PHYSICS OF NANOPARTICLES

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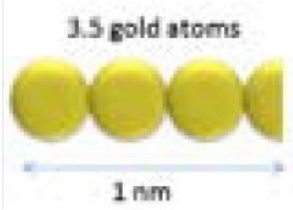
- **Introduction**
- **Properties of nanoparticles**
- **Synthesis of nanoparticles**

  planetary ball milling, CVD, laser pyrolysis
- **Applications**

Introduction

'Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale



Three and a half gold atoms placed in a row equal 1 nm

Nano - Greek prefix - dwarf or something very small

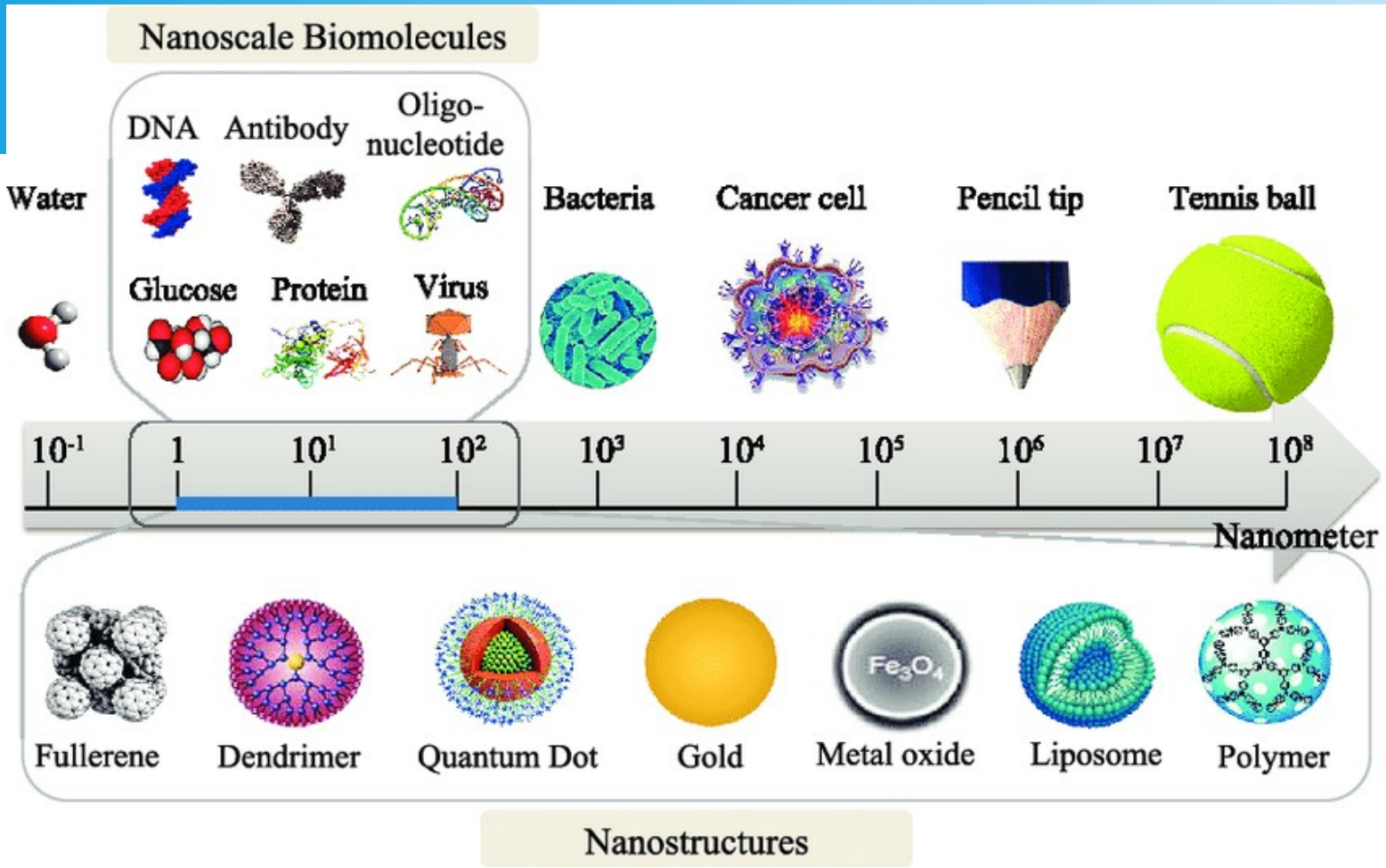
According to ISO and ASTM,

" The scale from 1nm to 100 nm defines the size of a nano particle.

For three dimensional particles, two or three dimensions must be in between 1nm to 100 nm range.
Below 1 nm is due to clusters of atoms not a particle and it is designated as nano objects or elements of nano structures"

Introduction

Object	Typical dimension
Diameter of Sun	1,393,000 km
Diameter of an earth	128,000 km
Height of Himalaya mountain	8,848 m
Height of a man	1.65 m
Fly	1 cm
Single human hair	80000 nm
Red blood carpuscules	10,000 nm
Limit of eye's ability to see	10,000 nm
E coil bacteria	2000 nm
Visible spectrum	700 to 400 nm
Virus	20-250 nm
Size of a nanoparticle	1-100 nm
Quantum dot	5 nm
DNA	2 nm
Carbon nanotube	1.3 nm
Buckyball	1 nm
Size of hydrogen atom	0.1 nm



