Day 5

NANOTECHNOLOGY

- sciene, engg, and applica^n of materials & devices at nanometer scale - (1 to 100 nanometers) ($1nm = 10^{-9}m$)

- manipulating atoms & molecules - create new materials with unique physical, chem, and biological props.

KEY POINTS : Scale : Atomic / molecular level.

Goal : Design / control structures, for specific func^n

Properties : May have higher strength, lighter wt., better conductivity, novel optical behaviour compared to bulk material.

WHY NANOSCALE

1 nm (Nanometer) = 10^{-9} m (1 thousand millionth) of m.

Interest : At nanoscale, materials have physical and chemical properties that differ significantly from their larger-scale counterparts.

Examples : • water molecule : 0.1 nm
- Gold particle : 10 nm
- Virus : 100 nm to 1 μm
- Hair : 100 μm
- RBC's : 5-10 μm
- Fullstop (dot) : 1 mm
- Watermelon : 10 cm
- Benzene : 0.5 nm
- Carbon nanotubes : 5 nm (diameter)

Nanomaterial - Nano Powder

- Fine powdered material → nanometer scale (< 100 nm)
- Key properties: High surface area to vol^m ratio:
  Responsible for special properties not found in bulk material
- Advantages / special properties:
  → Enhanced reactivity
  → Improved mechanical strength
  → Unique optical, magnetic & Electrical behavior
  → Better sintering for ceramics & metals

What is nanomaterial

↳ at small scale → materials have fundamentally different properties than at the bulk due to increased surface area to volume ratio.

→ Increased interaction & reactivity
→ Nanoscale effects (less material needed)
→ Diff properties at nanoscale

Characteristics [Most of them are novel, why?]

novel materials: new forms of existing materials with the characteristics that differ significantly from familiar naturally occurring forms.

Nanomaterials can have, one, two or three dimensions in the nanoscale:

Classification of Nanomaterials by Dimentions

→ 0 Dimensional → nanospheres, clusters → fullerenes, gold nanoparticle etc

→ 1 Dimensional → nanotubes, wires, rod → Carbon/Gold nanotubes etc

→ 2 Dimensional → Thin films, plates, layered → carbon coated nanoplate, etc graphene sheet

→ 3 Dimensional — Bulk NMs, polycrystals → Liposome, Polycrystaline etc.

0-D Nanomaterials : nanoscale rang (1-100 nm)

e.g. - gold nanoparticle (Au NPs)

• properties - no dimension exceeds nanoscal essentially nano particle

- Quantum dots (CdSe, PbS)

- Fullerenes (C_{60})

1-D Nanomaterials : 2 dimension in nanoscale, 3rd dimen^{n} much larger

E.g. - Carbon nano Tube (CNT)

• properties: High ascpect ration nano wires, nano tubes.

- Zinc oxidize nanowire (ZnOWs)

- Silver nanorods.

2-D Nanomaterial - 1 dimention in nanoscale, two dimension much larger.

E.g. - Graphene

• properties - sheet like, large S.A., unique Electric properties

- Molybdenum disulphide (MoS_2) nanosheets

- Hexagonal boron nitride (h-BN) sheets

3-D Nanomaterial - Extend in all 3 dimensions, but composed of nanoscale building blocks,

properties: Bulk materials with nano crystallin. structure of nano composites

e.g. → Nanocrystallin metals

- Nano composits (polymer matrix with nanosilica)

- Nanoporous materials

TYPES OF NANOMATERIALS

→ Most current nanomaterials could be organized in 4 types
- → Carbon Based Materials
- → Metal Based Materials
- → Dendrimers
- → composites

Types of Nanomaterials

→ Earlier known natural Carbon allotrops : Diamond, Graphite

→ Carbon based nanomaterials : Composed of carbon atoms
→ Classification: Based on Geometrical structure.

