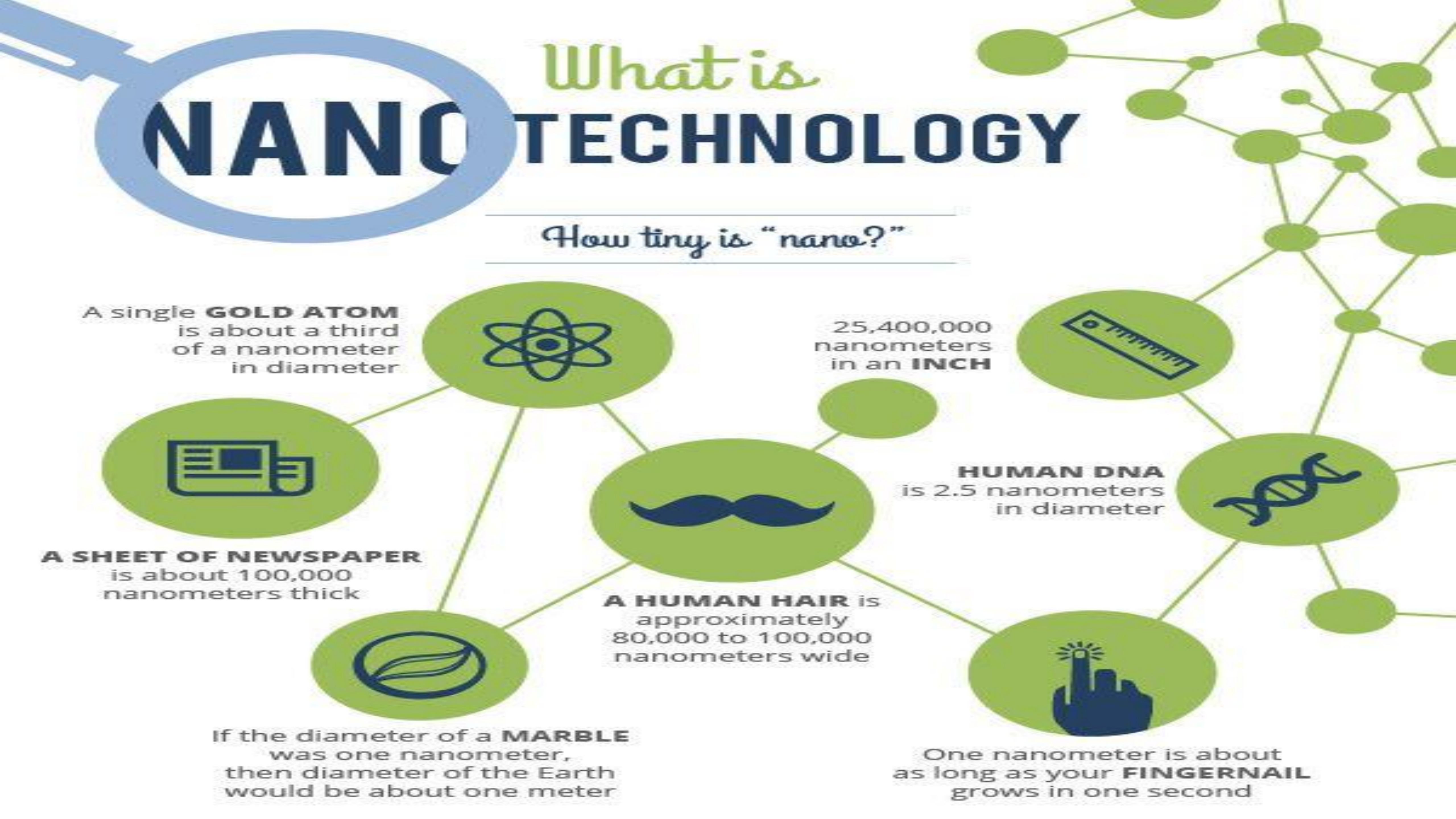
Figure from: The New York Times; Images courtesy of the Stained Glass Museum, Britain

Fundamental concepts in Nanoscience and Nanotechnology

- It's hard to imagine just how small nanotechnology is.
- One nanometer = is a billionth of a meter, or **10^{-9}** of a meter.
- Here are a few illustrative examples:

  •1 inch = 25,400,000 nanometers
  • A sheet of newspaper is about 100,000 nanometers thick

- **Nanoscience and nanotechnology** involve the ability to see and to control individual atoms and molecules. Everything on Earth is made up of atoms—the food we eat, the clothes we wear, the buildings and houses we live in, and our own bodies.


What is
NANOTECHNOLOGY
How tiny is "nano?"
A single GOLD ATOM is about a third of a nanometer in diameter
25,400,000 nanometers in an INCH
A SHEET OF NEWSPAPER is about 100,000 nanometers thick
HUMAN DNA is 2.5 nanometers in diameter
A HUMAN HAIR is approximately 80,000 to 100,000 nanometers wide
If the diameter of a MARBLE was one nanometer, then diameter of the Earth would be about one meter
One nanometer is about as long as your FINGERNAIL grows in one second

EVERYDAY USES OF NANOTECHNOLOGY

National Nanotechnology Day (Oct. 9) is a yearly event in the U.S. to celebrate the tiny tech. Here, we take a look at various consumer products that utilize nanotechnology and the chemistry behind them.

