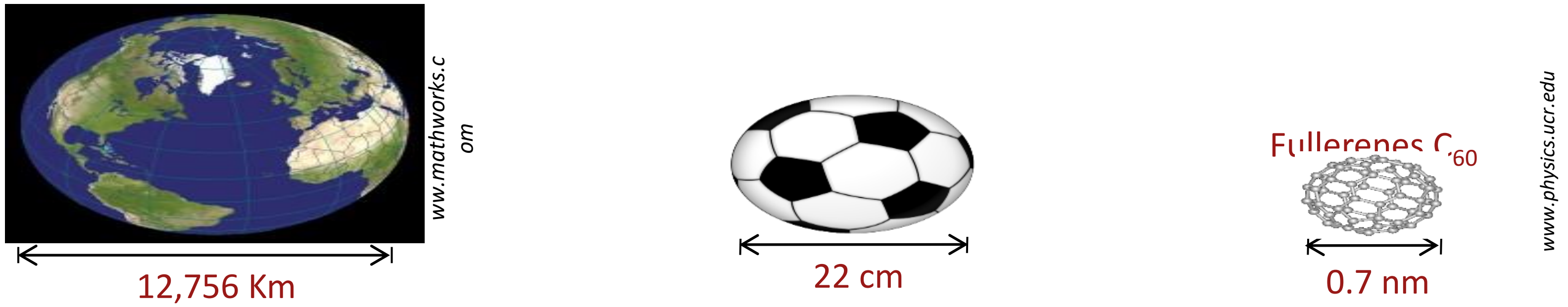
What Is Nanotechnology?

- **Ability to understand, create, and use structures, devices and systems that have fundamentally new properties and functions because of their 1 - 100 nanometer – nanoscale structure**

NANOSTRUCTURES

A material structure assembled from a layer or cluster of atoms with size between 1 - 100 nm



1.27 × 107 m **0.22 m** **0.7 × 10-9 m**

10 millions times smaller

1 billion times smaller

Classification of Nanomaterials

2-D structures (1-D confinement):

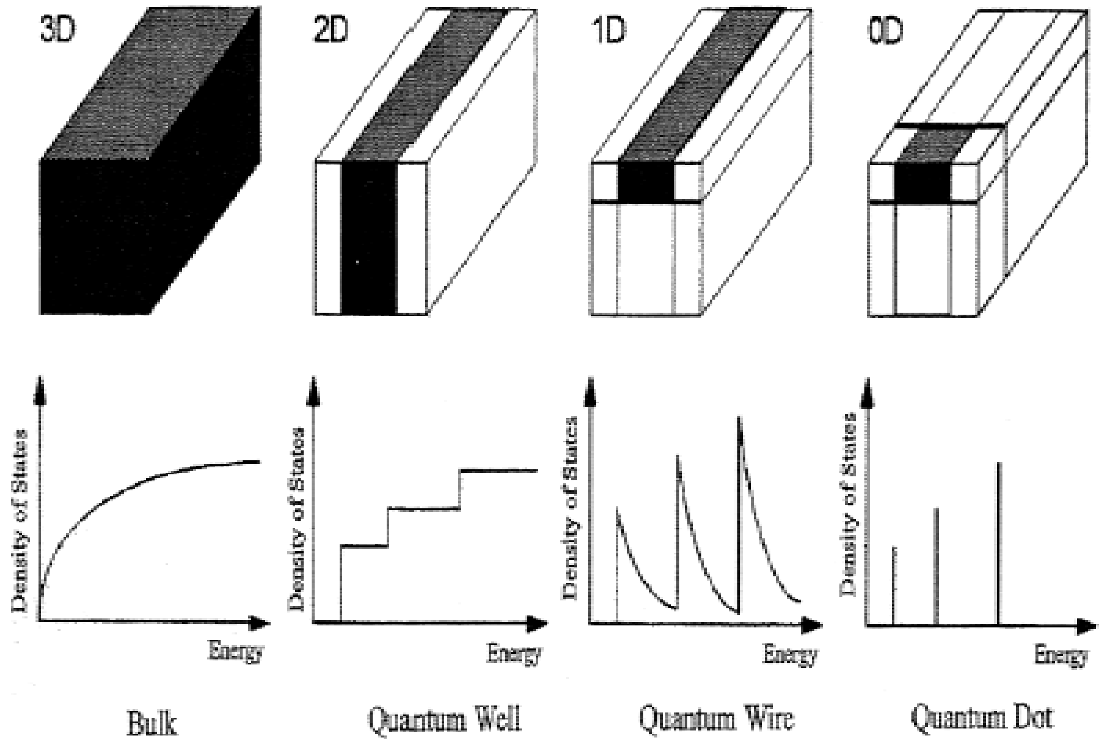
- Nano films.
- Planar quantum wells.
- Superlattices.