• Carbon nanostructures: Particles can be
- → Tube shaped
- → Horn-shaped
- → spherical
- → ellipsoidal

e.g.
- Graphite
- Amorphous Carbon
- Diamond
- fullerene
- Carbon Nanotubes
- Graphene

Applications :
- micro & nano electronics
- gas storage,
- pdtion of conductive plastic
- composites, displays, antifouling paints
- textiles, batteries with improved durability
- gas biosensors & others

* Fullerenes

– Allotropic form of Carbon (molecular form, carbon molecules)

→ Family : Atomic C_n clusters ($n > 20$) on spherical surface

→ Carbon atoms at vertices of pentagons & hexagons ; sp^2 hybrid, covalent bonds.

– C_{60} : Most common, 60 atom, 20 hexagon + 12 pentagon
diameter ≈ 0.7nm

→ Discovery Nobel Prize (1996) : R.F. Curl Jr. H.W. Kroto, RE Smalley.

Carbon Nanotubes (CNTs)

- C-allotrops with exceptional technical propeorties
- cylindrical, nm-scale diameter, made of rolled graphene sheets
- vary in length, diameter, chirality, and layers
- Types: SWCNTs (singlel walled)
  MWCNTs (multiple-walled)
- Discovered 1991 by Sumio Iijima (no nobel prize)

- SWCNTs: Dia 1-3 nm, length few μm
- MWCNTs: Dia 5-40 nm, length ~ 10 μm
- propeorties: High rigidity, strength, elasticity thermal & electrical conductivity

CNTs (Chirality & TYPES)

- SWCNTs based on chirality:
  a. Arm chair - Electrical conductivity > copper
  b. Zigzag - semiconductive
  c. Chiral - Semi-conductive
- MWCNTs: Multiple layers, variable chirality, excellent mechanical & electrical properties.

Graphene

- 2D allotrope of C, single atom-thick-layer.
- sp^2 hybd., σ & π bonds in hexagonal lattice.
- C-C-distance: 0.142 nm
- structural element of graphite, CNTs, fullerenes.

Properties: extremely high rigidity
high thermal stability

Applications • Electronics, • Energy storage • Composites • sensors • water filter • Biomedical

Nanomaterials Characteristics

- **1D N.M.** → layers, multilayers, thin films, platelets and surface coatings. They have been developed and used for decades, particular in the electronics industry.
- **2-D N.M.** → nanowires, nanofibres made from a variety of element other than Carbon, nanotubes and, as ubsd of this group, Carbon nanotube.
- **3-D N.M** → nano particles and include precipitates, colloids and quantum dots (tiny particles of semiconductor material) and nanocrystalline material

When Did Nano-Tech start ?

↳ Nanotech & Nanosci. aren't entirely new
↳ nanoscale polymers are made from decades
↳ Nano tech used in Computer Chips for 20+ years
↳ Recent advances in atom/molecule manipulation have accelerated nano technology

Nanotech Approaches

Bottom-up:
- Build structure atom by atom/ molecule-by-molecule
- Used to synthesize nano materials

Top-down:
- shapes larger materials into nanoscal forms using cutting, milling, etching
- Used mainly for patterning existing materials.

CNT SYNTHESIS : Bottom Up or Top-down?

- Both possible, but mostly done by bottom-up methods:
  - Arc discharge, laser ablation, chem vapour deposition (CVD)
  - Build CNTs atom by atom / molecule-by-molecule
- Top-down used for structuring, not for synthesis of CNTs.
- CNT synthesis ⇒ Bottom-up method

Top-down v/s Bottom-up approaches

- Top-down
  - └ start with large structures, brk down to nanoscale
  - └ Hierarchical, central command (lithography)
- Bottom-up
  - └ Build up from small units (atom/molecules)
  - └ collective, decentralized assembly

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Magnetism

- └ key property in nanotech. materials
- └ Used in various applications, often manipulated at the nanoscale.