Finger nail grows 1nm/second

Human Hair 80000nm in diameter

Transistor of pentium core duo processor 45nm

Things Natural

Dust mite
200 mm

Ant
~5 mm

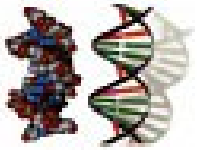
Fly ash
~10 - 20 mm

Human hair
~10 - 50 mm wide

Red blood cells
with white cell
~ 2 - 5 mm

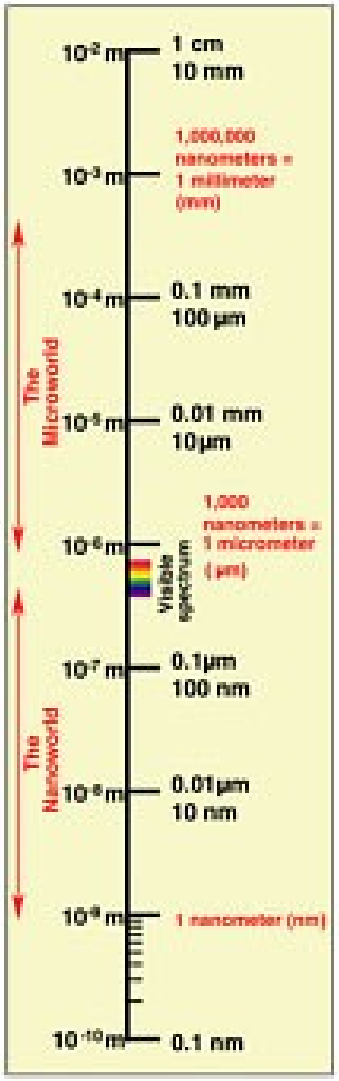
~10 nm
diameter

ATP synthase



DNA
~2 1/2 nm diameter

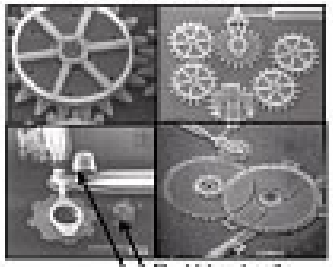
Atoms of silicon
spacing ~tenths of nm



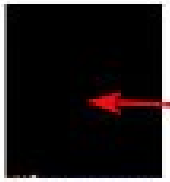
Things Man-made

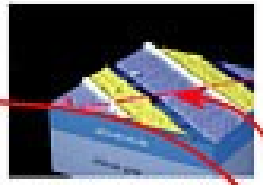
Head of a pin
1-2 mm

Microelectromechanical devices
10-100 mm wide

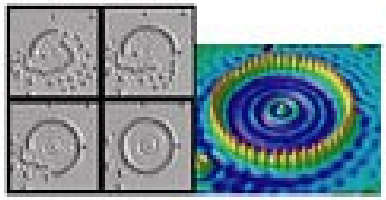


Red blood cells
Pollen grain





Nanotube electrode
Nanotube transistor



Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm

Carbon nanotube
~2 nm diameter

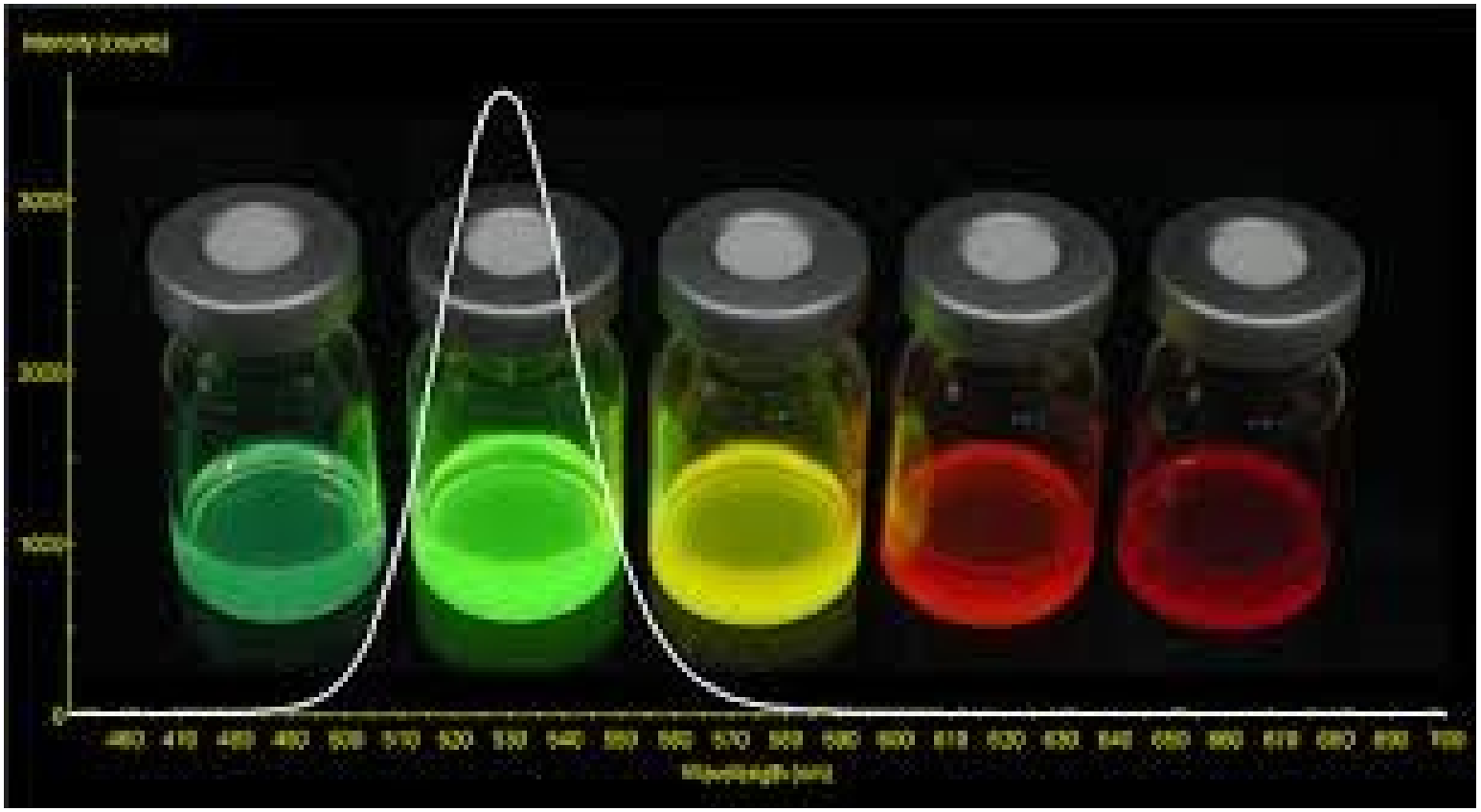
21st Century Challenge

Assemble nanoscale building blocks to make functional devices, e.g., a photosynthetic reaction center with integral semiconductor storage

