

## Physical and Chemical Nature of Nanoparticles

When the size of the nanomaterial is reduced, and the nanoscale level is reached, it is possible that the same material will display totally different properties (chemical and physical properties). This is because matter at the nanoscale no longer follows Newtonian physics but rather quantum mechanics. When we look at nanosized particles of substances, there are **four main things that change from macroscale objects**.

- **First.** Due to the small mass of the particles, gravitational forces are negligible. Instead electromagnetic forces are dominant in determining the behavior of atoms and molecules.
- **Second.** At nanoscale sizes, we need to use quantum mechanical descriptions of particle motion and energy transfer instead of the classical mechanical descriptions.
- **Third.** Nano sized particles have a very large surface area to volume ratio.
- **Fourth.** At this size, the influences of random molecular motion play a much greater role than they do at the macroscale.

The discovery that the properties of a substance can change with size has helped us to expand our understanding of the nature of matter and to develop new products that take advantage of the novel properties of materials at the nanoscale.

## Physical Properties of Nanoparticles

Physical properties of NPs include: shape, size, specific surface area, agglomeration, aggregation, state of size distribution, surface morphology/topography, and structure including crystallin, defect structure, and solubility.

The size, shape, surface area, and size distribution of NPs are important in their uptake by organisms.



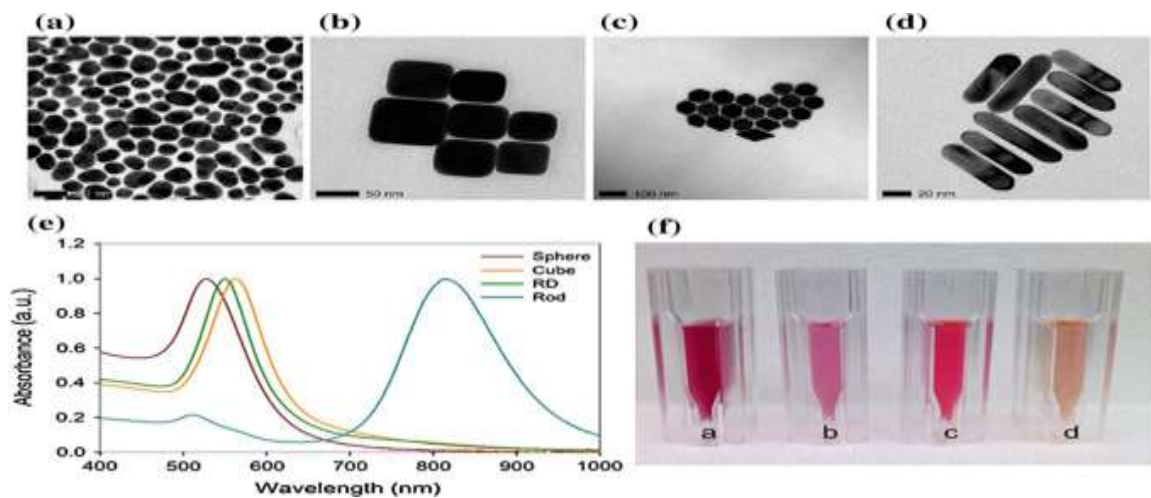
## Size and Shape

The size and shape can be identified as the most important parameter to define the nanomaterial in general.

NPs below 20–30 nm in size are characterized by an excess of energy at the surface and are thermodynamically.

The design of NPs has gained a lot of attention, resulting in particles with various shapes such as spheres, rods, tubed, fibers, and disks, etc. and more extraordinary geometries such as worms, squares, urchins, and ellipsoids.

The optical properties of NPs also depend on its size and shape.



**Difference in the optical properties of gold NPs for different shapes**

## Increased surface-to-volume ratio

One of the distinguishing properties of nanomaterials is that they have an increased surface area. It has already been stated that a nanomaterial is formed of at least a cluster of atoms, often a cluster of molecules. It follows that all types of bonding that are important in chemistry are also important in nanoscience.

**They are generally classified as:**

### **Intramolecular bonding (chemical interactions):**

These are bonding that involve changes in the chemical structure of the molecules and include ionic, covalent and metallic bonds;

### **Intermolecular bonding (physical interaction):**

These are bonding that do not involve changes in the chemical structure of the molecules and include :