Application of Nanotech

- └ Medicine : Diagnostic, drug delivery, tisso engg. cryonics.
- └ Info/communication : Memory storage, novel semiconductors & optoelectronics, quantum computers
- └ Heavy Industry : Aerospace, catalysis, construction, ~~sports~~ vehicle
- └ consumer goods : Foods, optics, textiles, cosmetics, sports
- └ Environment : soil remedition, sensing, air/water purification

Environmental applications

- └ carbon capture
- └ sensors
- └ Remediation
- └ Wastewater treatment
- └ Energy
- └ Drinking water purification

After this

Major forces acting in nature

gravity, electricity, and magnetism.

- Electric current & magnets can exert force on each other

1. Magnetic Levitation : Maglev Train
   - ↳ Electromagnetic Suspension (EMS)
   - ↳ Electrodynamic Suspension (EDS)
   - ↳ Magnetic repulsion
   - ↳ N-N or S-S . repulsion
   - ↳ No contact → No friction → high speed → smooth trave

→ All magnet have north & south pole

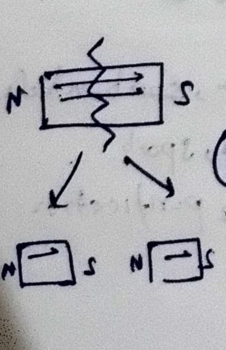
→ Like poles repel. Unlike poles attract

→ Compass needle → small bar magnet → freely rotate
   ↳ points N. → north seeking

→ Core of earth → giant magnet.

- Northern lights (aurora ~~lights~~ borealis) & southern lights (aurora australis) are result from the interaction b/w the solar wind and earth's magnetic field (makes the air glow)

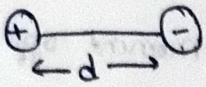
Magnetic Materials → Materials in which the domains will line up in order to form mag. field.
e.g. Iron, Cobalt, & nickel



(No monopole in magnets)

Magnetism → attrⁿ or repulⁿ by magnetic material.

Magnetic dipole – Any two opp poles seperated by a finite distance.



Origin of Magnetic Moment

1) orbital Motion – Orbital magnetic moment
2) spin Motion – spin magnetic moment

Magnetic Moment: $\mu_{eff} = \mu_{s.o} = 2\sqrt{s(s+1)} = \sqrt{n(n+2)}$ BM

$n \rightarrow$ no. of odd e^-.

if ther is a possibility from the orbital angular momentum

- $\mu = \sqrt{L(L+1) + 4s(s+1)}$
- if $L > 0$, its possible
- of orbital contribn like $3d^7$ of os
- Complexes of cobalt(II)

→ An atom is said to be magnetic if it carries a permanent dipole moment

→ Every substance is formed from an assembly of atoms which can be either non-magnetic or magnetic.

Magnetic materials classification

1. Diamagnetic Materials –
2. Paramagnetic Materials –
3. Ferromagnetic Materials –
4. Antiferromagnetic Materials
5. Ferrimagnetic Materials.

DIAMAGNETISM

- Non magnetic atoms (no permanent dipole moment)
- ORIGIN :
  - Random orbital orientations → net moment = 0
  - Electron motion around nucleus → magnetic moment.
  - External field → induced magnetic moment opp to applied field
- PROPERTIES :
  - Weak magnetization ; repel mag. field lines
  - Exist in magnetic-atom substances but masked by strong magnetism
  - Relative permeability < 1
  - Magnetic susceptibility independent of field strength
- SUSCEPTIBILITY :
  - Small & -ve → Temp. independent (organic, light elements)
  - Intermediate & -ve → < 20k varies (alkali earth, Bismuth)
  - Large & -ve → Below T_c (superconductors)

PARAMAGNETISM

- Magnetic atoms with permanent dipole moments.
- ORIGIN :
  - Electron → orbital + spin magnetic moments
  - No field → moments random (thermal motion) → no magnetization
  - Field applied → dipoles allign → induced +ve dipole moment.
- PROPERTIES :
  - small & +ve susceptibility ; independent of field
  - Random spin allignment w/o field
- SUSCEPTIBILITY :
  - small & +ve → Temp. independent (Alkali metals, transⁿ metals, rare earth)
  - Large & +ve → $\chi = \frac{C}{T}$ (Curie law)
    - $\chi = \frac{C}{(T-\theta)}$ (Curie-Weiss Law)