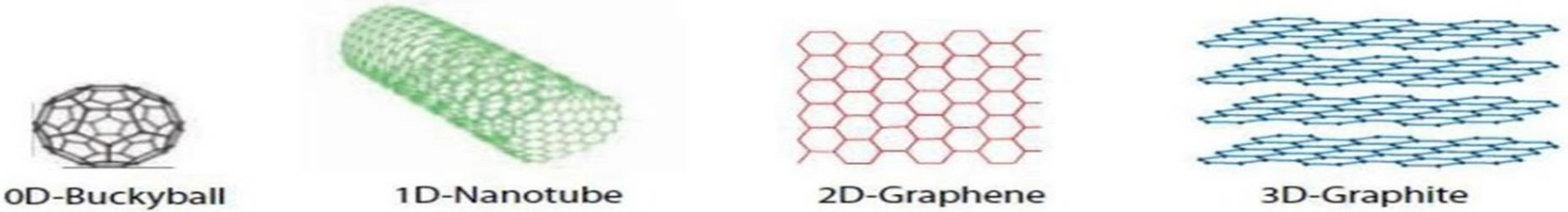
1-D structures (2-D confinement):

- Nanowires.
- Quantum wires.
- Nanorods.
- Nanotubes.

0-D structures (3-D confinement):

- Nanoparticles.
- Quantum dots.





Zero-dimensional nanomaterials

- ✓ These nanomaterials have all three dimensions (x, y, and z) within the nanoscale range or are not dimensional outside the Nano metric range (>10 nm).
- ✓ QDs, fullerenes, and nanoparticles are examples of 0D nanomaterials.
- ✓ They can be amorphous or crystalline, single crystalline or polycrystalline, exhibit various shapes and forms, and be metallic or ceramic

One-dimensional nanomaterials

- ✓ this class have two of their there dimensions (x, y) in the nanoscale range, but one dimension of the nanostructure is outside the non-metric range (>10 nm).
- ✓ such as nanofibers, nanotubes, nanohorns, nano rods, thin films, and nanowires,
- ✓ They can be amorphous or crystalline, single crystalline or polycrystalline, chemically pure or impure.
- ✓ 1D nanoparticles can be metallic, ceramic, or polymeric.

Two-dimensional nanomaterials

- **have plate-like shapes with two dimensions outside the nanometer range, but 1D (x) is at the nanoscale (between 1 and 100 nm).**
- **Coatings and thin-film multilayers, Nano sheets or nano walls, free particles, tubes, fibers, ultrafine-grained over layers, wires, and platelets.**
- **can be amorphous or crystalline, made of various chemical compositions, deposited on a substrate, or integrated into a surrounding matrix material, metallic, or polymeric**

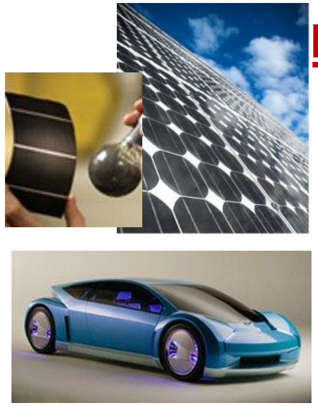
Three-dimensional nanomaterials

- **3D nanomaterials or bulk materials are nanomaterials that are not confined to the nanoscale in any dimension or dimension range.**
- **the bulk material is made up of individual blocks that are in the nanometer scale (1–100 nm)**
- **It includes nanoparticle dispersion, bundles of nanowires and nanotubes, and multi-nano layers in which the 0D, 1D, and 2D structural elements are in close contact and form interfaces.**
- **Thin films with atomic-scale porosity, colloids, and free nanoparticles with various morphologies**