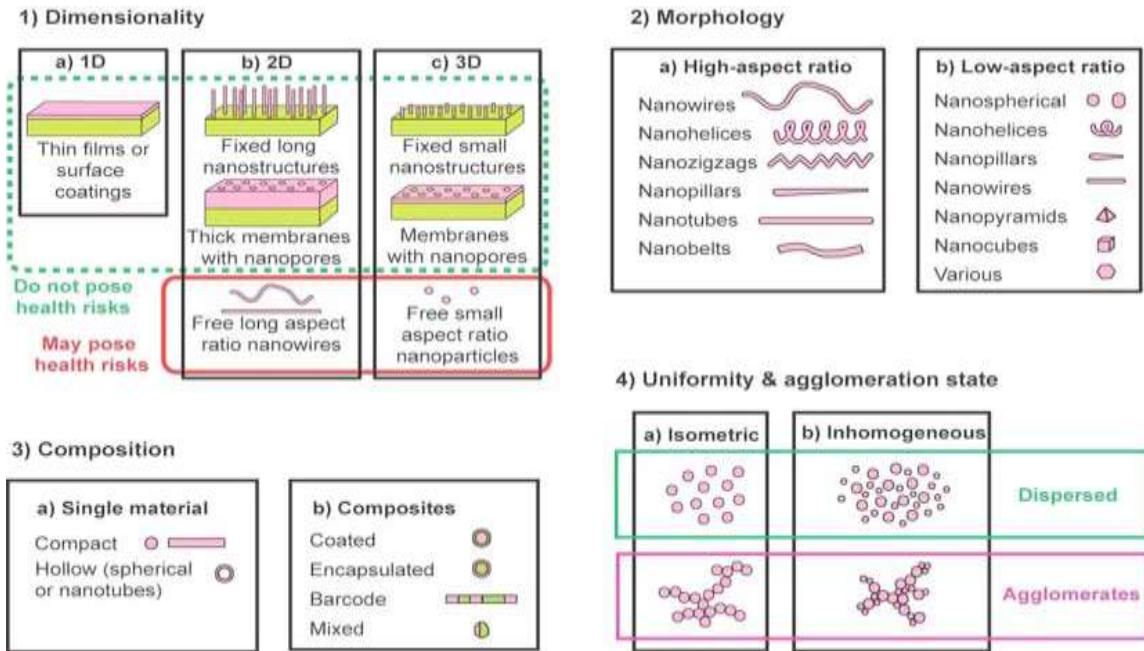
Ion-ion and ion-dipole interactions; van der Waals interactions; hydrogen bonds; hydrophobic interactions.

## **Surface energy**

Atoms and molecules that exist at the surface or at an interface are different from the same atoms or molecules that exist in the interior of a material.

This is true for any material.

Atoms and molecules at the interface have enhanced reactivity and a greater tendency to agglomerate: **surface atoms and molecules are unstable, they have high surface energy.**



## Chemical Properties of Nanoparticles

Chemical properties include the elemental composition of nanomaterials and its surface chemistry such as zeta potential and photocatalytic properties.

The chemical properties of a material are determined by the type of motion of its electrons.

## Electrical properties

Some nanomaterials exhibit electrical properties that are absolutely exceptional.

Their electrical properties are related to their unique structure. Two of these are **fullerenes and carbon nanotubes**.

## Optical properties

Some nanomaterials display very different optical properties, such as color and transparency, compared to bulk materials.

Nanomaterials in general can have peculiar optical properties as a result of the way light interacts with their fine nanostructure.

## ❖ Other properties

### Optical properties

- The reduction of materials' dimension has pronounced effects on the optical properties
  - One is due to the increased energy level spacing → quantum size effect
  - the other is related to surface plasmon resonance.
- The size dependence on the optical properties of nanoparticles is the result of two distinct phenomena:
  - Surface plasmon resonance for metals
  - Increased energy level spacing due to the confinement of delocalized energy states. Most prominent in semiconductors

### Magnetic properties

In general, the magnetic behavior of a material depends on the structure of the material and on its temperature.

The typical size of expected magnetic domains is around 1  $\mu\text{m}$ .

When the size of a magnet is reduced, the number of surface atoms becomes an important fraction of the total number of atoms, surface effects become important, and quantum effects start to prevail.

### Mechanical properties

Some nanomaterials have inherent exceptional mechanical properties which are connected to their structure.

One such material is carbon nanotubes: these are extremely small tubes having the same honeycomb structure of graphite, but with different properties compared to graphite.

They can be single-walled or multi-walled.

Carbon nanotubes are 100 times stronger than steel but six times lighter!!

- Mechanical properties:
  - ✓ Hardness
  - ✓ Strength
  - ✓ capacity of tensile deformation

## Thermal properties

The fact that in a nanomaterial a larger fraction of the atoms is at the surface influences some physical properties such as the **melting point**.

Given the same material, its melting point will be lower if it is nano-sized.

Surface atoms are more easily removed than bulk atoms, so the total energy needed to overcome the intermolecular forces that hold the atom 'fixed' is less, thus the melting point is lower.

### Thermal properties

- Most nanomaterials have a lower melting point than their bulk forms.

The Melting point of Nanoparticles decreases with size.

**Variation of the melting point of gold nanoparticles with size**

- The thermal conductivity of a material depends on its form (e.g. diamond is a good thermal conductor but nanotubes are 2 times better than diamond).

**A CPU heat sink**

**A heat sink with carbon nanotubes**