Introduction to Nanomaterials & Nanotechnology

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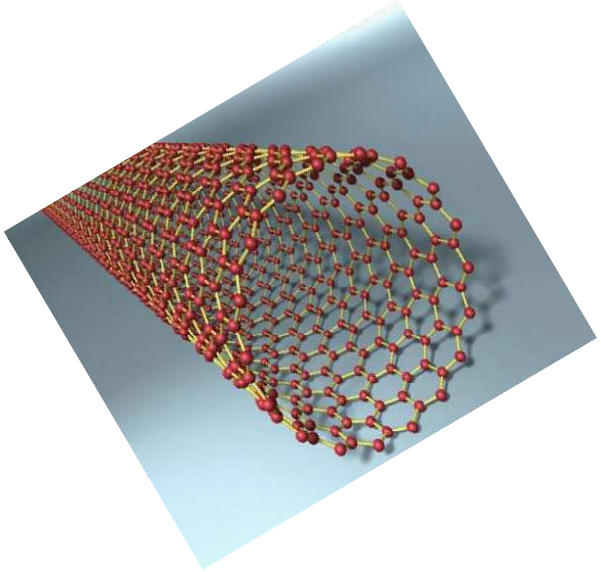
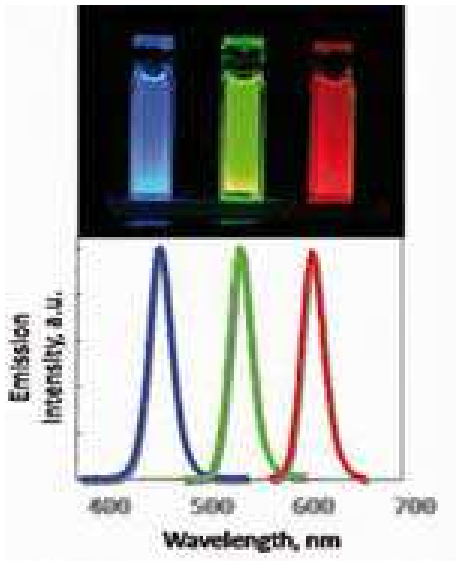
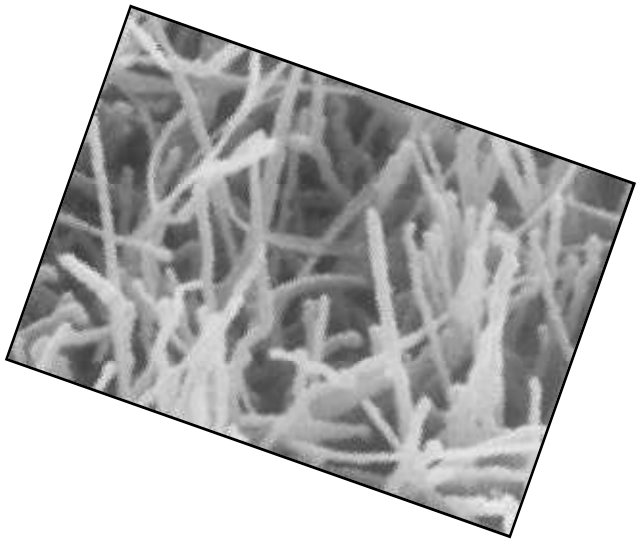






What is nanotechnology?

- The word ‘nano’ derives from the Greek νᾶνος (Latin *nanus*), meaning "dwarf".
- **“The science of manipulating atoms and molecules to make new materials and devices”.**
- An emerging, **interdisciplinary field** involving:
  - **Chemistry**
  - **Physics**
  - **Biology**
  - **Engineering**
  - **Materials Science**
  - **Computer Science**
- Occurs at the **1-100 nanometer range at least in one dimension.**

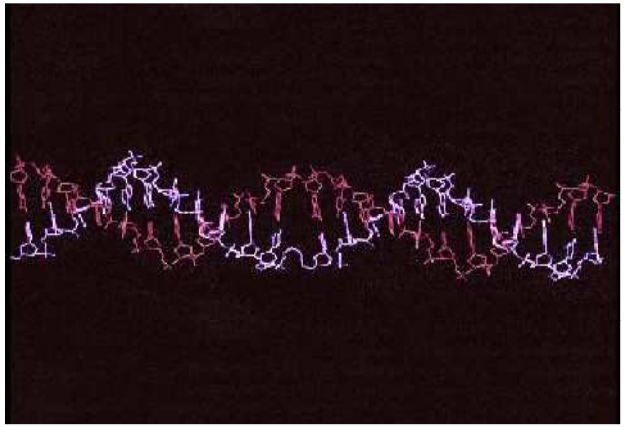
How big is "nano"?

- It is a millionth of a millimetre or a billionth of a metre i.e. **1nm = 10^{-9} m.**
- *The nanoscale is 1000 times smaller than the micro meter.*
- **[1 uM** = 1000 **nM;** 10 lakhs=1 **million;**

  1000 million = 100 crore = 1 **billion**]
- Atom: ~0.1 nanometers.
- 10 H atoms placed side by side make 1 nm.