WHAT IS NANOTECHNOLOGY?

Nanotechnology involves the applications of nanoparticles, which are collections of atoms or molecules less than 100 nm across. Because of their small size, the particles have properties that can differ from those of larger amounts of the same material.

ANTIMICROBIAL USES

Products such as bandages, soaps, and surgical implements use silver nanoparticles for their antimicrobial effects. However, the particles' effectiveness in some applications has been questioned, and the materials may cause environmental problems.

SUNSCREENS

Many sunscreens contain titanium dioxide and/or zinc oxide nanoparticles because the materials can absorb UV radiation. Titanium dioxide also finds use in some foodstuffs as a whitening agent.

CLOTHES

UV-absorbing titanium oxide and zinc oxide nanoparticles can be incorporated into clothes to prevent sunburn and sometimes to act as antistatic agents. Silicon dioxide nanoparticles can prevent stains and help clothing repel water.

SPORTS EQUIPMENT

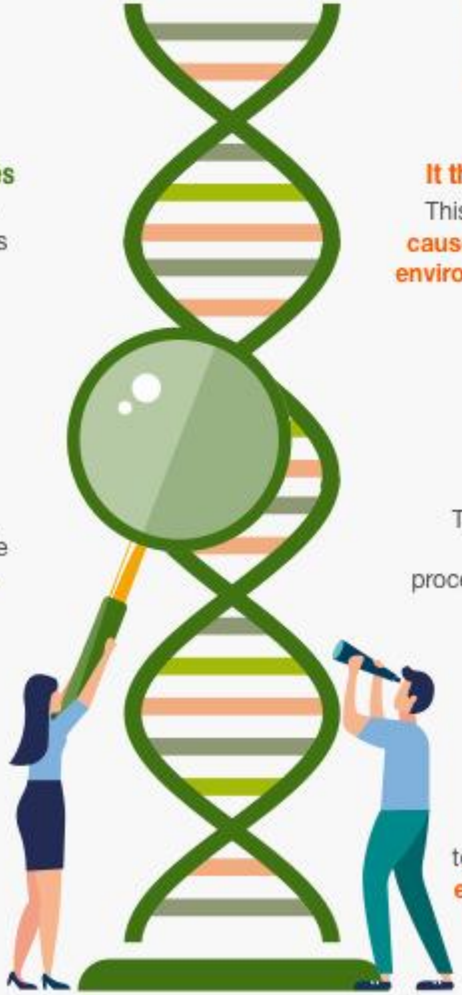
Sports equipment such as tennis rackets and bicycles are sometimes built using nanomaterials including carbon nanotubes. The nanotubes improve strength and durability and decrease weight. Titanium nanoparticles can also be used.

QUANTUM DOTS

Quantum dots, which are nanoparticles of semiconductors such as cadmium selenide, absorb light of one color, such as blue light, and emit it as another depending on particle size. The particles are more energy-efficient than light-emitting diodes.

IBERDROLA

Nanotechnology,
up close



Advantages

Promoting renewable energies
It enables new ways to obtain and store energy. It also makes **solar panels cheaper** and more efficient.

It extends the limits of electronics
Unlike silicon microchips, nanochips will make it possible to build **very precise circuits** at an atomic level.

It allows a more effective medicine
Arteries can be unblocked, cells can be selectively attacked, **damaged genes can be repaired** and faster and more precise surgeries can be performed.

Disadvantages

It threatens the environment
This type of technology could **cause negative effects on the environment** by generating new toxins and pollutants.

It has an impact on the job market
The obsolete materials and changes in production processes could **destroy jobs,** but this technology could create others.

It compromises the safety
The properties of this technology could **facilitate espionage,** the production of nanoweapons and smart bullets.

Source: NNI and 'Houston Chronicle'.

Sources of Nanomaterials

- Sources of nanomaterials can be classified into **Three main categories** based on their origin:

1. **Incidental nanomaterials**, which are produced incidentally as a byproduct of industrial processes such as nanoparticles produced from vehicle engine exhaust, welding fumes, combustion processes and even some natural process such as forest fires;
2. **Engineered nanomaterials**, which have been manufactured by humans to have certain required properties for desired applications.
3. **Naturally produced nanomaterials**, which can be found in the bodies of organisms, insects, plants, animals and human bodies. However, the distinctions between naturally occurring, incidental, and manufactured NPs are often blurred. In some cases, for example, **incidental NMs can be considered as a subcategory of natural NMs**.

