University of Anbar

College o Science – Dept. of Physics

Lectures of

NanoScience #1

for 4th level of physics students

by

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Chapter Two

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2.4. Nanomaterials

Nanomaterials are all structures are found into scale of (1-100)nm, that are found in several shapes and types[1]. Those materials have been very different to the bulk materials (materials in large scale), and often possess unique physical and chemical properties that due to the size effect which lead to increase in the surface area with the volume particle.

Generally, nanomaterials' properties depend on several factors such as;

- Size.
- Shape.
- Surrounding media.
- Structure.

2.5. Classification of nanomaterials

Most popular classification of nanomaterials depends on the geometrical dimension numbers of nanoparticle or on the electron confinement into these dimensions;

A. According to the dimension into scale[2];

1- Zero-dimensional (0D): all three dimensions sit into the nanoscale (e.g. $d \leq 100nm$), such as nanoparticles and nanopores. In semiconductors, these systems are called (quasi- zero) dimensional due to electron is unable to move freely.

2- One-dimensional (1D): there is one dimension does not sit into nanoscale, but into macroscale, such as nano(tubes, wires, rods).

3- Two dimensional (2D): there are two dimensions do not sit into nanoscale such as thin films, nano(layers, coating).

4- Three dimensional (3D): there are not any dimensions of material into nanoscale, these materials are called bulk materials but consist nanocrystalline assemblages in the nanosize and have nano- properties.

Figure (2-1) illustrates the classification of nanomaterials according to the dimensions' scale.