- DNA double-helix:

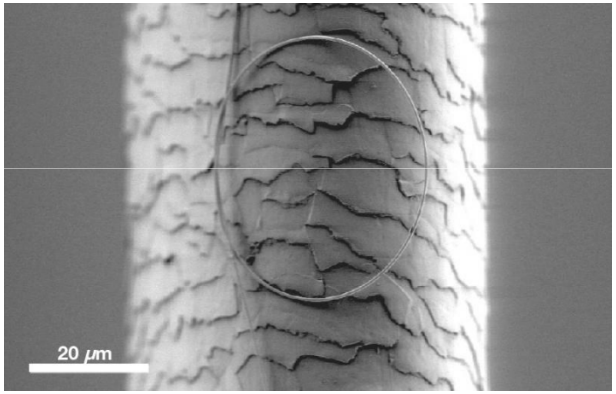
~2 nm in diameter.



- Human hair:

50,000–100,000 nm

in diameter.



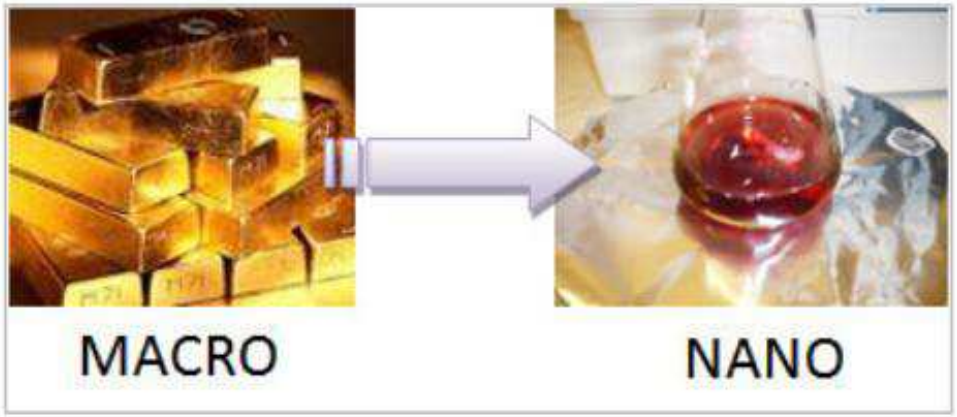
- One piece of paper:

~100,000 nanometers thick.

- Girl 1.5m (5ft) tall: ~1500 millions nanometers tall.
- (1ft ≈ 0.3m; 1″ ≈ 0.0254m)

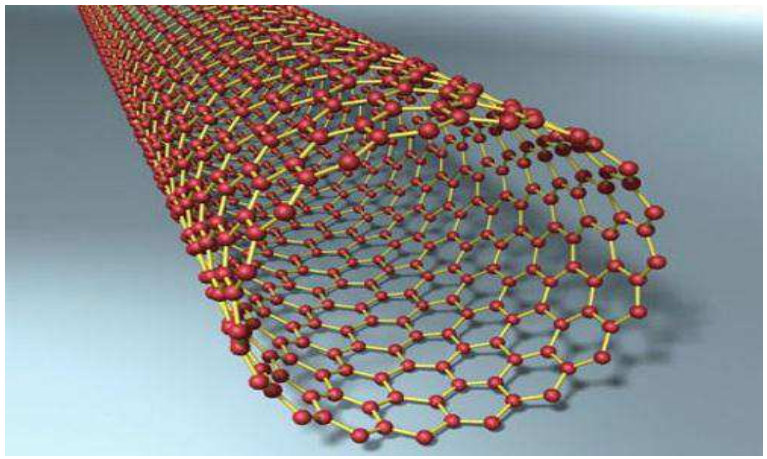
What's so special about the nanoscale?

- Gold is **golden** at macro and micro scale, but at nanoscale colour and reactivity changes.



- Metallic copper is transparent on the nanoscale.

- **Carbon**, which is quite soft in its normally occurring form (graphite), becomes incredibly hard when it's tightly packed into a nanoscopic arrangement called a **nanotube**.

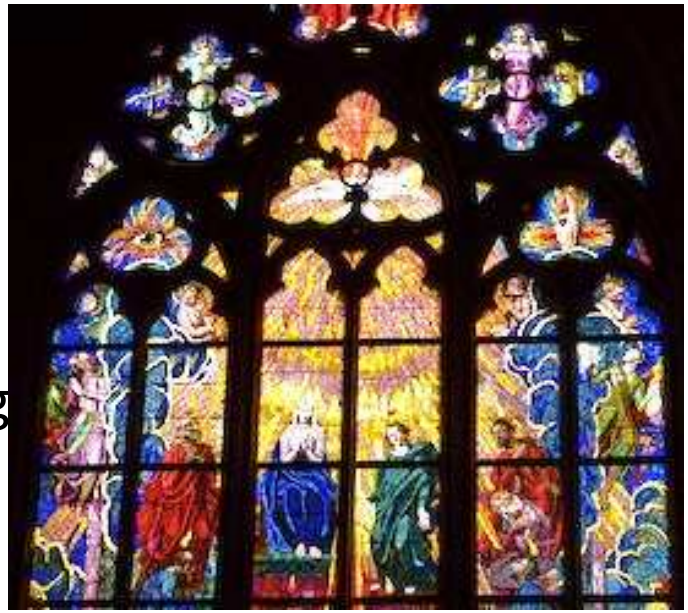


Much more stronger than steel of the same diameter.