1. Incidental nanomaterials

- **Photochemical reactions, volcanic eruptions, and forest fires are some of the natural processes that lead to the production of natural NPs as mentioned. In addition, skin and hair shedding of plants and animals, which is frequent in nature, contributes to NP composition in nature. Dust storms, volcanic eruptions, and forest fires are events of natural origin that are reported to produce high quantities of nanoparticulate matter that significantly affect worldwide air quality.**

2. Engineered nanomaterials

- Simple combustion during cooking, in vehicles, fuel oil and coal for power generation, airplane engines, chemical manufacturing, welding, ore refining, and smelting are some of the anthropogenic activities that lead to NP formation.

- NMs such as carbon NPs, TiO_2 NPs and hydroxyapatites are present in commercial cosmetics, sporting goods, sunscreen and toothpaste. Thus, these synthetic NPs are a new genre of NPs that may induce adverse environmental and human health effects.

3. Naturally produced nanomaterials

- Apart from incidental and engineered nanomaterials, nanoparticles and nanostructures are present in living organisms ranging from microorganisms, such as bacteria, algae and viruses, to complex organisms, such as plants, insects, birds, animals and humans.

- Recent developments in the equipment to visualize nanomaterials help in identifying the morphology of these naturally formed NMs, which will eventually lead to the better understanding of these organisms.

- The knowledge about the nanostructures present in microorganisms is important for the further use of these organisms for beneficial biomedical applications.

Types and classification of nanomaterials

- **Most current NPs and NSMs can be organized into four material-based categories:**

1. Carbon-based nanomaterials
2. Inorganic-based nanomaterials
3. Organic-based nanomaterials
4. Composite-based nanomaterial

1. Carbon-based nanomaterials

- **Generally, these NMs contain carbon, and are found in morphologies such as hollow tubes, ellipsoids or spheres. Fullerenes (Buckyball, C60), carbon nanotubes(CNTs), carbon nanofibers, carbon black, graphene (Gr), and carbon onions are included under the carbon-based NMs category. Laser ablation, arc discharge, and chemical vapor deposition (CVD) are the important production methods for these carbon-based materials fabrication (except carbon black)**

2. Inorganic-based nanomaterials

- **These NMs include metal and metal oxide nanoparticles (NPs) and nanostructured materials (NSMs). These NMs can be synthesized into metals such as Au or Ag NPs, metal oxides such as TiO_2 and ZnO NPs, and semiconductors such as silicon and ceramics**

3. Organic-based nanomaterials

- **These include NMs made mostly from organic matter, excluding carbon-based or inorganic-based nanomaterials (NMs). The utilization of noncovalent (weak) interactions for the self-assembly and design of molecules helps to transform the organic NMs into desired structures such as dendrimers, micelles, liposomes and polymer NPs**

4. Composite-based nanomaterials

- Composite NMs are multi-phase NPs and NSMs with one phase on the nanoscale dimension that can either combine NPs with other NPs or NPs combined with larger or with bulk-type materials (e.g., hybrid nanofibers) or more complicated structures, such as a metal-organic frameworks. The composites may be any combinations of carbon-based, metal-based, or organic-based NMs with any form of metal, ceramic, or polymer bulk materials. NMs are synthesized in different morphologies as mentioned in Figure 1 depending on the required properties for the desired application.

