Nanomaterials

NANOMATERIALS

- 1 nm = 10^{-9} m
  = length of 10 H or 5 Si aligned in a line
- Dimensions of nanomaterials lie in b/w bulk material & atoms/molecules
- Upto μm bulk properties are observed
  Quantum effects are seen for dimensions of atoms/molecules

- Properties of nanomaterials are different from bulk materials
  - Au - bulk ⇒ Yellow
    Au - nano ⇒ Red
  - Al - bulk ⇒ Stable
    Al - nano ⇒ Combustile (used as rocket fuel)
  - Melting Point is lower for any material at nano range

- Classification of Nanomaterials
  - 0 D Nanomaterials
    - Materials with all dimensions within nanorange where no dimension is allowed outside of nanorange.

    ex: Quantum Dots, Nanoclusters
  - 1D Nanomaterials
    - Materials with 1 dimensions out of nanorange

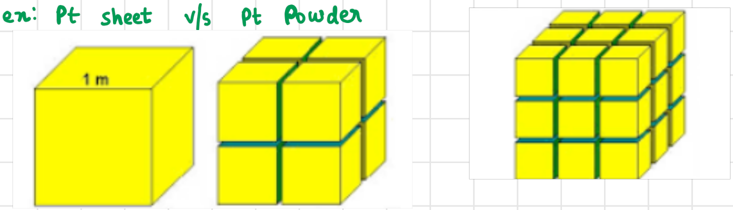
    ex: nanotubes, nanowires
  - 2D Nanomaterials
    - Materials with 2 dimensions out of nanorange

    ex: Nanofilms, Nanocoatings
  - 3D Nanomaterials
    - Materials with all dimensions out of nanorange

    ex: Dispersions of nanoparticles, bundles of nanowires

- Reasons why properties of nanomaterials & bulk materials are different
  - <u>Large fraction of surface atoms / unit volume</u> :
    - Properties are dictated by surface atoms rather than bulk atoms

ex: Pt sheet v/s Pt Powder

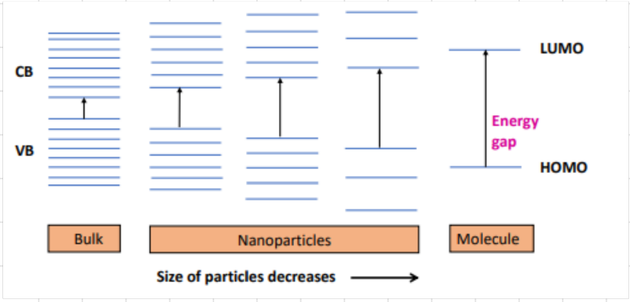


- <u>Large Surface Energy</u>
  - Surface atoms are held with less force compared to bulk
  - High Surface activity

Ex: Al

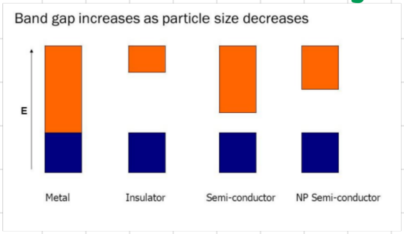
- <u>Spatial / Quantum confinement</u>
  - <u>3D</u>
    - All carriers act as free carriers in all 3 direction
  - <u>2D</u>
    - Carriers act as free carriers in a plane (First observed in Semiconductors)
  - <u>1D</u>
    - Carriers act as free carriers in direction of wire
  - <u>0D</u>
    - Carriers confined in all 3 directions.

  - 1 mole = 10^{23} atoms ; Nanomaterials = 10–1000 atoms



- <u>Reduced Imperfections</u>
  - Bulk material – metal lattice imperfections (dislocations, kink etc.,)
  - Nanomaterial – small lattice ⇒ less imperfections

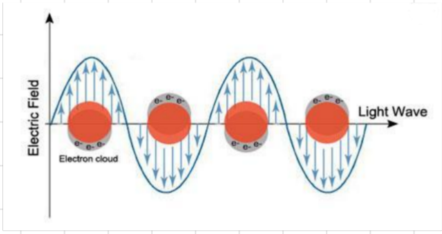
- Properties of Nanomaterials
  - Bulk materials - Altered only by structure & composition
    Nano materials - Altered even on change of size
  - Surface area dependant properties
    - Surface area increases on moving from bulk to nano scale
    - Nanomaterials have significant proportion of atoms at surface
    - Catalytic activity, gas adsorption etc., depend on surface area
      ex: Bulk Gold as catalyst X
      Nano Gold as catalyst ✓
    - Chemical Reactivity ∝ Surface Energy
- Electrical Properties
  - Electrical Conductivity of Bulk materials > Nanomaterials
  - Due to spatial confinement
    - Electric bands in bulk material are continuous
    - In nanomaterials, Electronic bands are discrete & band gap increases
    - Conductors as bulk may become semiconductor/insulator in nano.