History of Nanoscience:

- **Roman** glass workers (4th Century) produced the " **Lycurgus cup"-** made from soda lime glass stained with the **Au and Ag nano Particles -**looks green (in reflected light) and red (in transmitted light).

➢ At **Medieval Age**: The colourful window stained with different **coinage metal nanoparticles.**



➢ In the 17th Century extremely strong but flexible **Damascus sword** was prepared by using **CNTs and iron carbide (Fe_3C) nanowire**. These were extraordinarily strong enough to bend from hill to tip.

Ref. book: An Introduction to Nanomaterials and Nanoscience by A. K. Das & M. Das, C.B.S. Publishers & Distributers Pvt. Ltd., 2017

- **Michael Faraday** (1857) ⟶ explained the **colour of origin of glass windows** from the **presence of metal nanoparticles**. He prepared the red coloured gold nanoparticles (preserved in the Royal Institution, London).
- **J.C. Maxwell** (1867) ⟶ proposed the concept of a tiny called 'Maxwell's Demon'.
- **G. Mie** (1908) ⟶ explained the **variation of colour glasses with the size** of the metal particles dispersed in the glasses.
- **R.A. Zsigmondy** (first decade of the 20th century) ⟶ studied on the **optical properties of gold** and other nanoparticles and won the 1926 Nobel Prize in Chemistry for his work.
- In 1959, American physicist **Richard Feynman** in a famous speech "***There's plenty of room at the bottom***," gave the idea about nanotechnology; envisioned the possibility and potentiality of nanotechnology.


Richard Feynman

- **Gordon E. Moore** (1965), the co-founder of Intel Corporation, made an amazing forecast: **the number of transistors on a chip of given area would double in every 1.5 yrs i.e. the dimension of a transistor size decreases by a factor 2 in every 1.5 yrs. His prediction indicated that today's transistors would lie in the nanoregime.**

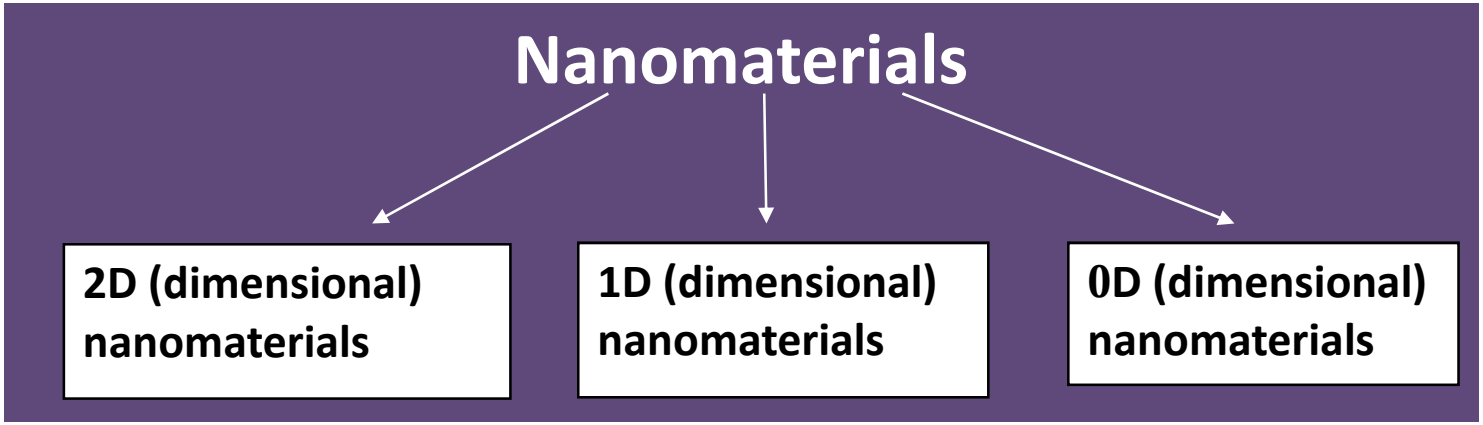
- 1974, Japanese engineering professor **Norio Taniguchi** had named this field "**nanotechnology.“**
- In 1980, **Dr. K. Eric Drexler** first published his groundbreaking book ***‘Engines of Creation: The Coming Era of Nanotechnology’***.
- In 1991, carbon nanotubes were discovered by another Japanese scientist, **Sumio Iijima**.
- **In** 2016 , Nobel Prize in Chemistry **: Jean-Pierre Sauvage, Sir J. Fraser Stoddart, and Bernard Feringa, for the novel idea of turning molecules into machines.**

Different Types of Nanomaterials:

- **Nanomaterials depending on the number of directions of quantum confinement (QC)*:**

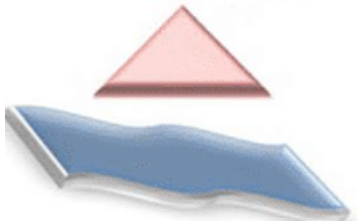
➢ **3D-bulk system** ⟶ all the three dimensions are in the macroscopic range

➢ **Nanomaterials** ⟶ at least one dimension is in the nanoregime (1-100nm) to introduce the quantum confinement effect.