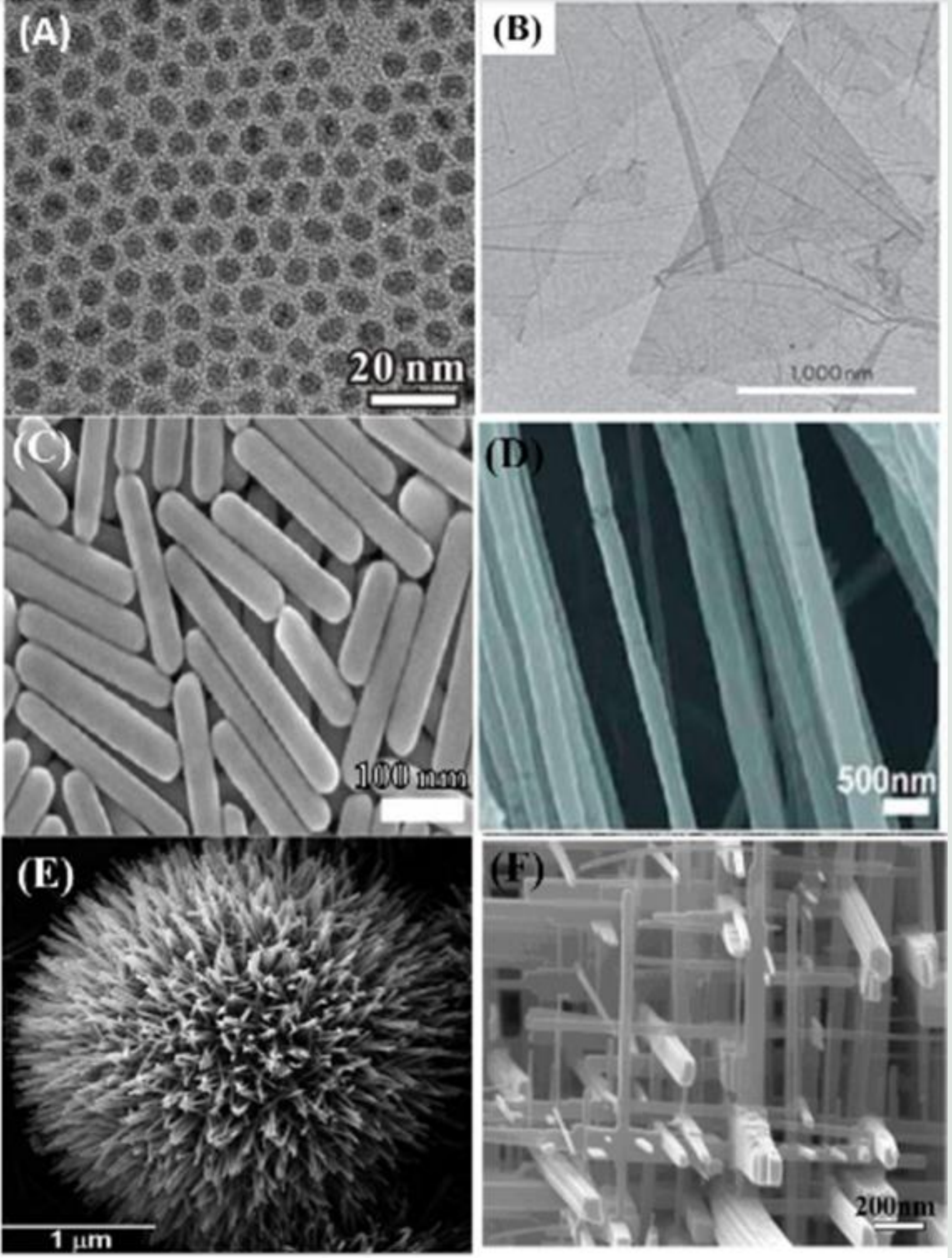


Figure 1: Nanomaterials with different morphologies:

(A) nonporous Pd NPs (0D), copyright Zhang et al.; licensee Springer, 2012,

(B) Graphene nanosheets (2D), copyright 2012, Springer Nature,

(C) Ag nanorods (1D), copyright 2011, American Chemical Society,

(D) polyethylene oxide nanofibers (1D), copyright 2010, American Chemical Society,

(E) urchin-like ZnO nanowires (3D), reproduced from [14]with permission from The Royal Society of Chemistry,

(F) Tungsten trioxide (WO_3**)** nanowire network (3D), copyright 2005 Wiley-VCH.

Beilstein J. Nanotechnol.2018,9

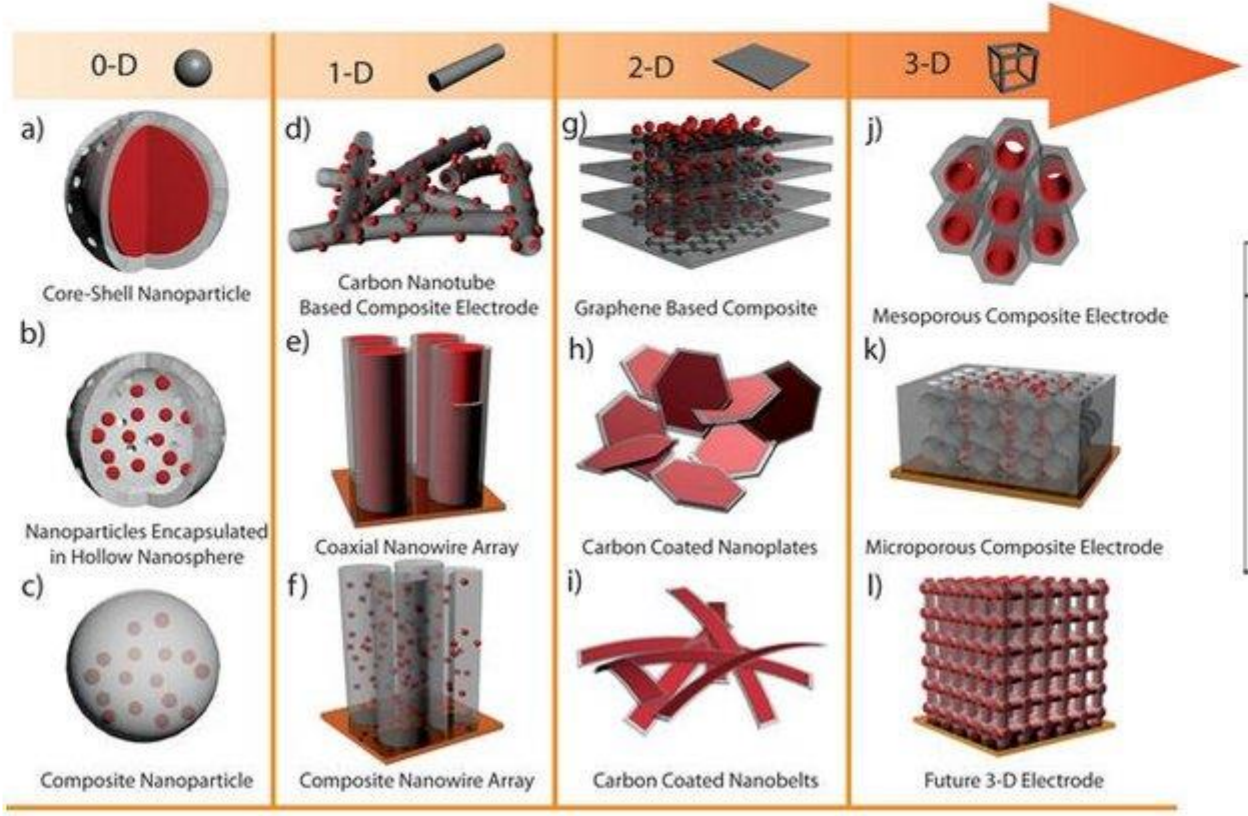
Nanomaterial classifications based on dimension