Nanotechnology Applications

Information Technology

- Smaller, faster, more energy efficient and powerful computing and other IT-based systems



Energy

- More efficient and cost effective technologies for energy production
  - Solar cells
  - Fuel cells
  - Batteries
  - Bio fuels

Medicine

- Cancer treatment
- Bone treatment
- Drug delivery
- Appetite control
- Drug development
- Medical tools
- Diagnostic tests
- Imaging

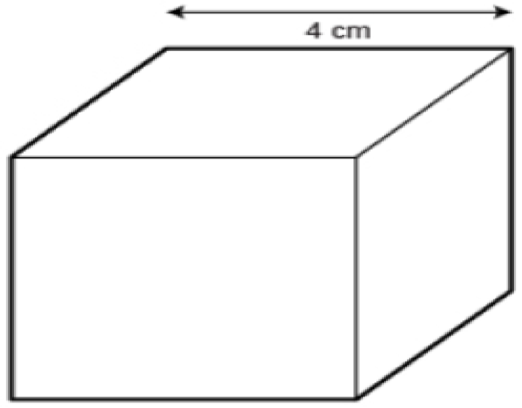
Consumer Goods

- Foods and beverages
  - Advanced packaging materials, sensors, and lab-on-chips for food quality testing
- Appliances and textiles
  - Stain proof, water proof and wrinkle free textiles
- Household and cosmetics
  - Self-cleaning and scratch free products, paints, and better cosmetics

Surface-to-Volume Ratio in nanoparticle

- Compared to the bulk counterparts, a large fraction of atoms is present on the surface which have less neighbors than bulk atoms. Specific surface area is given by
- Area is a function of a dimension squared, e.g. d^2, x^2 or r^2. Volume is a function of that dimension cubed, e.g. d^3, x^3 or r^3.
- Surface-to-volume (d^2 / d^3) scales as the inverse of the dimension: e.g. d^{-1}
- In other words, as the dimension approaches smaller and smaller limit, the surface-to volume ratio scales as the inverse of the dimension.

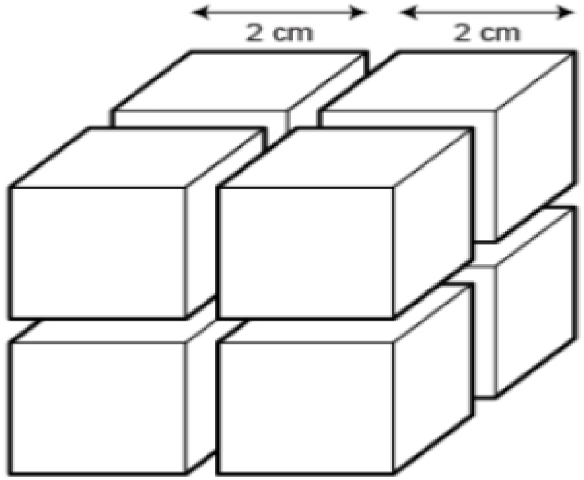
The cube on the left has the same volume as the smaller cubes added together on the right



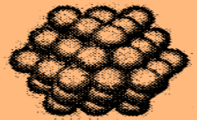
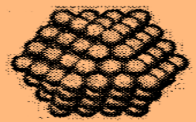
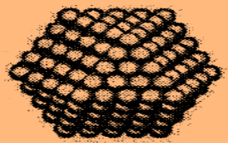
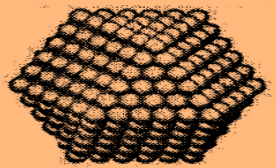
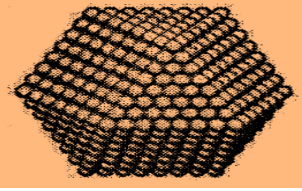
$$Surface\ area = 4 \times 4 \times 6 = 96\ cm^2$$