➢ **2D (dimensional) nanomaterials** ⟶ QC occurs in one direction i.e. this direction remain in nanoregime (1-100 nm).

e.g. Ultrathin film, ultrathin layer etc.

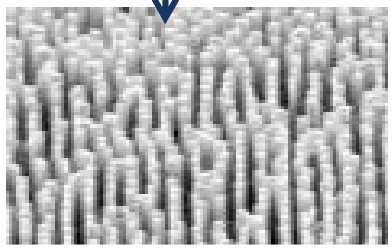
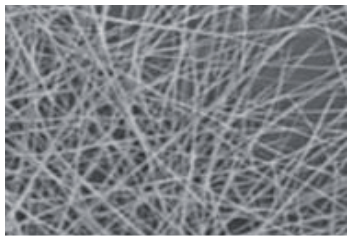


* Ref. book: An Introduction to Nanomaterials and Nanoscience by A. K. & M. Das, C.B.S. Publishers & Distributers Pvt. Ltd., 2017

Different Types of Nanomaterials:

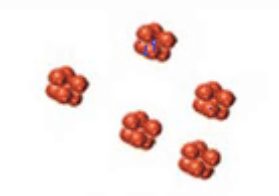
- **1D (dimensional) nanomaterials** ⟶ QC occurs in two direction i.e. these two directions remain in nanoregime (1-100 nm).

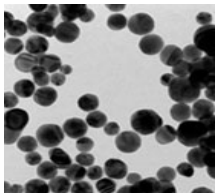
  e.g. nanotubes, nanorods, nanowires, etc.

- **0D (dimensional) nanomaterials** ⟶ QC occurs in all the three direction i.e. these three directions remain in nanoregime (1-100 nm).

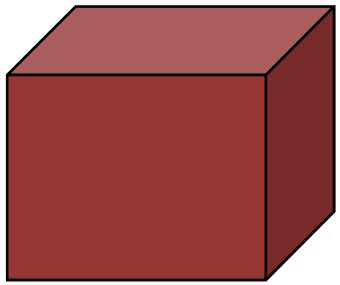
  e.g. quantum dot – nanoparticles, nanocubes etc.



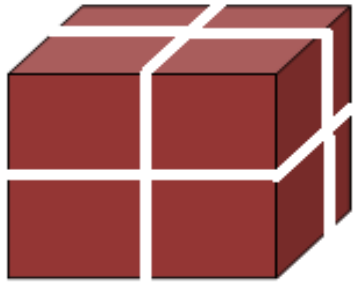


Some Reasons for special properties of nanoscale materials

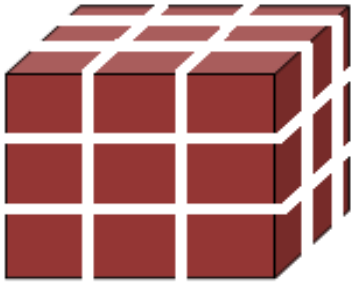
- **Increase of Surface area/Volume ratio**



Area = 6 x $1cm^2$ = 6 cm^2



Area= 6 x $(1/2cm)^2$ x 8 =12 cm^2



Area= 6 x $(1/3cm)^2$ x 27 =18 cm^2

→ Better catalytic efficiency

If a bulk material is subdivided into an ensemble of individual nanomaterials, the total volume rer the same, but the **collective surface area is greatly increased.** This is schematically shown in **Figure**

Some Reasons for special properties of nanoscale materials

- **Small size effect (Quantum size effect)**

✓ The particles are so small that **electrons are not free to move** about as in bulk gold. As the movement is restricted, **the particles react differently with light.** → **Tunable fluorescent emission**

✓ Electronic states are quite different from bulk. Discrete energy levels; Quantum confinement effect occurs, increases the energy gap between energy levels leading to metal to semiconductor to insulator transition.

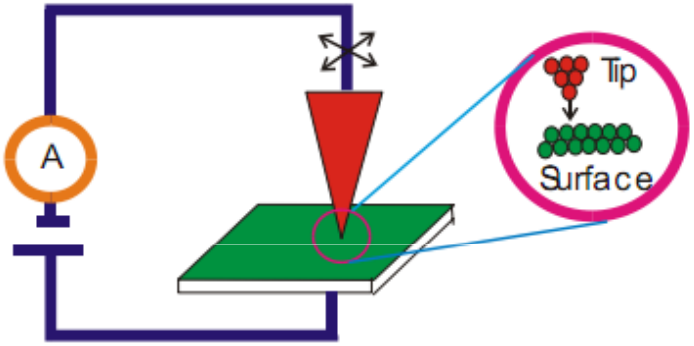
- **Decreased imperfections and defects**: reason for changing **electrical conductivity** than bulk matter. etc.
- This more structural perfection in the nanomaterials improves their mechanical properties (increases mechanical strength e.g. hardness, toughness etc.).
- **Increased paramagnetism and supermagnetism behaviour**

→ **Magnetic Property changes**

- **Due to smaller size, permeability through the biological membrane increases.** → **Biological Property**

How do we work on the nanoscale?