- <u>Nanoparticles are mainly classified into four types:</u>

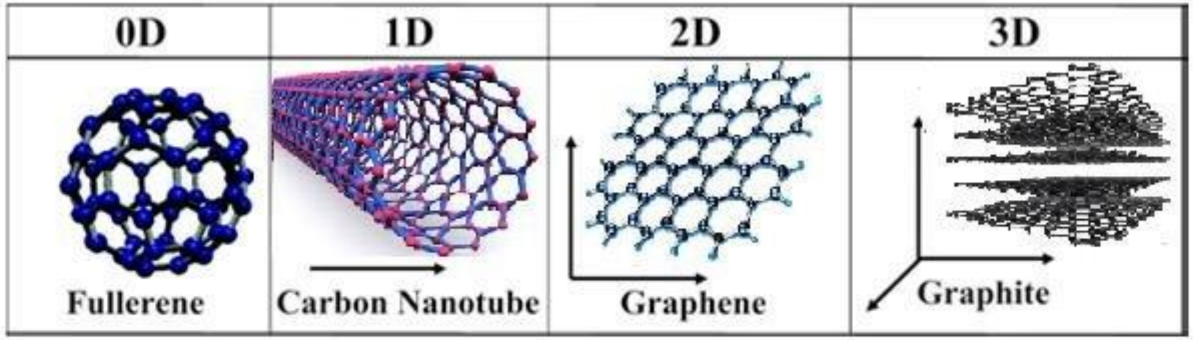
1. <u>Zero-dimensional (0D) nanostructures</u>: In this, all of the three dimensions are in the nano metric range. Ex. Nano particles or well separated nano powders.
2. <u>One-dimensional (1D) nanostructure:</u> In this, two dimensions are in the nano metric range and third dimension remains large. These structures have shape like rods. Ex. Nano tubes, Nano rods etc.
3. <u>Two-dimensional (2D) nanostructure</u>: In this, only one dimension is in the nano metric range while other two dimensions remain large. These display plane like structures. Ex. Nano thin films, Nano coating, Nano layers etc.
4. <u>Three-dimensional (3D) nanostructure:</u> In this, all three dimensions are outside the nano metric size range. It may consist of group of nano wires, nano tubes, or different distribution of nano particles.

Nanomaterial classifications based on dimension

- **(0D), (1D), (2D), and (3D)**



(**Source:** Tiwari et al., 2013)



(**Source:** Bergmann and Machado, 2015)

Nanomaterial classifications based on origin

Apart from dimension and material-based classifications, NPs and NSMs can also be classified as natural or synthetic, based on their origin:

(i) Natural nanomaterials: are produced in nature either by biological species or through anthropogenic activities. The production of artificial surfaces with exclusive micro and nanoscale templates and properties for technological applications are readily available from natural sources. Naturally occurring NMs are present through the Earth's spheres (i.e., in the hydrosphere, atmosphere, lithosphere and even in the biosphere),regardless of human actions. Earth is comprised of NMs that are naturally formed and are present in the Earth's spheres, such as the atmosphere, which includes the whole of troposphere, the hydrosphere, which includes oceans, lakes, rivers, ground water and hydrothermal vents, the lithosphere, which is comprised of rocks, soils, magma or lava at particular stages of evolution and the biosphere, which covers micro-organisms and higher organ-isms, including humans.

Nanomaterial classifications based on origin

(ii) Synthetic (engineered) nanomaterials are produced by mechanical grinding, engine exhaust and smoke, or are synthesized by physical, chemical, biological or hybrid methods. The question of risk assessment strategies has arisen in recent times as there is increased fabrication and subsequent release of engineered NMs as well as their usage in consumer products and industrial applications. These risk assessment strategies are highly helpful in forecasting the behavior and fate of engineered NMs in various environmental media. The major challenge among engineered NMs is whether existing knowledge is enough to forecast their behavior or if they exhibit a distinct environment related behavior, different from natural NMs. Currently, different sources related to potential applications are used for the production of engineered NMs

Synthesis of nanomaterials

Nanomaterials Synthesis Approaches

Bottom-up approach

Top-down approach

Top-Down approach

In Top-down techniques, the starting material is solid state

Physical processing methods:

- ✓ Mechanical methods :
  - cutting , etching, grinding
  - ball milling
- ✓ Lithographic techniques:
  - Photo Lithography
  - Electron Beam Lithography

Bottom-Up approach

All the Bottom-up techniques, the starting material is either gaseous state or liquid state of matter

- Physical and chemical processing methods:

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, Microemusion route, pyrolysis.

