

NANOPHYSICS

NANOPHYSICS

Nanophysics is the branch of physics that studies the behavior, properties, and phenomena of materials and structures at the nanoscale, typically between **1 and 100 nanometers (nm)**.

WHY STUDY NANOPHYSICS?

At the nanoscale, materials exhibit **unique physical, chemical, optical, and electrical properties that differ significantly from their bulk counterparts** due to:

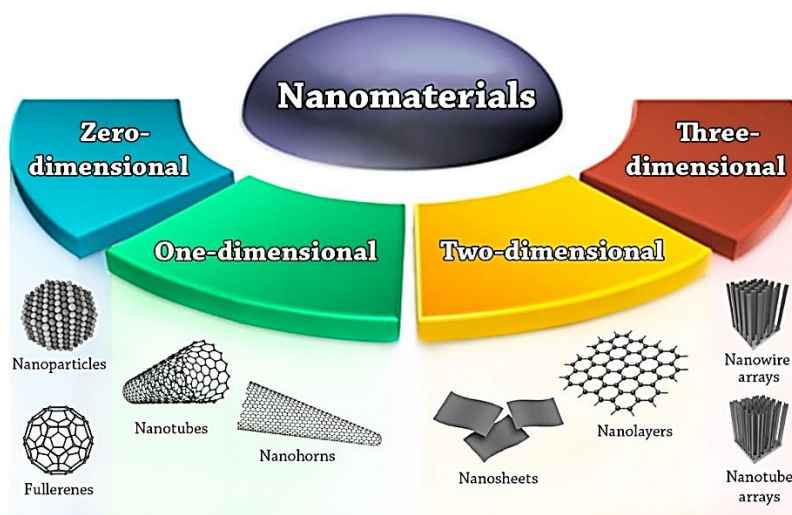
- **Quantum effects**
- **Large surface area to volume ratio**
- **Surface and interface effects**

KEY CONCEPTS IN NANOPHYSICS

- **Nanoscale:** Size range of 1–100 nm ($1\text{ nm} = 10^{-9}\text{ m}$).
- **Surface Area to Volume Ratio:** Nanoparticles have a very high ratio, making surface atoms more significant in determining properties.
- **Quantum Confinement:** When particles are very small, electrons and holes are confined, changing energy levels and optical/electrical properties.
- **Discrete Energy Levels:** Unlike bulk materials with continuous energy bands, nanoparticles have discrete energy states.
- **Surface Plasmon Resonance:** Collective oscillation of electrons at the nanoparticle surface interacting with light, leading to unique optical properties (e.g., colours in gold nanoparticles).

TYPES OF NANOMATERIALS

- **0D (Zero-dimensional): Quantum dots** (all dimensions in nanoscale).
- **1D (One-dimensional): Nanotubes, nanowires** (two dimensions in nanoscale, length much larger).
- **2D (Two-dimensional): Graphene sheets** (one dimension in nanoscale).
- **3D (Three-dimensional): Nanoparticles, nanoclusters** (all three dimensions in nanoscale).



IMPORTANT NANOMATERIALS

- **Quantum Dots:** Semiconductor particles that emit light when excited.
- **Carbon Nanotubes:** Cylindrical carbon structures with extraordinary strength and electrical conductivity.
- **Graphene:** Single layer of carbon atoms arranged in a hexagonal lattice, exceptional electrical, mechanical properties.
- **Fullerenes:** Spherical carbon molecules (buckyballs).

METHODS OF NANOPARTICLE SYNTHESIS

- **Top-down Approach:** Breaking down bulk materials into nanoscale particles (e.g., lithography, mechanical milling).
- **Bottom-up Approach:** Building materials atom by atom or molecule by molecule (e.g., chemical vapor deposition, self-assembly).

APPLICATIONS OF NANOPHYSICS

- **Medicine:** Targeted drug delivery, imaging, and diagnostics.
- **Electronics:** Smaller, faster semiconductors, quantum computing components.
- **Energy:** Efficient solar cells, batteries, and catalysts.
- **Environment:** Water purification, pollution control.
- **Materials Science:** Stronger, lighter materials.

INSTRUMENTS USED IN NANOPHYSICS

- **Scanning Tunneling Microscope (STM):** Images surfaces at atomic scale using tunneling current.
- **Atomic Force Microscope (AFM):** Measures surface forces and topography at nanoscale.
- **Transmission Electron Microscope (TEM):** High-resolution imaging of nanoparticles.

UNIQUE PROPERTIES AT NANOSCALE

Property	Effect at Nanoscale
Melting Point	Usually lowers compared to bulk
Electrical Conductivity	Can increase or decrease
Optical Properties	Change due to quantum confinement
Mechanical Strength	Often enhanced
Chemical Reactivity	Generally increases

CHALLENGES IN NANOPHYSICS

- Controlling particle size and shape precisely.
- Stability and aggregation of nanoparticles.
- Health and environmental risks of nanoparticles.