- Scientists have developed electron microscopes to "see" things on the nanoscale and also manipulate them.



➢ **Scanning Tunneling Microscope** (STM) : Works by sensing the Tunneling current between the sharp tip and the conducting surface when the tip is brought close to the surface.

➢ **Atomic Force Microscope** (AFMs)

➢ **Transmission Electron Microscope** (TEM)

➢ **Scanning Electron Microscope** (SEM)

Fabrication of Nanomaterials

Top down approach

e.g. Ball Milling technique, Lithography etc.

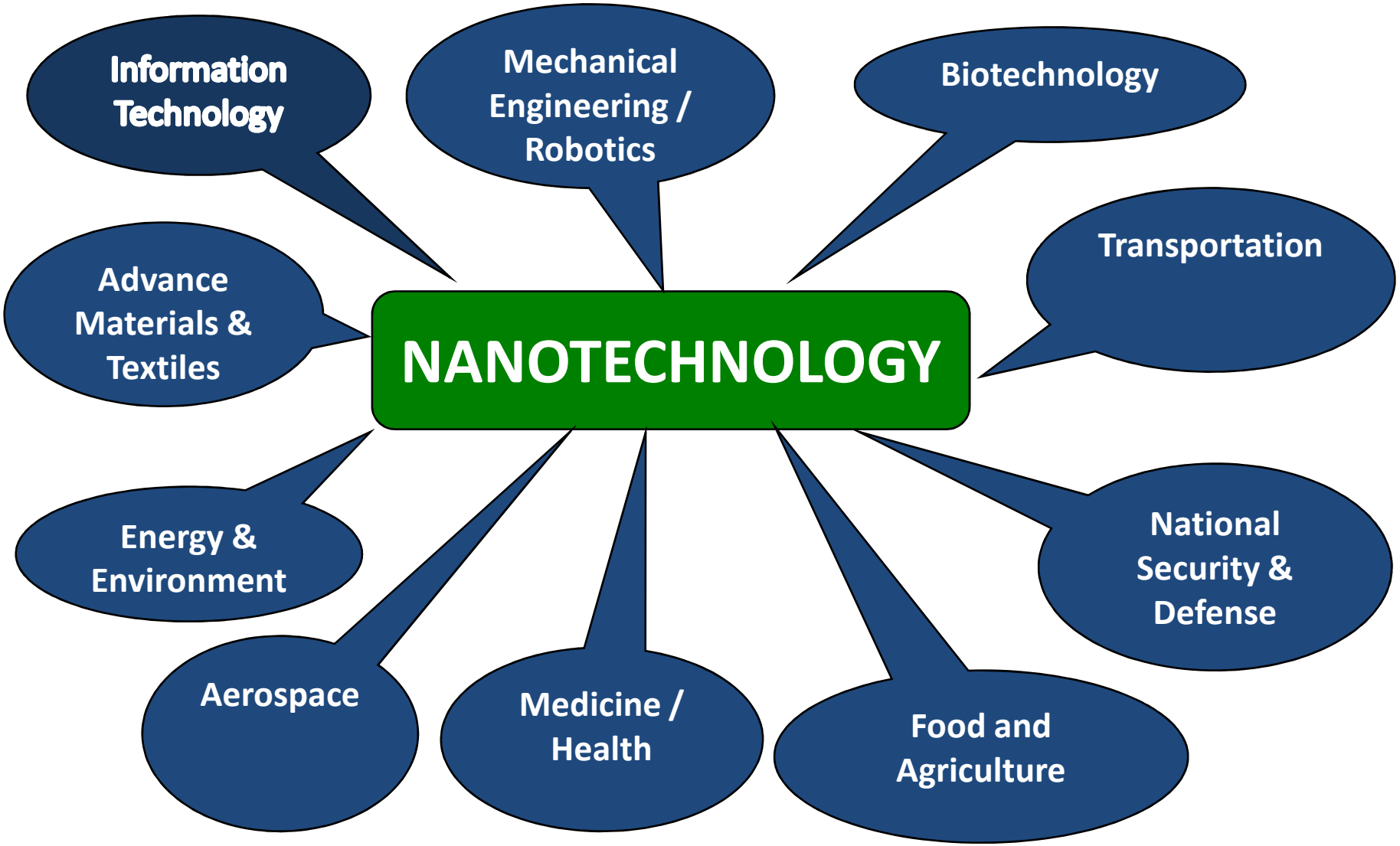
Cut into pieces in nanoscale

Bottom up approach

e.g. Sol-gel process, Chemical vapour deposition, Physical vapour deposition etc.

Assemble atoms to nanostructures

What can we use nanotechnology for?