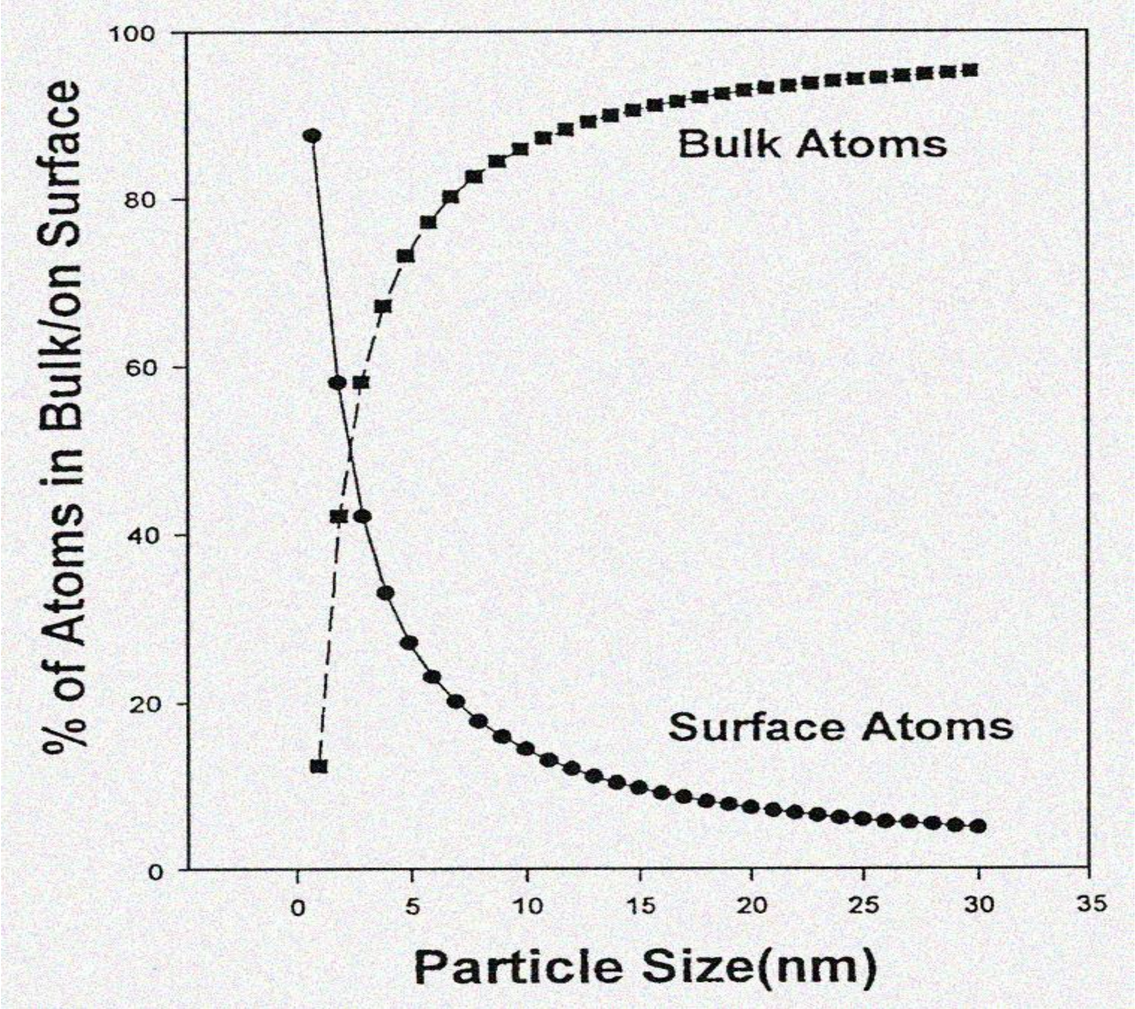
$$Surface\ area\ of\ one\ cube = (2 \times 2) \times 6\ \ faces = 24\ cm^2$$

