INTRODUCTION TO NANOMATERIALS

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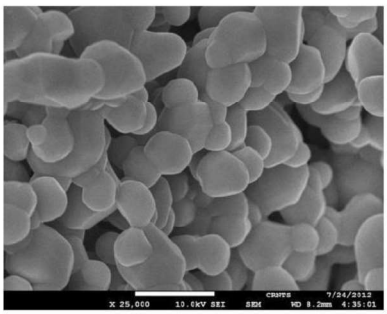
Physical Properties of nanomaterials

- Nano-sized materials exhibit some remarkable properties that may be different from the physical properties of bulk materials.
- Some are known but a lot more to be discovered
- The origin of these unique properties may be attributed to
  - Large fraction of surface atoms
  - Large surface energy
  - Quantum confinement
  - Reduced imperfections



- Mechanical
- Electrical
- Optical
- Thermal
- Magnetic

Types of Physical properties :

– Optical (e.g. color, transparency)

– Electrical (e.g. conductivity)

– Mechanical (e.g. hardness, melting point)

– Magnetic (e.g. Super Paramagnetism)

Optical properties in Nanomaterials

➢Nanomaterials have attracted much interest due to their novel optical properties, which differ remarkably from bulk crystals.

➢Applications based on optical properties of nanomaterials include optical detector, sensor, imaging, display, solar cell, photocatalysis, photoelectrochemistry and biomedicine.

➢ The optical properties of nanomaterials depend on parameters such as size, shape, surface characteristics, and other variables including doping and interaction with the surrounding environment.

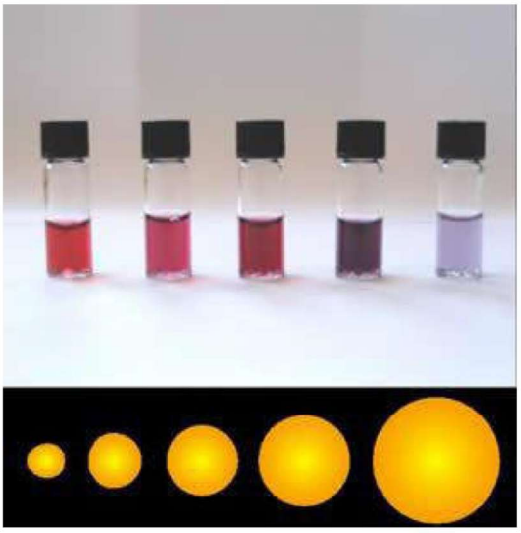
➢ Shape can have dramatic influence on optical properties of metal nanostructures.

✓Bulk Gold appears Yellow in color.

✓Nanosized Gold appears Red in color.

✓The particles are so small that electrons are not free to move about as in bulk gold.

✓Because this movement is restricted, the particles react differently with light.

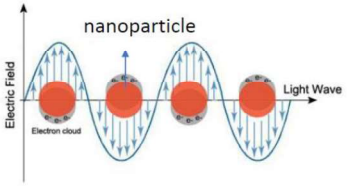


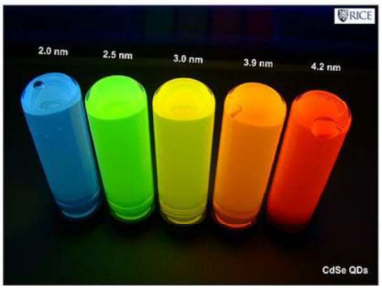
Optical properties of nanomaterials can be significantly different from bulk crystals. E.g. The optical absorption peak of a semiconductor nanoparticle shifts to short wavelength, due to an increased band gap. The colour of metallic nanoparticles may change with their sizes due to surface plasmon resonance.

Bulk gold	small particle of gold
shine as a metal;	no metallic, don't shine
Chemically not reactive (make jewel)	Reactive

Optical Property

- Optical properties of nanomaterials can be significantly different from bulk crystals. E.g. The optical absorption peak of a semiconductor nanoparticle shifts to short wavelength, due to an increased band gap.
- The wavelength of light absorbed increases as a function of increasing nanoparticle size.
- The colour of metallic nanoparticles may change with their sizes due to **surface plasmon resonance.** Eg. Bulk gold appears yellow while gold nanoparticles appear red below 20nm.
- **Incident light frequency is absorbed based on plasmon resonance frequency which in turn depends on particle size.**





Emission colors of CdSe nanoparticles of different sizes. Smaller particles emit blue light because the exciton energy increases as the size decreases

Electrical Properties

The properties like conductivity or resistivity are come under category of electrical properties. These properties are observed to change at nanoscale level like optical properties.

✓The electronic structure of Nano materials is different from its bulk material.

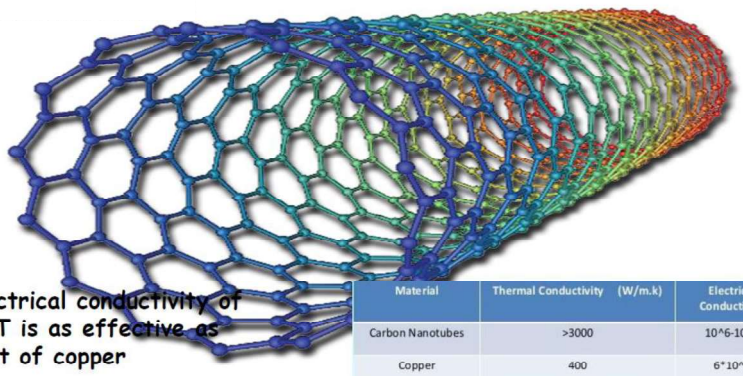
✓The density of the energy states in the conduction band changes.