Size matters – on reducing size, material can have significantly different properties at larger scale

This lead in to synthesis of new materials in general known as nano-materials

Nanoshells designed to absorb various wavelengths of light



CdSe quantum Dots that fluroscent in to different colors depending on their size

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

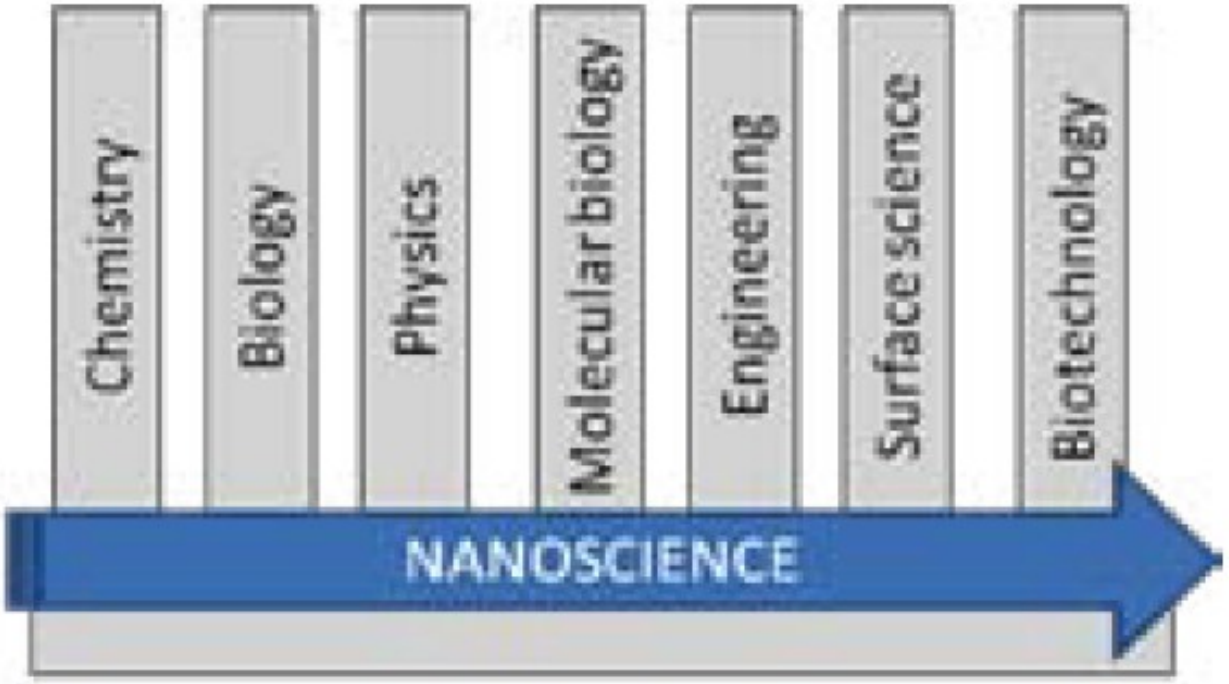
Appears **green in reflected light** **and** **red in transmitted light**

Red Colour is due to presence small amount of **Gold nano powder**

Nanoscience depend on the exceptional properties of matter at the nanoscale level.

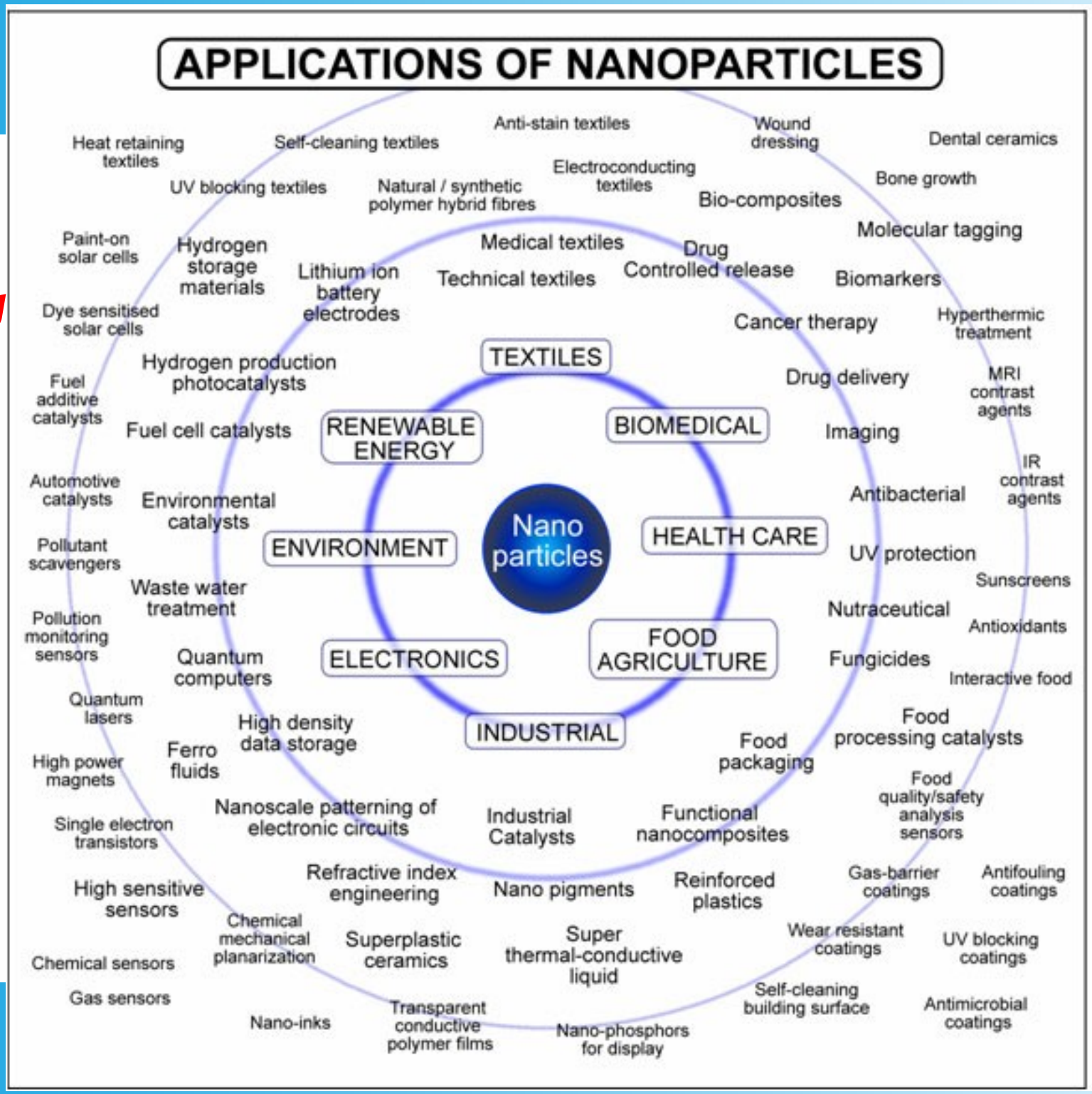
‘nano’ doesn’t only mean ‘1000 times smaller than micro’, and nanotechnologies are not just an extension of microtechnologies to a smaller scale.