FERROMAGNETICSM

→ Strong magnetisation even w/o field (exchange coupling)
→ Field → strongly attracts magnetic lins
→ Characteristic T_c (curie temp) → below T_c spontaneou magnetiza" exist.
→ Spin allignmont : parallel
→ Exhibits hysterisis ; consist of domains
→ Susceptibility : very large & +ve → $\chi = \frac{C}{(T-\theta)}$
- $T > T_C$ → paramagnetic
- $T < T_C$ → ferromagnetic

→ Examples: Fe, Co, Ni, Gd.

ANTIFERROMAGNETISM

→ Weak magnetism; similar to paramagnetism
→ close atoms → antiparallel spin allignment
→ Susceptibility ↑ with temp till Neel temp (T_N), then decreases.
→ Spin allignmont : antiparallel
→ Susceptibility : small & +ve
- $\chi = \frac{C}{(T+\theta)}$ when $T > T_N$
- $\chi \propto T$ when $T < T_N$

→ Examples : salts of transition metals.

FERRIMAGNETISM

→ Special case of antiferro; antiparallel spins of unreal magnitude - ~~net mag~~
→ Possesses a net magnetic moment that dissapears above Curie Temp (T_c) → net magnetiza" ≠ 0
(analogous to Neel Temp. T_n)
→ Above T_a → thermal agitation randomizes spin → material become paramagnetic.
→ Spin alighment : antiparallel, diff magnitudes.
→ Ferrimagnetic domain can form magnetic bubbles for memory storage.
→ Susceptibility (χ) : very large & +ve
$$\chi = \frac{C}{(T \pm \theta)}, \text{ paramagnetic for } T > T_n$$

→ e.g. Ferrites

Magnetic Material Types

1. Ferromagnetism – parallel spins (↑↑↑), strong magnetization
2. Antiferromagnetism – antiparallel equal spins (↑↓↑↓), net M = 0
3. Ferrimagnetism – antiparallel unequal spins (↑↓↑), net M ≠ 0

Application of Magnetic Materials

- Soft Magnetic Materials – Enhance magnetic flux (B), used in crores of electromagnets, motors, transformers.
- Data Storage Materials – For magnetic recording.
- Permanent Magnets – For strong, stable magnetic fields.
- Power – High inductance x magnetic field product

HYSTERESIS LOOP

- soft magnets → narrow loop, low coercivity → electrical applican
- Hard magnets → wide loop, high coercivity → permanent magnets
- Square loop → memory storage (computer application).

SOFT MAGNETIC MATERIALS (TABLE HIGHLIGHTS)

- High permeability (μ), low coercivity, low resistivity.
- Examples:
  - Ingot iron: μ(max) = 5000, $H_c = 80$ A/m, $B_r = 2.14$ T
  - Silicon iron (3% Si): μ_r(max) = 50000, $H_C = 60$ A/m.
  - Permalloy (Fe–79% Ni): μ_r(max) = 1000000, $H_C = 4$ A/m

Magnetic Recording Materials

- key parameters: Particle length, aspect ratio, magnetization, coercivity, surface area, Curie temp.
- Example: $\gamma - Fe_2O_3 \rightarrow M = 0.44$ Wb/m², $H_c = 22\text{–}34.4$ A/m, $T_c \approx 600°C$

Hard / Permanent Magnet Materials

- High coercivity (H_c), high energy product $(BH)_{max}$.
- example:
  - Fe–Co steel: $H_c = 0.02$ T, $T_c = 887°C$
  - $Nd_2Fe_{14}B$: $(BH)_{max} = 210\text{–}445$ kJ/m³, $T_c = 312°C$
  - $SmCo_5$: $H_c = 0.91$ T, $T_c = 727°C$