$$Total\ Surface\ area = 24 \times 8 = \ 192 cm^2$$



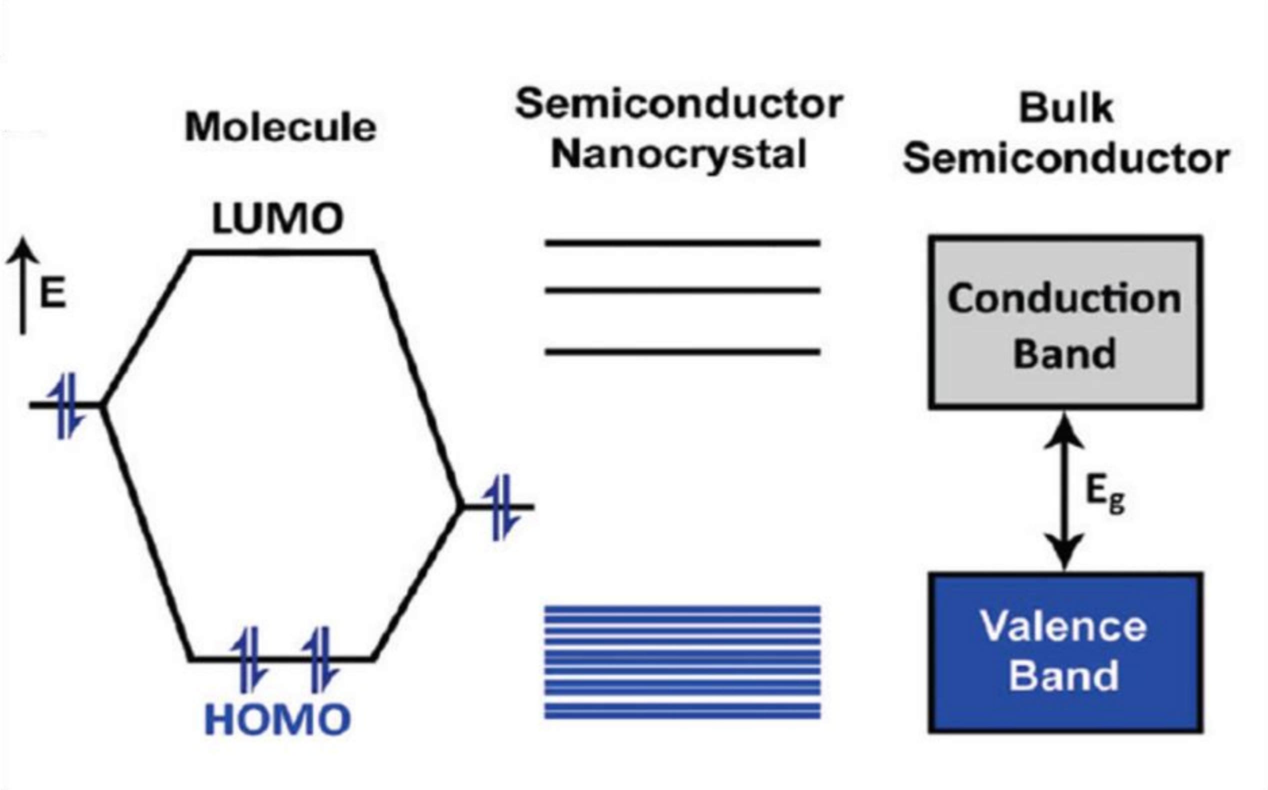
Percentage of Surface Atoms

Full-shell Clusters		Total Number of Atoms	Surface Atoms (%)
1 Shell		13	92
2 Shells		55	76
3 Shells		147	63
4 Shells		309	52
5 Shells		561	45
7 Shells		1415	35



Quantum Confinement Effect

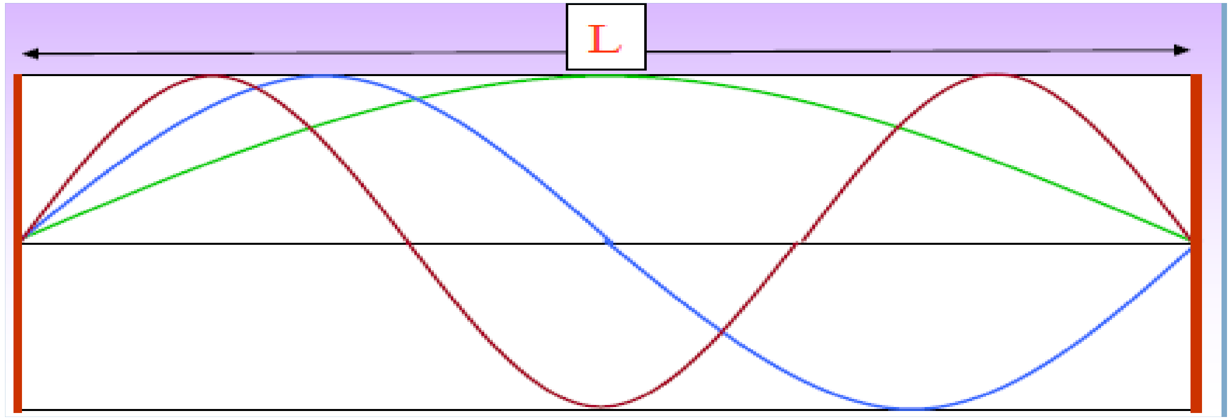
- An electron is considered to exist inside of an infinitely deep potential well, it cannot escape and is confined by the dimensions of the nanostructure
- The energy level spacing for a Nanomaterials are predicted to be inversely proportional to d^2