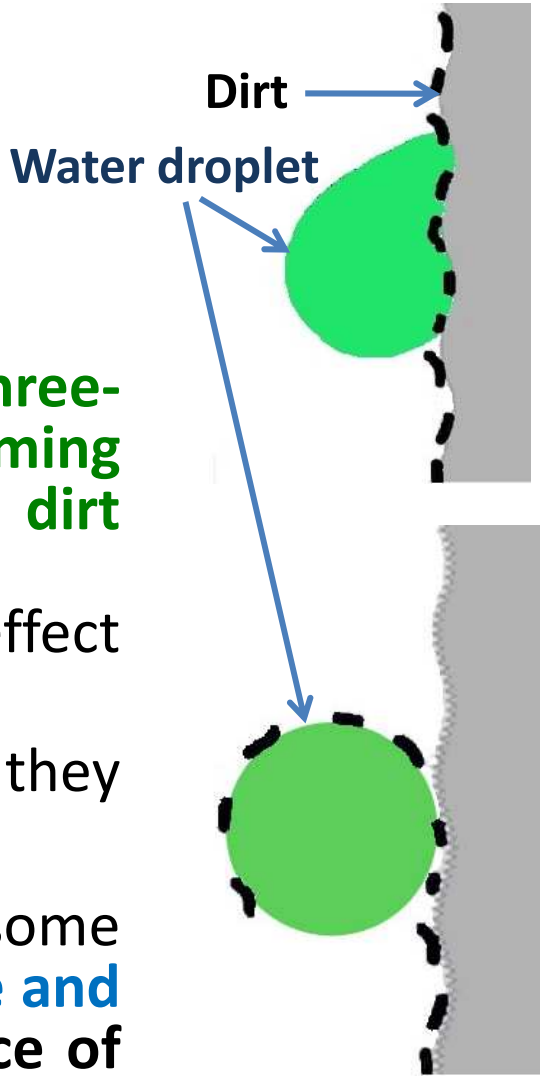
Nano-Textiles

Application in textiles	Nanomaterial used
▪Increase durability	Al_2O_3, SiO_2, Carbon nanotubes (CNT), ZnO
•Self-cleaning/ dirt and water repellent	CNT, Fluoro acrylate, SiO_2 , TiO_2
•Antibacterial	Ag, TiO_2, ZnO etc
•Wrinkle resistance	TiO_2, SiO_2
•Improved staining / reduce fade	Nanoporous hydrocarbon on Nitrogen coating
•UV protection	TiO_2, ZnO
•Fire proof	CNT, Boroxosiloxane, Montmorillonite (nano clay), Sb_3O_2
•Electro conductive and antistatic	Carbon black, CNT, Cu, Polypyrrole

Nano-Textiles

❖ Nano products :

- **Nano-Tex** (wrinkle-resistance, stain resistance),
- **Nanosphere** (water and soil resistant),
- **Nano-Pel** (Water-and-oil repellent finishing) etc.



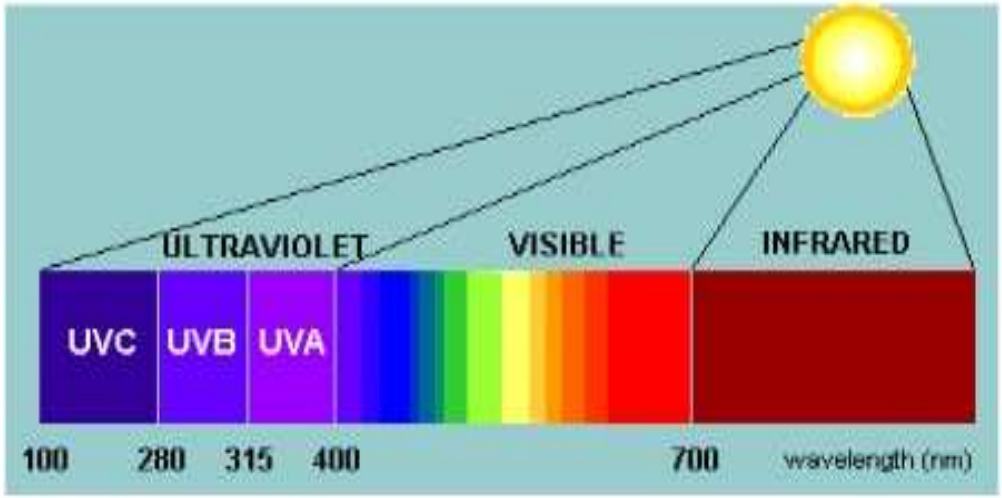
- **NanoSphere impregnation involves a three-dimensional surface structure with gel-forming additives which repel water and prevent dirt particles** from attaching themselves.
  The mechanism is similar to the lotus effect occurring in nature.
- The Nanowhiskers can repel stains because they **form a cushion of air around each fiber.**
- To overcome the limitations of using resin, some researchers employed **nano-titanium dioxide and nano-silica to improve the wrinkle resistance of cotton and silk respectively.**

Antimicrobial Fabric

- The silver nanoparticles are toxic to microbes, and so colonies will never form, and clothes using this material will not have odours.

Cosmetics

- Zinc oxide and titanium oxide are both employed as opaque sunblocks.



Sports materials

• **Polymer nanocomposites** barrier film **p**revents air loss from **Tennis balls** (**InMat**), so that tennis ball do not lose its bounce.

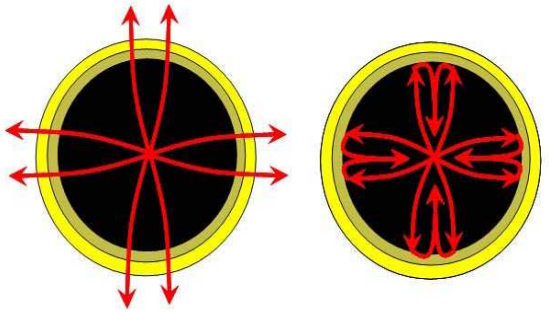
•**Tennis racquet** (**Wilson**) frames containing **silicon dioxide nanoparticles** - Increases **strength, stability** and power.