  - Due to Surface Scattering
    - Electrical Conductivity ∝ $\frac{1}{\text{Surface Scattering}}$
    - e^- have mean free path
      If nanomaterial is smaller than mean free path of e^-, elastic/inelastic scattering may happen
    - Elastic scattering has no affect on conductivity
      Inelastic scattering causes e^- to lose velocity & electrical conductivity decreases

- ## Optical Properties

- Nano materials show unique optical properties
- Color depends on size of particle
  - **Due to Surface Plasmon Resonance**
    - Metals have +ve lattice points surrounded by sea of e^-
    - When radiation falls, surface e^- are polarized which oscillate with a frequency
      These collective oscillations are called Plasmons
    - When Plasmon frequency matches with frequency of radiation, Resonance occurs & radiation is absorbed & material looks coloured
    - Plasmon frequency depends on :
      - Size
      - Shape
      - Nature of metal



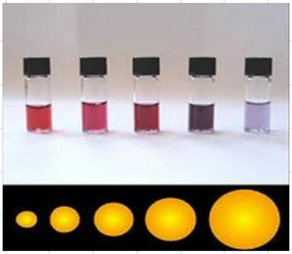
  - **Due to Increase in energy gap**
    - Increase in energy gap b/w valence band & conduction band
    - As size of nanomaterial ↓ , Energy gap ↑
      and wavelength of light moves towards smaller values (Blue Shift)

ex: Colloidal suspension of gold nanoparticles :

Gold spheres $> 50nm \Rightarrow \lambda = 575nm$

$10-20nm \Rightarrow \lambda = 524 nm$

$2-5 nm \Rightarrow \lambda = 517 nm$



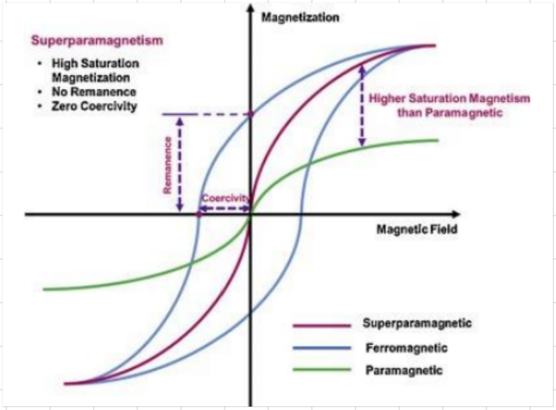
- Mechanical Properties
  - Strength of nanomaterials greater than bulk materials
    - Nanomaterials have 1 (or) 2 orders of magnitude of strength higher than bulk materials

  ex: Cu can be bent easily
  Cu particles < 50 nm considered as super hard materials (Don't show same malleability & ductility)
    - This is because of reduced probability of dislocation, kinks & vacancies

- Thermal Properties
  - Low MP & phase transition temperature due to large fraction of surface atoms which are bound by lesser no. of bonds compared to bulk.
  - No. of bonds to be broken in nanomaterials during melting is less than that of bulk materials
  - Size of particles is smaller than path length of photons arising due to lattice vibrations (Photon Scattering) which decreases thermal conductivity

- Magnetic Properties
  - For Ferromagnetic materials Fe, Co, Ni, Their ferromagnetism changes to super paramagnetism in nanometer scale because of high surface energy
  - In presence of magnetic field, they get magnetized with high susceptibilities
  - Bulk Au & Pt → Non-magnetic

    Nano Au & Pt → Magnetic



Applications of Nanomaterials

Medicine

→ Enhance Targeted delivery of drug

→ Injectible nanobots acting as detectors & informers

→ Antibacterial activity - Ag Nanoparticles

Energy Storage

→ High surface area thus act as electrodes in fuel cells

Cosmetics

ZnO & TiO_2 in Sunblocks

Catalysis

→ Au, Ag Nanoparticles are good catalysts

→ Oxygen reduction r/n catalysts for fuel cells & metal air batteries

→ CO oxidation catalyst

Environment

→ Elimination of pollution using catalytic converters

→ Water purification by Carbon nanotubes

Consumer Electronics

→ Nano phosphors for good resolution in HDTV

→ Nanophosphors in white LED