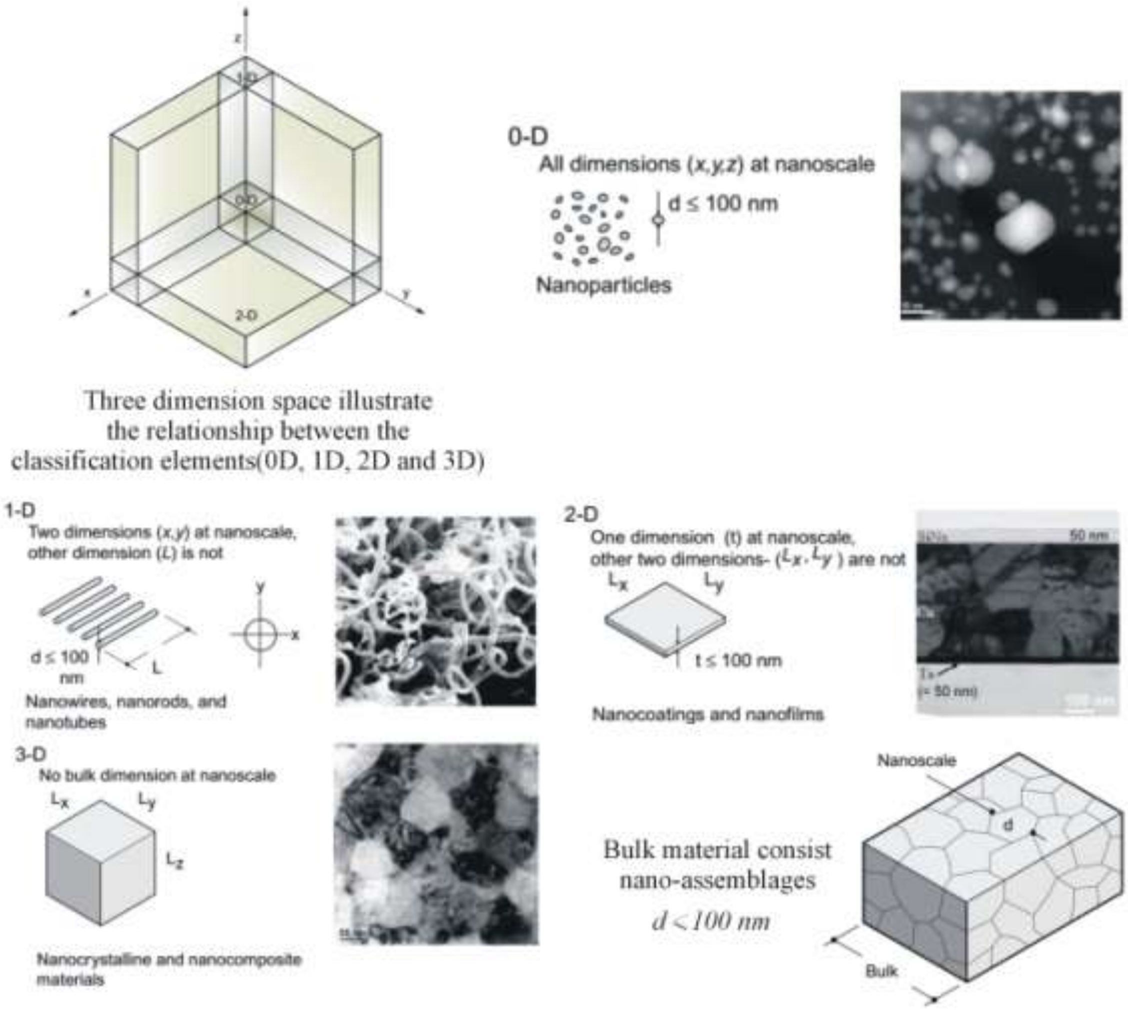


Figure (2-1) illustrate the classification of nanomaterials according to the dimensions' scale.

B. There is another classification based on the confinement the electron into nanoparticle (is called quantum confinement), this classification is opposite the last classification;
   1- One-dimensional (1D): the electron is confined into one direction due to the material possesses one dimension in nanoscale such as (thin films, nanolayers, nanocoating).
   2- Two dimensional (2D): the electron is confined into two directions due to the material possesses two dimensions in nanoscale such as nano (tubes, wires, rods).

3- Three dimensional (3D): the electron is confined into three directions because of all dimensions into the nanoscale such as nanoparticles and nanoporous.

Additionally, there are another classifications of nanomaterials such as according to shape (spherical, stare shape, cage shape, rods, flowers, cubic… etc.) or according to the structure (crystalline and amorphous).

2.6. Size Effects

Frequently, we hear the phrase that says "nanomaterials possess unique properties"?

Where did these materials get these properties despite keeping their chemical composition unchanged?

The reduction in the size leads to many effects in the parameters and properties of the material.

2.6.1. Surface area to volume ratio

One of the most fundamental differences between nanomaterials and bulk materials is the difference in the ratio of the surface area of the particle to its size; the electronic properties are now tunable via the particle size. With respect to the electrical properties of nanoparticles and of all types of arrangement built from nanoparticles, the most important property is the amount of energy required to add one extra electron to an initially uncharged particle, in other words, makes the appearance of the electrical activity of the particle on the surface, this makes the nanoparticles different in their behavior, as the normal material is bound to the interaction of their internal atoms with each other, which makes the interaction between these atoms confined within the inside substance and affects on the quantitative activity of the substance.

As a result of the different forms of nanomaterials, this causes a change in the ratio of surface/size according to a geometrical form. This explains possession nanoparticles different properties depending on their size and shape, although they retain their chemical composition. This size effect may be regarded as the start of the metal-nonmetal transition such that, in another terminology, these nanoparticles may also be labeled as artificial atoms[3].

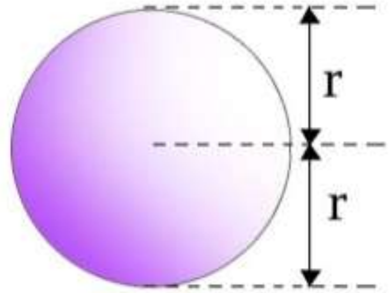
Now we can calculate the ratio between the surface area and the volume for varied geometrical shapes, as following[1];

1- Spherical Shape:

the surface area of sherical shape is

$$A = 4\pi r^2 \ldots\ldots\ldots (2-1)$$

the volume of sherical shape is



$$V = \frac{4}{3}\pi r^3 \ \ldots\ldots\ldots (2-2)$$

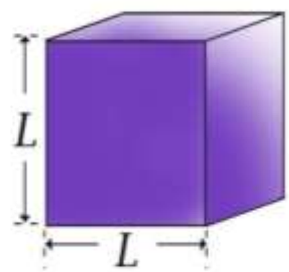
then , the ratio of area/volume is,

$$\frac{A}{V} = \frac{3}{r} \ \ldots\ldots\ldots\ldots \ (2-3)$$

2- cubic Shape:

the surface area of cubic shape is

$$A = 6L^2 \quad \ldots\ldots\ldots\ldots (2-4)$$



and the volume of cubic shape is

$$V = L^3 \ \ldots\ldots\ldots\ldots\ldots \ (2-5)$$

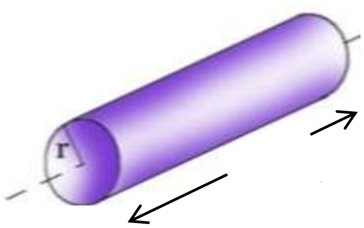
then , the ratio of area/volume is,

$$\frac{A}{V} = \frac{6}{L} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-6)$$