•**Resin containing buckyballs** (fullerenes) used to make **badminton raquets** (**Yonex**).

•**Bicycle** (**Eston Cycling**) parts made with **carbon nanotubes-** Increases stiffness without weight increase.

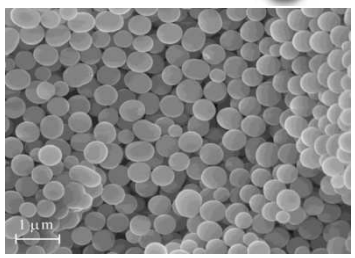
•**Fishing rods** (**St Croix Rods**) made with a **epoxy resin in silica nanoparticles-** Increased strength without weight increase.

•Jeremy Wariner used a new **shoe** designed using nanotechnology by **Adidas** (in the event men's 400m race) **in the 2008 Olympic Games.**



Ordinary tennis ball

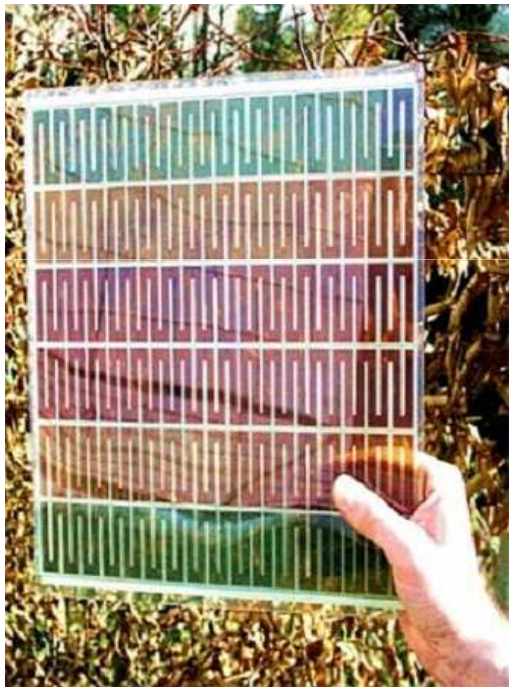
Tennis ball with nanocomposite gas barrier



Energy sector

- Fuel cell catalysis; hydrogen production photo-catalysis; solar cells; lithium ion battery etc.

- Newer solar panels now incorporate “nanocrystalline silicon”. **This increases conversion efficiency**.



- Other Examples: Titanium Dioxide Nanoparticles in Dye Solar Cells; Fullerene Derivates as Electron Acceptors in Polymer Solar Cells; Thin-Layer Solar Cells etc.

Nanomaterials for Aviation Industry

- **Properties of Materials required for Airframe Structure:**

Light Weight; High Strength; High Toughness; Corrosion Resistance; Easy Reparability & Reusability; Less Maintenance & Durability .

Nanomaterials can fulfill these requirements.

• Some **CNT based composites** which can be used for airframe structure are - CNT/Epoxy, CNT/Polyimide: **wide range of Young's Modulus, High Specific Strength and Thermal Performance.**

• **Nanoclays** reinforced Polymer Composites: **Barrier Properties, Thermal and Flame Retardent**

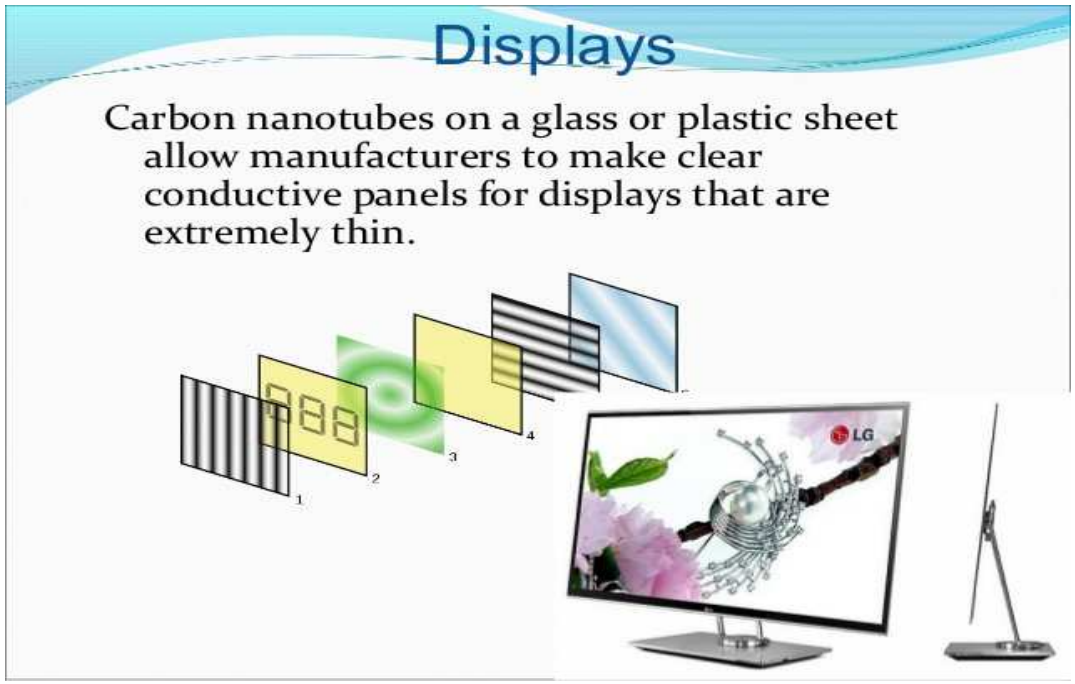
• **Metal Nps** incorporated Composites: **extraordinary electrostatic discharge and electromagnetic interference (EMI) shielding properties**