It is an entirely new paradigm that opens entirely new scientific opportunities.



Nanoscience is a horizontal integrating interdisciplinary science that cuts across all vertical sciences and engineering disciplines

It's plenty

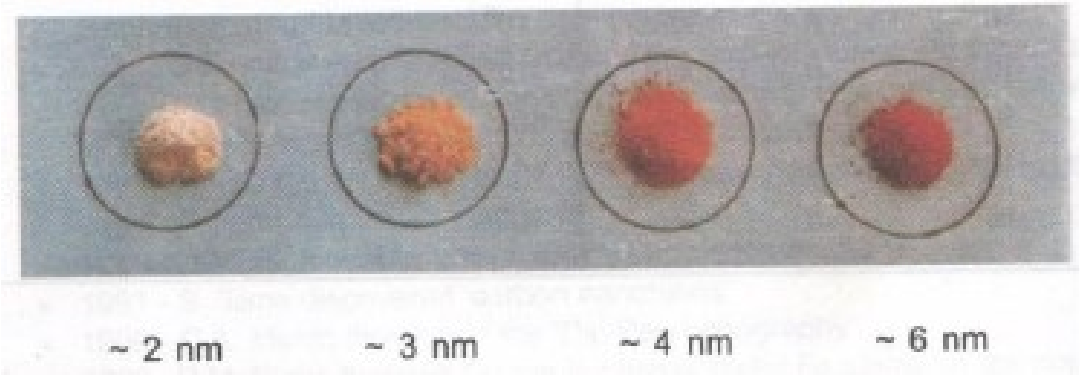

APPLICATIONS OF NANOPARTICLES
Nano particles
TEXTILES
BIOMEDICAL
HEALTH CARE
FOOD AGRICULTURE
INDUSTRIAL
ELECTRONICS
RENEWABLE ENERGY
ENVIRONMENT
Anti-stain textiles
Heat retaining textiles
Self-cleaning textiles
Wound dressing
Dental ceramics
Electroconducting textiles
Bone growth
UV blocking textiles
Natural / synthetic polymer hybrid fibres
Bio-composites
Molecular tagging
Paint-on solar cells
Hydrogen storage materials
Medical textiles
Drug Controlled release
Lithium ion battery electrodes
Technical textiles
Biomarkers
Dye sensitised solar cells
Cancer therapy
Hyperthermic treatment
Hydrogen production photocatalysts
Drug delivery
MRI contrast agents
Fuel additive catalysts
Fuel cell catalysts
Imaging
IR contrast agents
Automotive catalysts
Environmental catalysts
Antibacterial
Pollutant scavengers
UV protection
Sunscreens
Waste water treatment
Nutraceutical
Antioxidants
Pollution monitoring sensors
Quantum computers
Fungicides
Interactive food
Quantum lasers
High density data storage
Food processing catalysts
Ferro fluids
Food packaging
High power magnets
Food quality/safety analysis sensors
Nanoscale patterning of electronic circuits
Industrial Catalysts
Functional nanocomposites
Single electron transistors
Refractive index engineering
Nano pigments
Reinforced plastics
Gas-barrier coatings
Antifouling coatings
High sensitive sensors
Chemical mechanical planarization
Superplastic ceramics
Super thermal-conductive liquid
Wear resistant coatings
UV blocking coatings
Chemical sensors
Gas sensors
Self-cleaning building surface
Antimicrobial coatings
Nano-inks
Transparent conductive polymer films
Nano-phosphors for display

Properties of Nanoparticles

Optical Properties

change in optical Properties is due to smaller size, the electrons in them are not as much free to move as in case of bulk material
Due to this restricted movement of electrons, nano particles react difrently with light.

Size of GaAs nanoparticles	20 nm	10 nm	5 nm	2 nm
Energy gap in eV	1.42	1.46	1.61	2.78