Source: https://www.slideshare.net/Krishanyadav28/synthesis-of-nanomaterials

Top-Down approach

ADVANTAGES

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

DISADVANTAGES

Yields:

-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

Bottom-Up approach

ADVANTAGES

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

DISADVANTAGES

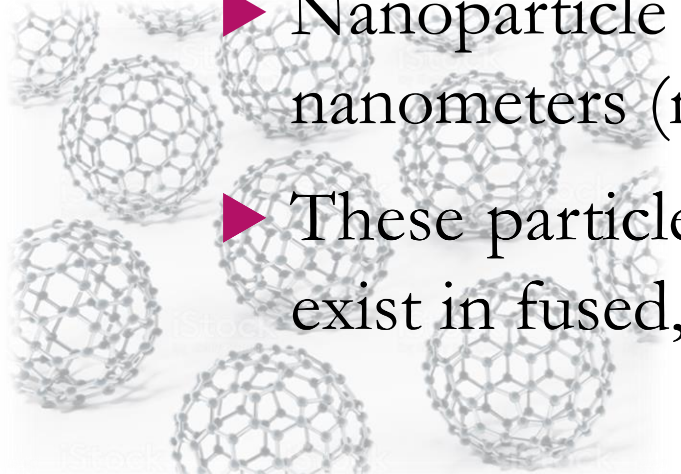
- Large scale production is difficult
- Chemical purification of nanoparticles is required

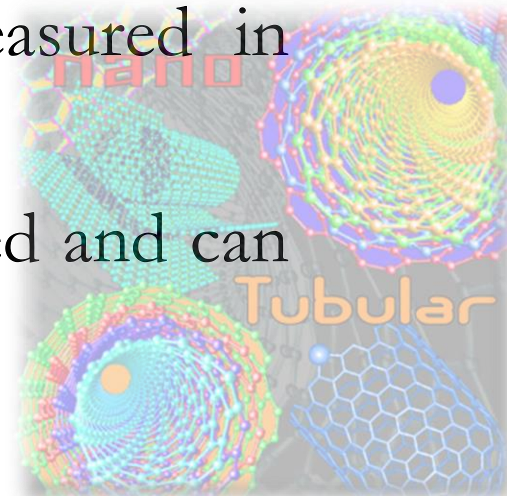
Characterization of nanomaterials

- Characterization refers to the study of material's features such as its **composition**, **structure** & various properties like physical, electrical, magnetic…etc.