Electronic energy states of a semiconductor

Quantum Confinement:

- The particle in a box model



$$k = \frac{2\pi}{\lambda}$$

$$k = \frac{n\pi}{L}$$

$$p_n = \frac{h}{\lambda_n} = \frac{nh}{2L}$$

$$E = \frac{p^2}{2m}$$

$$E = \frac{n^2 h^2}{8mL^2}$$

n → integer *(quantum number)*

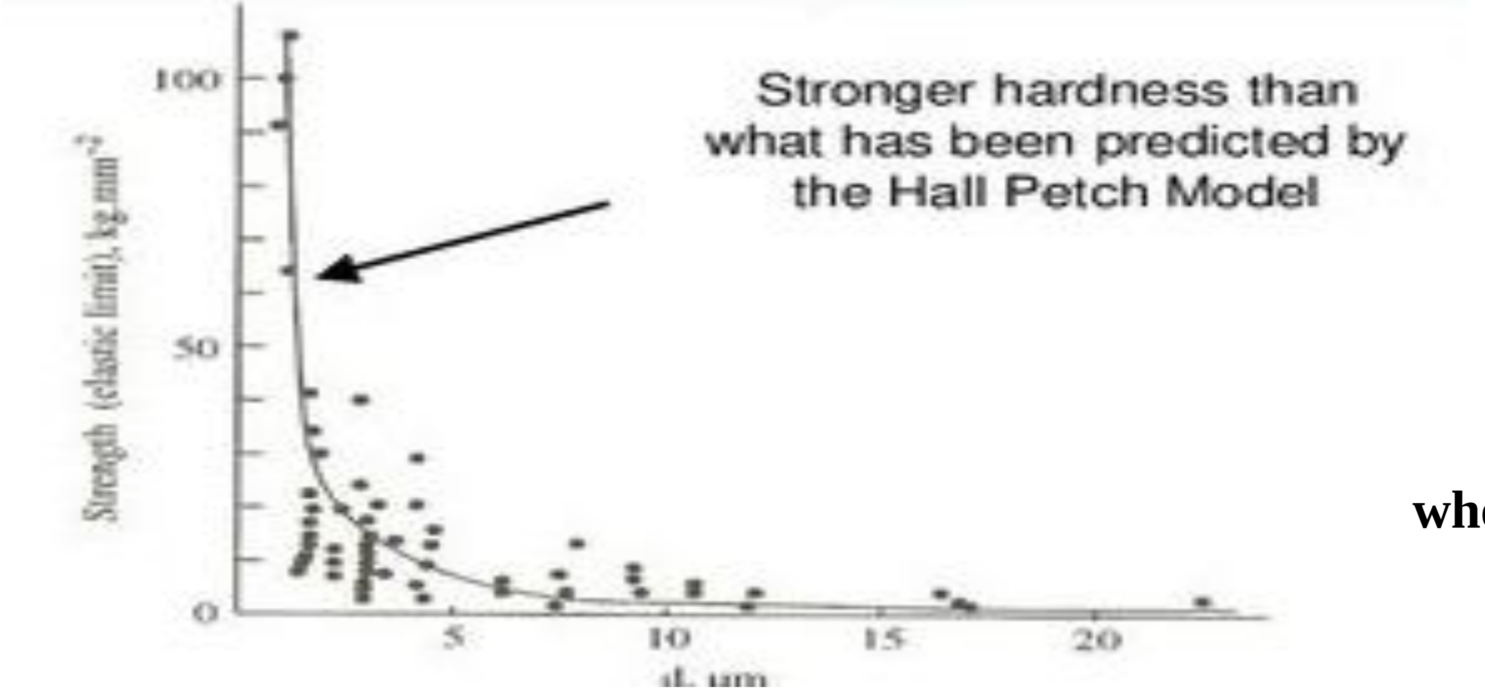
Quantization of Energy levels

Properties of nanomaterials

Mechanical properties:

the presence of large numbers of atoms on the faces of its outer surface, as the hardness of metallic materials and their alloys increases.