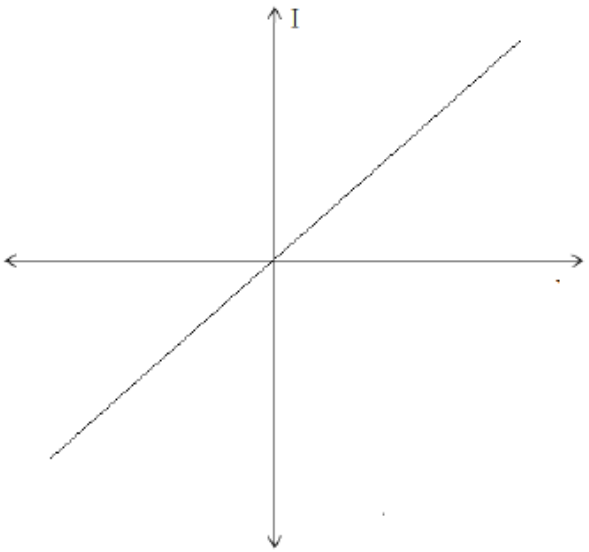
CDS nano particle

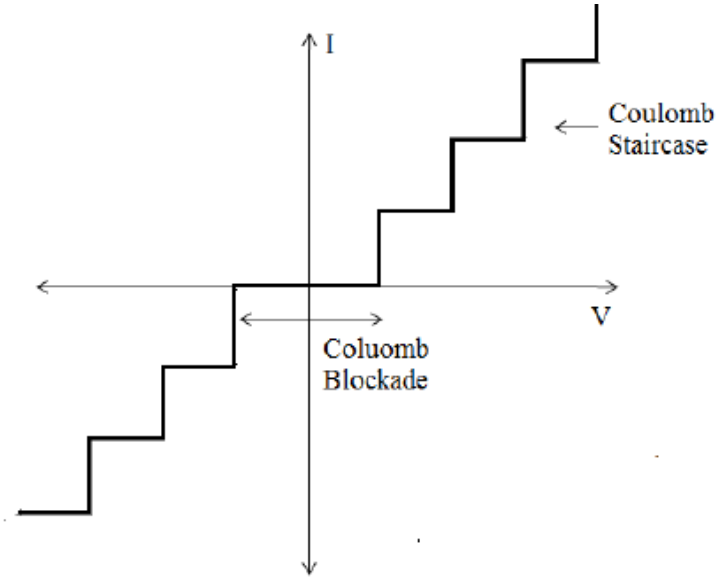
Quantum dots

Quantum dots are tiny particles of a semiconductor material ranging from 2 to 10 nm

Electrical properties

Electrical properties of nanoparticles are different than their bulk counterparts
The I-V characteristics of a quantum dot is not a straight line but it appears like a stair case.
from zero up to certain low bias voltage, there is no current - **Coulomb Blockade**
This is due to the fact that **unless a voltage of $e^2/2C$ is applied**, **a single electron cannot tunnel through the quantum dot**. The graph appears like a stair case due to repeated tunneling of electrons.





The resistivity of nanocrystalline materials is greater than their bulk analogs having microscrystalline boundaries.

This is because electrons will suffer scattering to a greater extent when the crystalline boundaries are smaller in size and more in number.

nanomaterials show superconducting properties under certain conditions.
A '**single electron transistor**' having size less than 10 nm has been demonstrated.
It's I-V characteristics is different than that of a conventional transistor.
good potential for low power and high density integrated circuit applications.

Structural Properties

The atoms in nano particles have a higher average energy than atoms in longer structures, because of the larger proportion of surface atoms, i.e. catalytic activity per atom exposed to surface as the catalyst is reduced in size at the nanoscale

Defects and impurities may be attracted to surfaces & interfacesand interaction between particles at those small dimensions can. depend on the structure and nature of chemical bonding at surface

Molecular monolayers can change or control surface propertig and to medicate the interaction between nanoparticles

Magnetic properties

Unusual magnetic behavior shown by nano particles is due to surface or interface effects, including symmetry breaking electronic environment or charge transfer and magnetic interaction & method of synthesis

Nano particles Show Super para magnetism at a transition temperature, which is smaller than the transition temperature of bulk materials

Nanocomposite Magnets consisting of uniform mixture of soft and hard phases

Reducing size may induce magnetic property in the material
For ex. Bulk gold & platinum are non magnetic but at nanosize they act as magnetic particle
Silver nano particle-ferromagnetic in nature with thiol capping

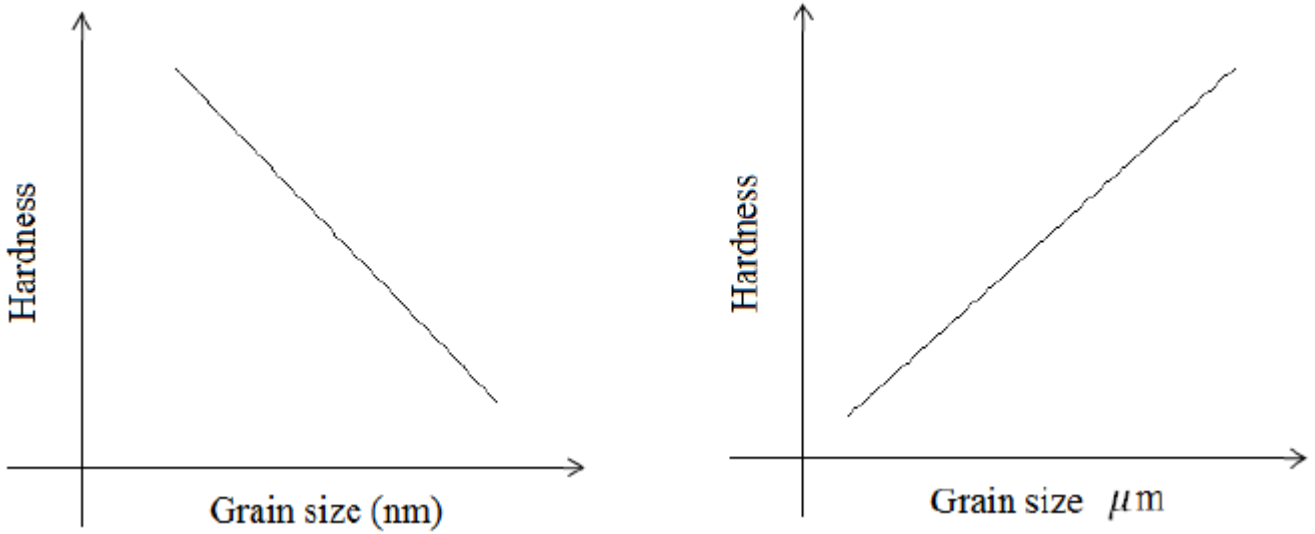
Giant magneto resistance phenomenon observed in nanoscale multi layers

Mechanical properties

Depend upon the strength of the bonds, impurities, the defects, grain boundaries , dislocations

For magnesium, in polycrystalline form (grain size > 1 μm), the Young's modulus is 4100 N/mm^2, however, when it is reduced to nanometric scale (grain size ~12 nm), the Young's modulus decreases to 3900 N/mm^2.