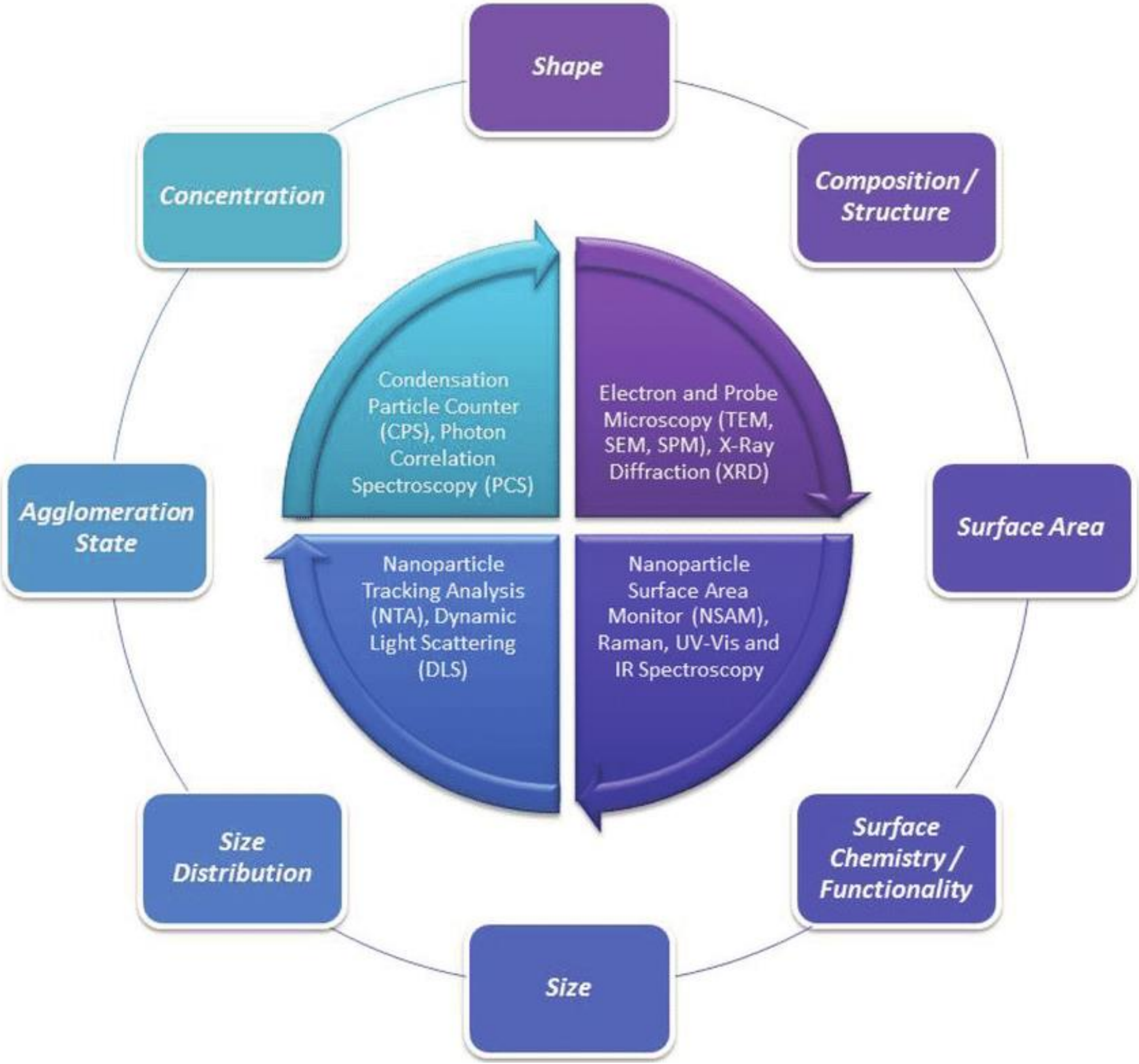
Nano = 10^{-9} (extremely small) Particle = Small piece of matter

- Nanoparticle is a microscopic particle whose size is measured in nanometers (nm).
- These particles can be spherical, tubular, or irregularly shaped and can exist in fused, aggregated or agglomerated forms.