• **SiC Nanoparticles** in alumina Yittria stablized nanozirconia: **crack healing, resulting in improved high-temperature, strength and creep resistance.**

Nanotechnology in Electronics

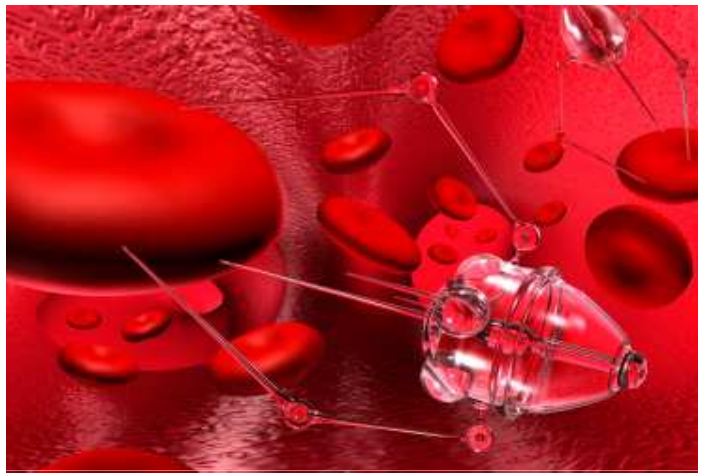
Advantages of Using Nanotechnology in Electronics:

- **Reducing the size of transistors** used in integrated circuits & increasing the density of memory chips
- **Decreasing the weight and thickness** of the **screens**
- **Improving display screens** on electronics devices.
- **Reducing power consumption**.



Nano-medicine

- There are many possible medical uses of nanotechnology.
- **Nano-coatings** on hip and joint replacements to prevent rejection.



- **Nano-capsules of drugs** that will target cancer cells only i.e. nanotechnology may also be useful for developing ways to eradicate cancer cells without harming healthy, neighbouring cells.
- Detection and diagnosis, biomarking and imaging, MRI contrast agents, drug delivery, dental ceramics etc.
- **Plasters** and **bandages** can contain nanocrystals of **silver**, because it is toxic to bacteria.

Food and Agriculture

- **Nano-Pesticides, Nanosensors** for soil quality and for plant health monitoring
- **Food packaging** : Silicate nanoparticles in plastic packaging can provide a barrier to gases (oxygen) or moisture
- **UV-protection** : Zinc Oxide nanoparticles can block UV rays and provide anti-bacterial protection when added to plastic packaging
- **Protection from microorganism**: Nano-Ag (Silver nano refrigerator) etc.

Nano-cellulose food packaging

Environment

- **Pollution control and monitoring :**

✓ Ceria (CeO_2) nanocrystals doped with Au- nanoparticles can catalyze the oxidation of CO to CO_2 at a much lower temperature- this can be used in **automobiles to reduced air pollution.**

✓ TiO_2 nanoparticle-based photocatalytic degradation of air pollutants in self-cleaning systems

✓ Nanocatalysts for more efficient, and better-controlled **catalytic converters**

✓ Nanosensors for detection of toxic materials and leaks

Gas separation nanodevices.

Water treatment and remediation:

- **Nanosensors** for the **detection of contaminants** and pathogens;

  Nanoporous zeolites, nanoporous polymers, and attapulgite clays for water purification;

  Magnetic nanoparticles for water treatment and remediation;

  TiO_2 nanoparticles for the **catalytic degradation** of water pollutants.

  Nanomembranes for **water purification**, desalination, and detoxification.

Nanotechnology spans other Areas

- **Industrial**:
- Scratch-Resistant and Dirt-Resistant **Paints**; optical engineering, Nanoparticle Fillers for **Tyres** (enhance tyre performance and durability), catalysis, fabrication of **cutting tools and hard tip** etc.
- Samsung says that "Samsung WM1245A Washing Machine releases over 400 billion silver ions which penetrate deeply into fabrics of any kind and create a coat of sterilizing protection for a maximum of 99.99% disinfection and an added antibacterial effect of up to 30 days after washing".
- **Defence and security**: Highly sensitive sensors, smart materials etc.
- And many more……

FEAR

- Nuclear and atomic bombs can have different dimensions
- Cloning and miniaturization
- Nano medicine- worrying factor! Needed more Research……

- Acknowledgement: The material has been developed with the help of different text books, journal material and web help. For details contact through author mail (gorai_soma@rediffmail.com)