Palladium in polycrystalline form, the Young's modulus is 12,300 N/mm^2, but when it is reduced to nanometric form the Young's modulus is decreased to 8800 N/mm^2.



Synthesis of nanoparticles

1. Bottom Up approach
2. Top down approach

Ball milling method

Top down approach Mechanical method

Using this method the nanoparticles of metals and alloys are made.

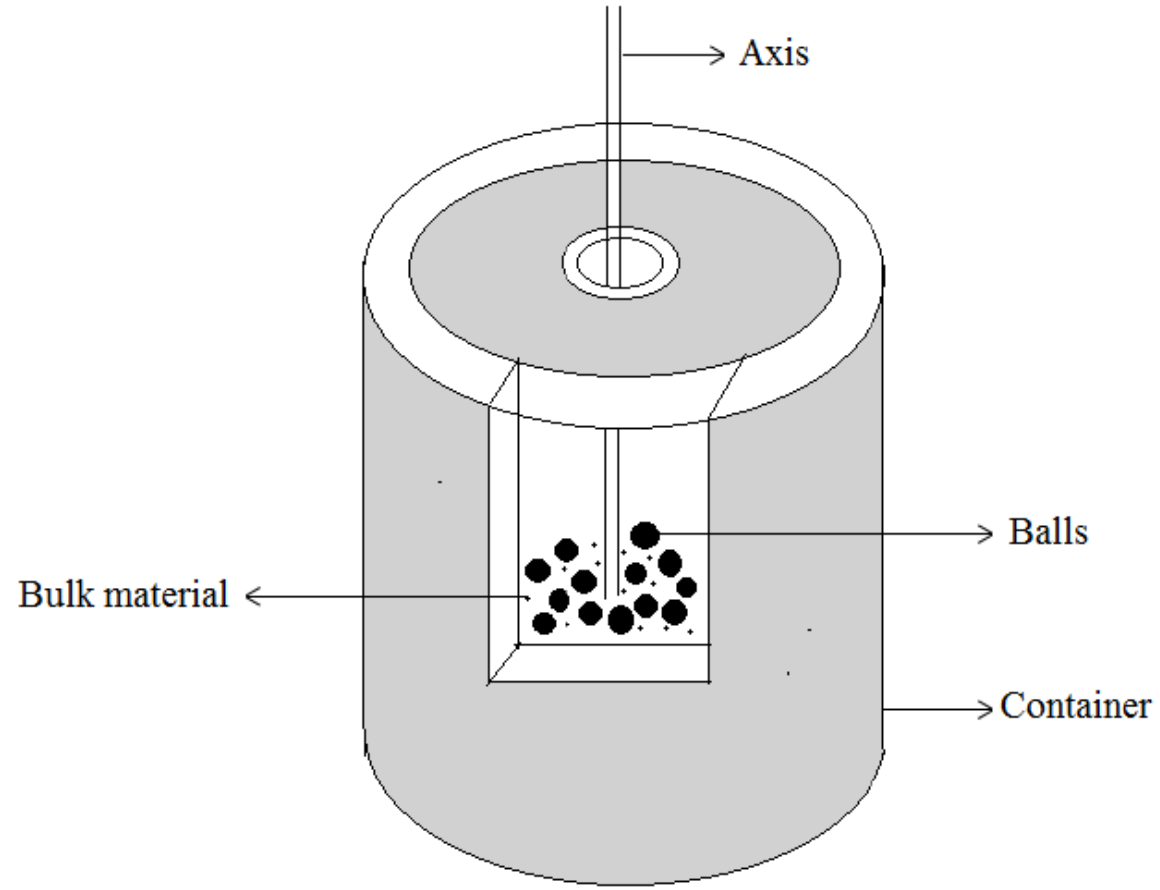
Different types of mills such as planetary, vibratory, rod, tumbler etc. are used.

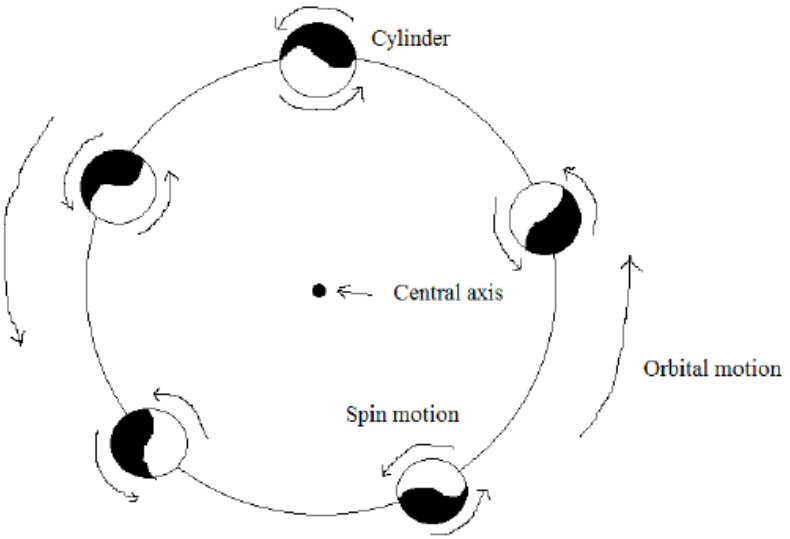
Container is filled with the hardened balls of steel or tungsten carbide and the bulk material in the form of powder or flakes.

The ratio of mass of balls to mass of powder is 2:1. The cylinder is less than half filled.

The containers are rotated with high speed around their own axis (spin motion).

The spinning cylinders are also rotated around certain axis like a planetary motion.


Axis
Balls
Bulk material
Container


Cylinder
Central axis
Orbital motion
Spin motion

Due to planetary motion, the powder is forced towards the walls and pressed against the walls, because of centrifugal force.

But due to spinning motion the powder is moved to other region of the cylinder. If the size of the balls is increased then the impact energy increases due to which size of nanoparticles is decreased however, defects are also introduced.