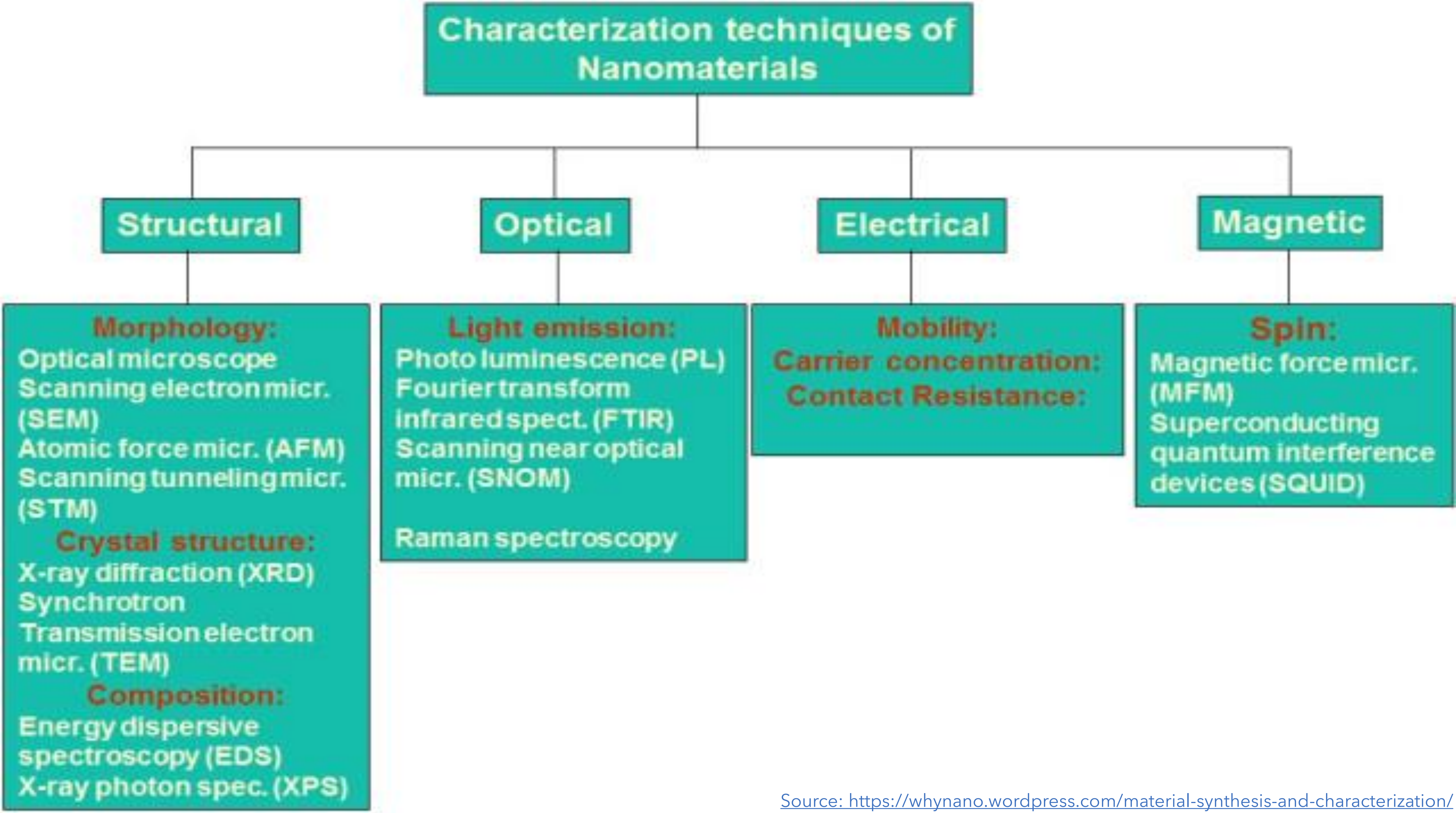




Source: https://www.slideshare.net/AnilPethe/characterization-of-nanoparticles



Characterization of nanomaterials



Source: https://whynano.wordpress.com/material-synthesis-and-characterization/

Nanoparticle Characterization Techniques

- Optical (Imaging) Probe Characterization Techniques
- Electron Probe Characterization Techniques
- Scanning Probe Characterization Techniques
- Photon(Spectroscopic) Probe Characterization Techniques
- Ion-particle probe Characterization Techniques
- Thermodynamic Characterization Techniques Nano particles Characterization Techniques

Optical (Imaging) Probe Characterization Techniques

Acronym	Technique	Utility
CLSM	Confocal laser-scanning microscopy	Imaging/ultrafine morphology
SNOM	Scanning near-field optical microscopy	Rastered images
2PFM	Two-photon fluorescence microscopy	Fluorophores/biological systems
DLS	Dynamic light scattering	Particle sizing
BAM	Brewster angle microscopy	Gas-liquid interface Imaging

Electron Probe Characterization Techniques

Acronym	Technique	Utility
SEM	Scanning Electron Microscopy	Imaging/ topology morphology
EPMA	Electron Probe Microanalysis	Particle size/ local chemical analysis
TEM	Transmission Electron Microscopy	Imaging/ Particle size shape
HRTEM	High Resolution Transmission Electron Microscopy	Imaging structure chemical analysis
LEED	Low Energy Electron Diffraction	Surface/ adsorbate bonding
EELS	Electron Energy Loss Spectroscopy	Inelastic electron interaction
AES	Auger Electron Spectroscopy	Chemical surface analysis

Scanning Probe Characterization Techniques

Acronym	Technique	Utility
AFM	Atomic Force Microscopy	Imaging/ topology/ surface structure
CFM	Chemical Force Microscopy	Chemical/surface analysis
MFM	Magnetic Force Microscopy	Magnetic material analysis
STM	Scanning Tunnelling Microscopy	Topology/Imaging /surface
APM	Atomic Probe Microscopy	Three dimensional Imaging
FIM	Field Ion Microscopy	Chemical profiles/ atomic spacing
APT	Atomic probe tomography	Position sensitive lateral location of atoms

Photon(Spectroscopic) Probe Characterization Techniques

Acronym	Technique	Utility
UPS	Ultraviolet photoemission spectroscopy	Surface analysis
UVVS	UV Visible spectroscopy	Chemical analysis
AAS	Atomic absorption spectroscopy	Chemical analysis
ICP	Inductively coupled plasma spectroscopy	Elemental analysis
FS	Fluorescence spectroscopy	Elemental analysis
LSPR	Localized surface plasmon resonance	Nanosized particle analysis

Ion-particle probe Characterization Techniques

Acronym	Technique	Utility
RBS	Rutherford back scattering	Quantitative- Qualitative elemental analysis
SANS	Small angle neutron scattering	Surface characterization
NRA	Nuclear reaction analysis	Depth profiling of solid thin film
RS	Raman Spectroscopy	Vibration analysis
XRD	X-ray diffraction	Crystal structure
EDX	Energy dispersive X-ray spectroscopy	Elemental analysis
SAXS	Small angle X-ray scattering	Surface analysis/ particle sizing (1-100 nm)
CLS	Cathodoluminescence	Characteristics emission
NMR	Nuclear magnetic resonance spectroscopy	Analysis of odd no. of nuclear species

Thermodynamic Characterization Techniques

Acronym	Technique	Utility
TGA	Thermal gravimetric analysis	Mass loss Vs. Temperature
DTA	Differential thermal analysis	Reaction heat capacity
DSC	Differential scanning calorimetry	Reaction heat phase changes
NC	Nanocalorimetry	Latent heats of fusion
BET	Brunauer-Emmett-Teller method	Surface area analysis
Sears	Sears method	Colloid size, specific surface area

THANK YOU