Their resistance to stresses and loads imposed on them increases,



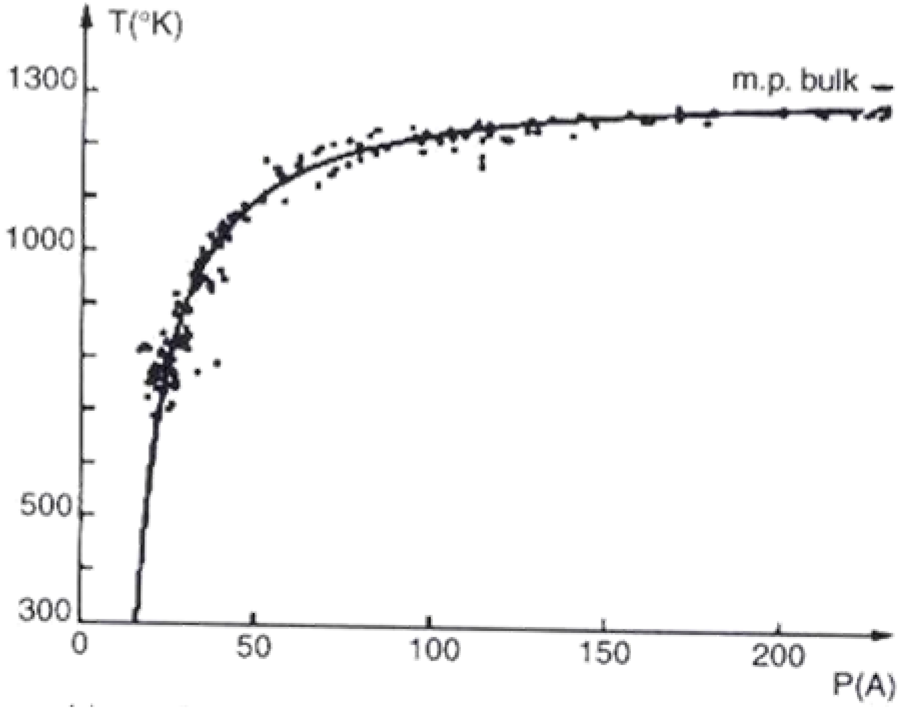
yield strength →	$\sigma_{TS} = \sigma_0 + \frac{K_{TS}}{\sqrt{d}}$
hardness	$H = H_0 + \frac{K_H}{\sqrt{d}}$

where σ0 is the friction stress and k is a constant

Thermal properties: **Melting point of a solid is the temperature at which it changes state from solid to liquid**.

- **heating a solid to a certain point, there will be enough energy to break the bonds holding the material together**
- **Since the atoms on the surface are bonded to fewer atoms, they are easier to pull apart**
- **At the nanoscale, Surface Area to Volume ratio increases, and thus melting requires less energy**

the melting point of gold in its natural size, which reaches 1064 C, decreases to 500 C after reducing its grains to about 1.35 nanometers.



The values of the melting points of the material decreased with reducing the dimensions

Magnetic properties:

- ✓ One of the fascinating properties of magnetic nanoparticles is the reduction from multidomains to a single domain as the particle size reduces to some limit values.
- ✓ The smaller the grains of the materials and the more atoms are present on their outer surfaces, the stronger and more effective their magnetic ability becomes,

which enables us to use them in large electrical generators, ship engines, the manufacture of high-precision analysis devices, and magnetic resonance imaging.

- **Electrical properties:** The charge carriers get scattered at grain boundaries resulting into decrease of electrical conductivity as compared to the bulk materials.