The impurities may be introduced due to balls and the presence of air or gases.

If impurities due to gases are to be avoided, highly pure gases should be used.

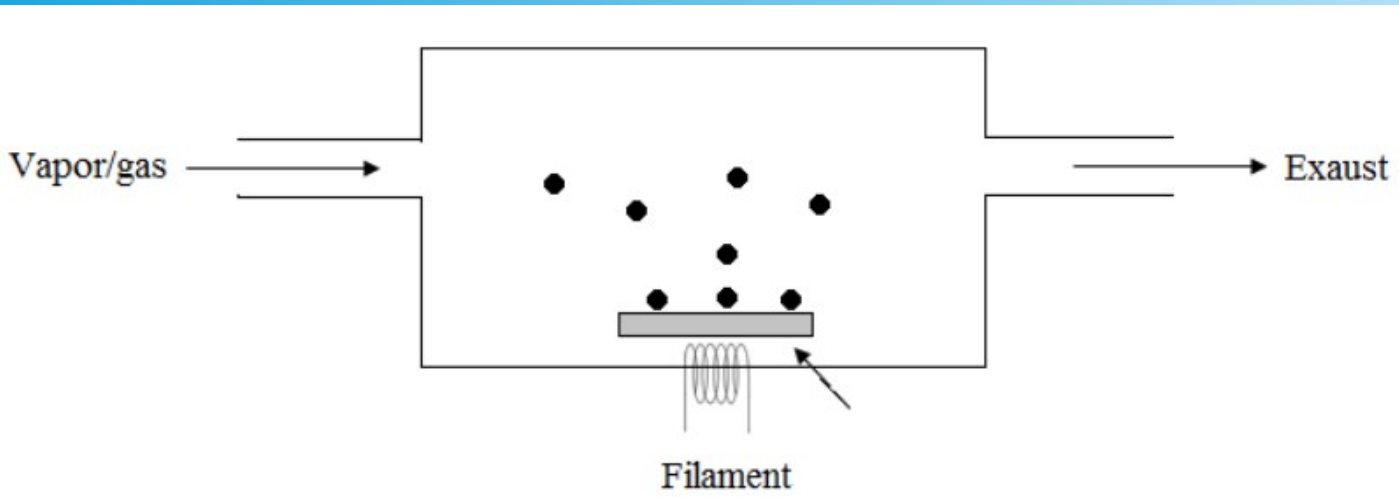
Due to the milling process, the temperature may be increased to 100^{o}C to 1100^{o}C.

To reduce the temperature, liquid nitrogen is used

Depending on the material refractory balls, steel balls, plastic balls are used.

This energy transfered is depends on rotational speed, number of balls, Milling time ,the milling medium.
- commonly used to prepare CeO_2, ZnO etc.

Chemical Vapor Deposition (CVD)



Evaporation and deposition of materials on the hot substrate and **their chemical reaction with the substrate**.

The nanoparticles of metals or metallic compounds can be formed.

The reactant in the form of vapor are pumped in the reaction chamber by using carrier gas, then vapor or gas is transported towards the substrate maintained at high temperature (usually ~ 300 to 1200^{o}C).

The gas or vapor is deposited on the substrate, where it undergoes a chemical reaction at appropriate sites.

The unwanted byproducts which have to be suitably removed from the substrate.

The quality of the product is governed by gas pressure and substrate temperature.

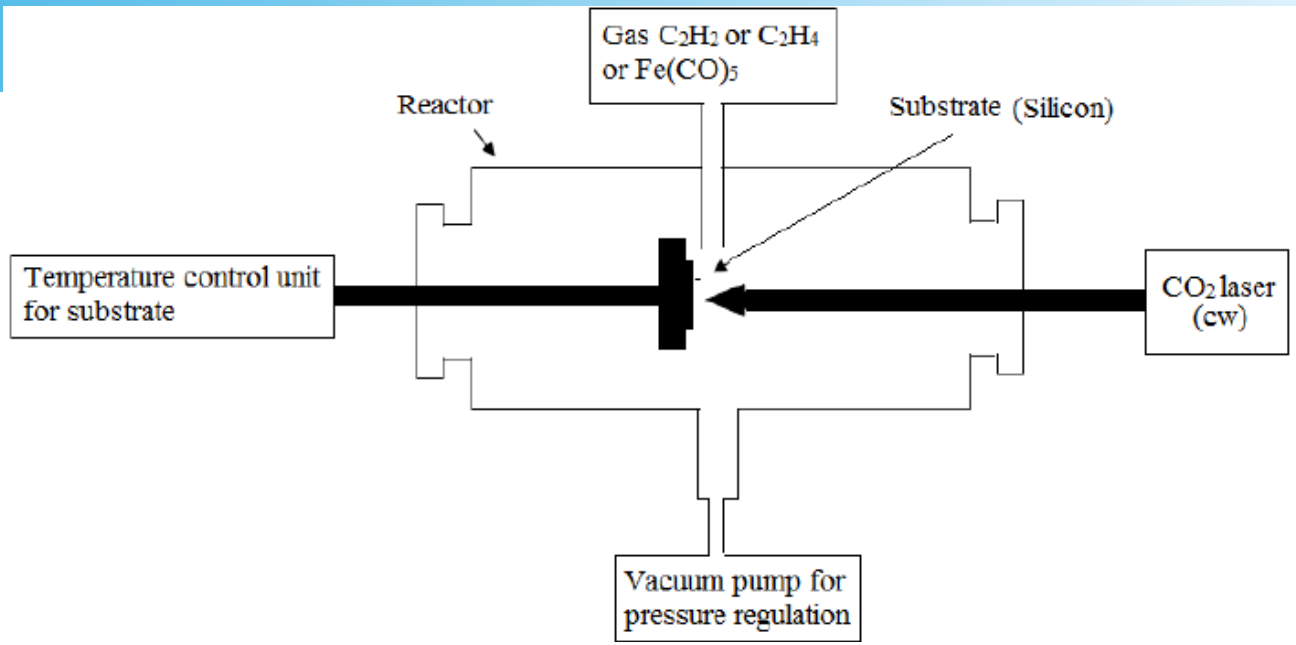
Simple instrumentation, ease of processing and economic viability.