3- Cylindrical Shape

the surface area of Cylindrical shape is

$$A = 2\pi r L \ \ldots\ldots\ldots\ldots (2-7)$$



and the volume of Cylindrical shape is

$$V = \pi r^2 L \ \ldots\ldots\ldots\ldots (2-8)$$

then , the ratio of area/volume is

$$\frac{A}{V} = \frac{2}{r} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2-9)$$

Example (2-1): A spherical particle with R radius results from aggregated nanoparticles with 10nm radius of each.

1. Test the effect of the size reduction on the area/size ratio when the size change with; $(R = 10, 8, 6,4,2,1,0.8,0.6,0.4, 0.2)\mu m$.
2. Sketch a graph illustrate the relation between size and the area/size ratio.

Solution:

1.

The size and the area of spherical shape are;

$$A_A = 4\pi R^2 \ , \ \ V_A = \frac{4}{3}\pi R^3 \ , A_n = 4\pi r^2 \text{ and } V_n = \frac{4}{3}\pi r^3$$

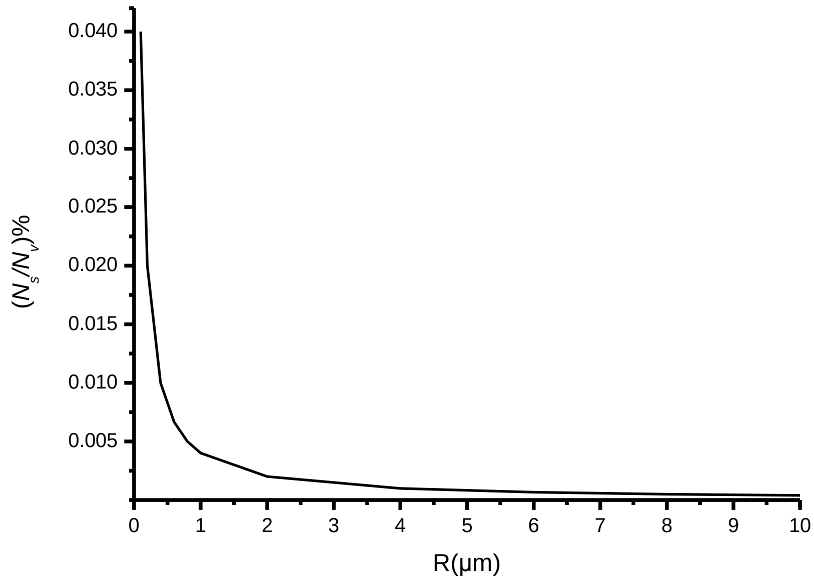
then, the numbers of nanoparticles inside the artificial particle and on its surface are;

$$N_v = \frac{V_A}{V_n} = \frac{(\frac{4}{3}\pi R^3)}{(\frac{4}{3}\pi r^3)} = \frac{R^3}{r^3} \ ; N_s = \frac{A_A}{A_n} = \frac{4\pi R^2}{4\pi r^2} = \frac{R^2}{r^2}$$

$R\ (\mu m)$	$R\ (nm)$	$r(nm)$	Nv	Ns	Ns/Nv
10	10^4	10	10^9	10^6	10^{-3}
8	8×10^3	10	5.12×10^8	6.4×10^6	1.25×10^{-3}
6	6×10^3	10	2.16×10^8	3.6×10^6	1.67×10^{-3}
4	4×10^3	10	6.4×10^7	1.6×10^5	2.5×10^{-3}
2	2×10^3	10	8×10^6	4×10^4	5×10^{-3}
1	10^3	10	10^6	10^4	10^{-2}
0.8	8×10^2	10	5.12×10^5	6.4×10^3	1.25×10^{-2}
0.6	6×10^2	10	2.16×10^5	3.6×10^3	1.67×10^{-2}
0.4	4×10^2	10	6.4×10^4	1.6×10^3	2.5×10^{-2}
0.2	2×10^2	10	8×10^3	4×10^3	5×10^{-2}

2. Graph[1]

[1] Note, the area/size ratio increases with the decreasing of the size of the fundamental structure.



2.6.2. Clusters and Magic Numbers