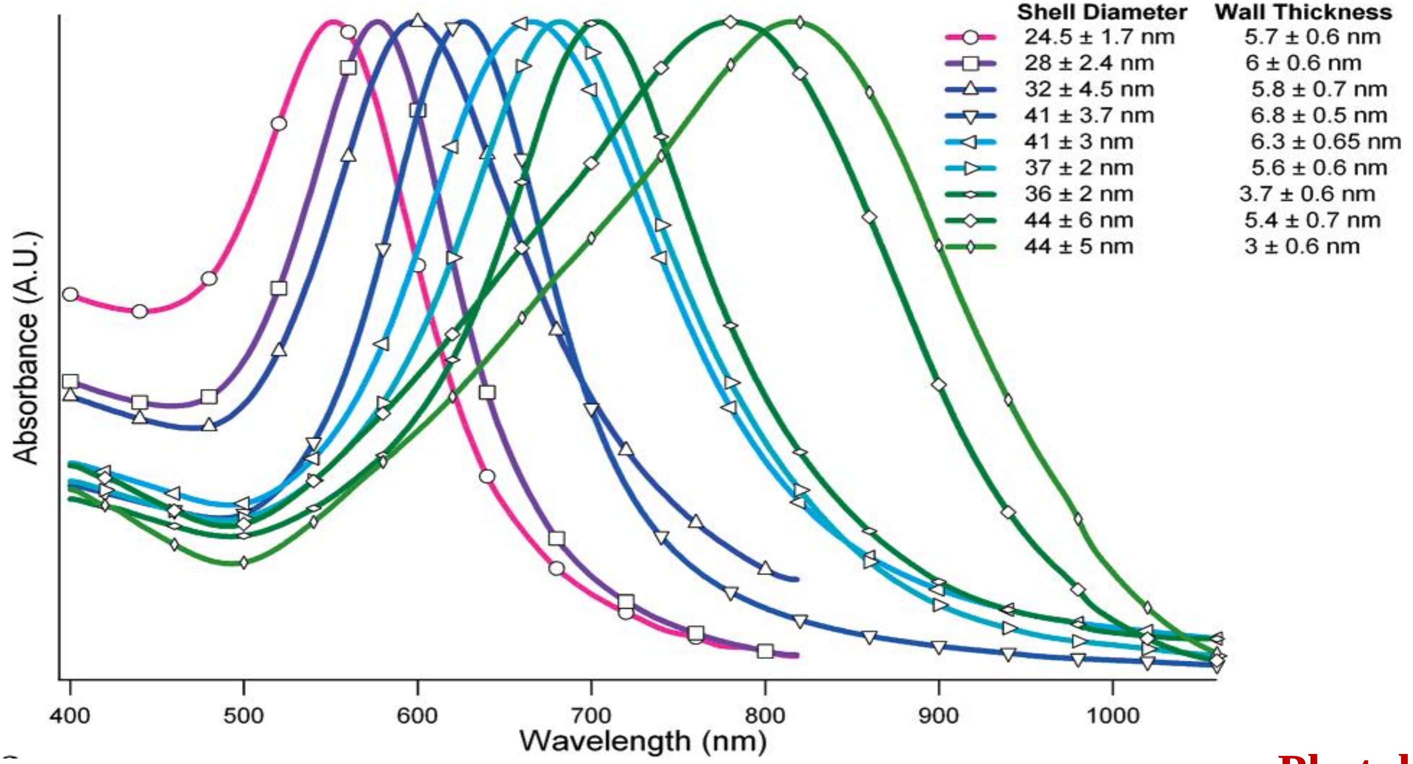
- **Biological properties:** Increasing the ability of nanomaterials to penetrate and penetrate biological barriers and obstacles.

Improving biocompatibility, which facilitates the access of drugs and therapeutic drugs to the affected part through membranes and blood vessels.

Optical properties:

- The blue shift of the UV-visible absorption and PL spectra with decreasing particle size.
- This behavior is due to what is termed quantum confinement.
- The effective bandgap of a nanoparticle: $E_g(R) = E_g(\infty) + \frac{\hbar\pi^2}{2d^2}\left(\frac{1}{m_e} + \frac{1}{m_h}\right)$

where Eg(∞) is the bulk bandgap, me and mh are the effective masses of the electron and hole



UV-visible absorption spectra of nine gold nanosphere samples with varying diameters

Photoluminescence CdTe QDs with different sizes under UV illumination, ranging from 1.7 nm (blue) to 6 nm (red) in size