Laser Pyrolysis

Pyrolysis means decomposition at high temperature

based on the decomposition of gases using laser

High power laser decomposes the gases like C_2H_2, C_2H_4, $Fe(CO)_5$



The decomposed atom interact with each other, grow in size to acquire nanoform and then get deposited on silicon substrate.

Used for synthesis of Carbon Nano Tubes, Al_2O_3, Si_3N_4

The characteristics of nanoparticles such as size and size distribution depend upon the gas pressure and substrate temperature

Presence of inert gases such as helium or argon is necessary

The apparatus also involves the pressure and temperature control units

Nanoparticles in the form of thin films are obtained by this method

Applications of nanoparticles

Automobiles

Parts of the automobile: Hard body parts, strong and rigid (CNT)

Painting: Smooth, Thin, Attractive

Window Glasses: Self cleaning glasses, Hydrophillic glasses

Motors: Wiper, window glass movement, removind CD Players,
Ni, Ti based nanoparticles were used

Tyres; nano clay based tyres, thinner, light weight and less rubber consuming

Energy

Energy from hydrogen – CNT used for storage, photo catalyst
Energy from Solar cell - cds, cdse, ZnO, CNT
Energy from reachargable batteries- Ni hydride, Aerogels.
- Magnetic Refrigeration

Electronics

- Q-bits for quantum computers

- Electro-chromic display - tungsten oxide nonoparticle

- Memory, storage devices- Spintronix

- Fe, Co, Ni - Used in Single eletron transistor, FET, Magnetic Tunnel Junction, Colossan MR (CMR)

Medical

Targetted drug delivery (nano capsules)

Detection of diseases (Molecular Imaging)

Artificial heart valves – silicon carbide

Space & defence

- Aerogels - contain nanopores - light weight suits & Jackets
- Solar cells in the space crafts - Power
- material for space vehicles
- biological weapons
- docomposition of warfare chemicals
- making the objects invisible

Cosmetics

-Sunsereen Lotions Zno, 170, abs UV radiation
-Creams with nanoparticles fill the wrinkles in the face,
-Harmles dyes & colors

Textile

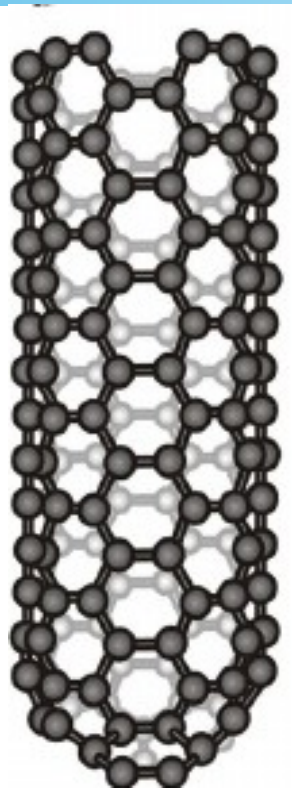
- fibers, threads & dyes with nanoparticles makes cloth wrinkle free and self cleaning silver nano particles also used to make germ free

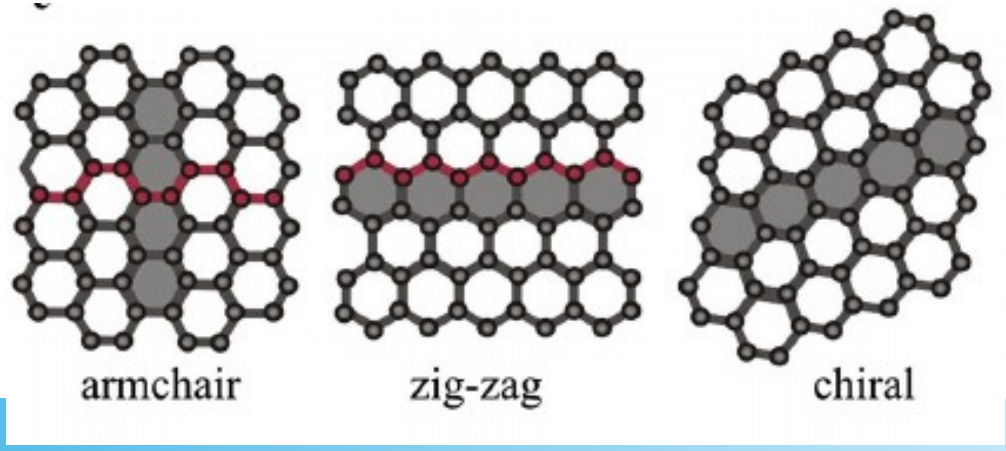
Sports & Toys -

- **Tennis balls - hanoclay - pores are filled and leakage of air avoided**
- **Packets - CNT used to make them strong and leight weight.**
- **Toys - nano based motors.**

Environment: Pollution control. CO, NO absorbers

Reference: Concepts of Engineering Physics: Prof. Dr. N. L. Mathakari, MITWPU




armchair
zig-zag
chiral

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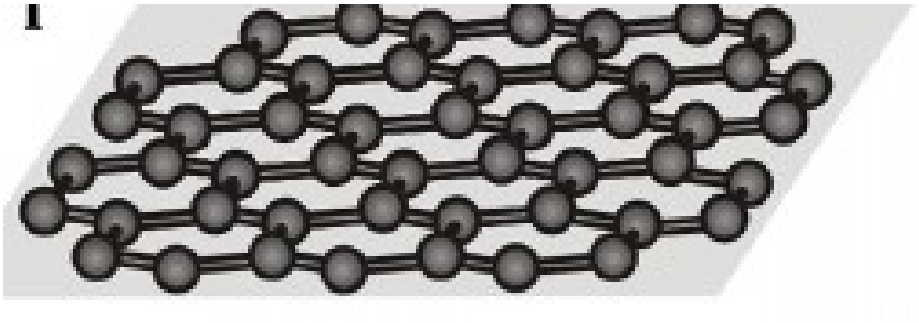

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