✓When the energy spacing between two energy levels is more than K_BT , **energy gap is created.**

✓Nano clusters of different sizes will have different electronic structures and different energy level separations.

✓The Ionization potential at Nano sizes are higher than that for the bulk materials.

Electrical conductivity decreases with a reduced dimension due to increased surface scattering. However, electrical conductivity of nanomaterials could also be enhanced appreciably, due to the better ordering in microstructure



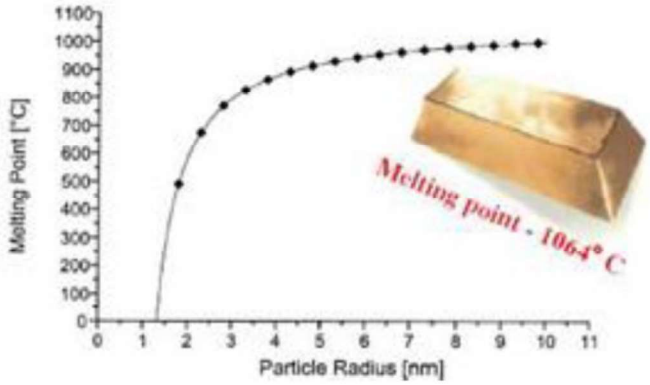
Electrical conductivity of CNT is as effective as that of copper

Very high current carrying capacity

Material	Thermal Conductivity (W/m.k)	Electrical Conductivity
Carbon Nanotubes	>3000	10^6-10^7
Copper	400	6*10^7
Carbon Fiber – Pitch	1000	2-8.5*10^6
Carbon Fiber – PAN	8-105	6.5-14*10^6

Thermal properties

Nanomaterials may have a significantly lower melting point or phase transition temperature and appreciably reduced lattice constants, due to a huge fraction of surface atoms in the total amount of atoms



Mechanical Properties

Mechanical properties of nanomaterials are one or two orders of magnitude higher than that of single crystals in the bulk form. The enhancement in mechanical strength is simply due to the reduced probability of imperfection .

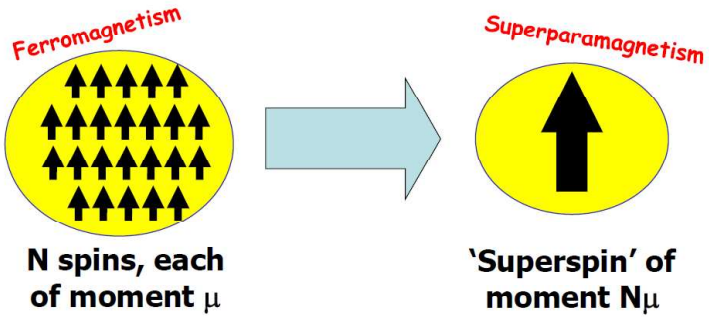
Magnetic Properties

✓Nano-structured materials are distinctly different from that of bulk materials.
✓Ferromagnetism disappears and transfers to super-paramagnetism in the nanometer scale due to the huge surface energy.
✓Surface atoms are not only different to bulk atoms, but they can also be modified by interaction with other chemical species .
✓The Magnetic Moment of Nano particles is found to be very less when compared them with its bulk size.
✓It should be possible that non-ferromagnetic bulk materials exhibit ferromagnetic-like behavior when prepared in nano range.

Changes in properties

Magnetic properties

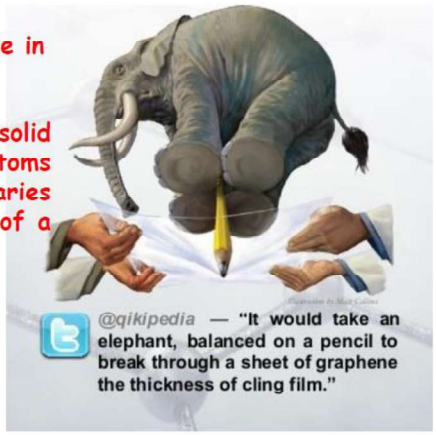
Magnetic properties of nanostructured materials are distinctively different from that of bulk materials. Ferromagnetism of bulk materials disappears and transfers to superparamagnetism in the nanometer scale due to the huge surface energy.



Mechanical properties of nanomaterials may reach the theoretical strength, which are **one or two** orders of magnitude **higher than** that of single crystals in the bulk form. The enhancement in mechanical strength is due to the **reduced probability of defects**.

Grain boundaries play a significant role in the materials properties

As the grain size d of the solid decreases, the proportion of atoms located at or near grain boundaries relative to those within the interior of a crystalline grain, scales as 1/d.



Examples of Size effect

	Property	Influence of size reduction on Property
Due to Surface to Volume Ratio	Structural	Decrease or Increase of Lattice parameters, Structure Transformation
	Mechanical	Enhancement of hardness, strength, ductility Increase in wear resistance
	Thermal	Decrease of melting point and Phase transition temp.
Due to Quantum Confinement	Electronic	Increase in band gap
	Optical	Increase of absorption in UV range Nonlinear optical properties