Nanoscience
(Introduction)

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Definition of Nanoscience and Nanotechnologies

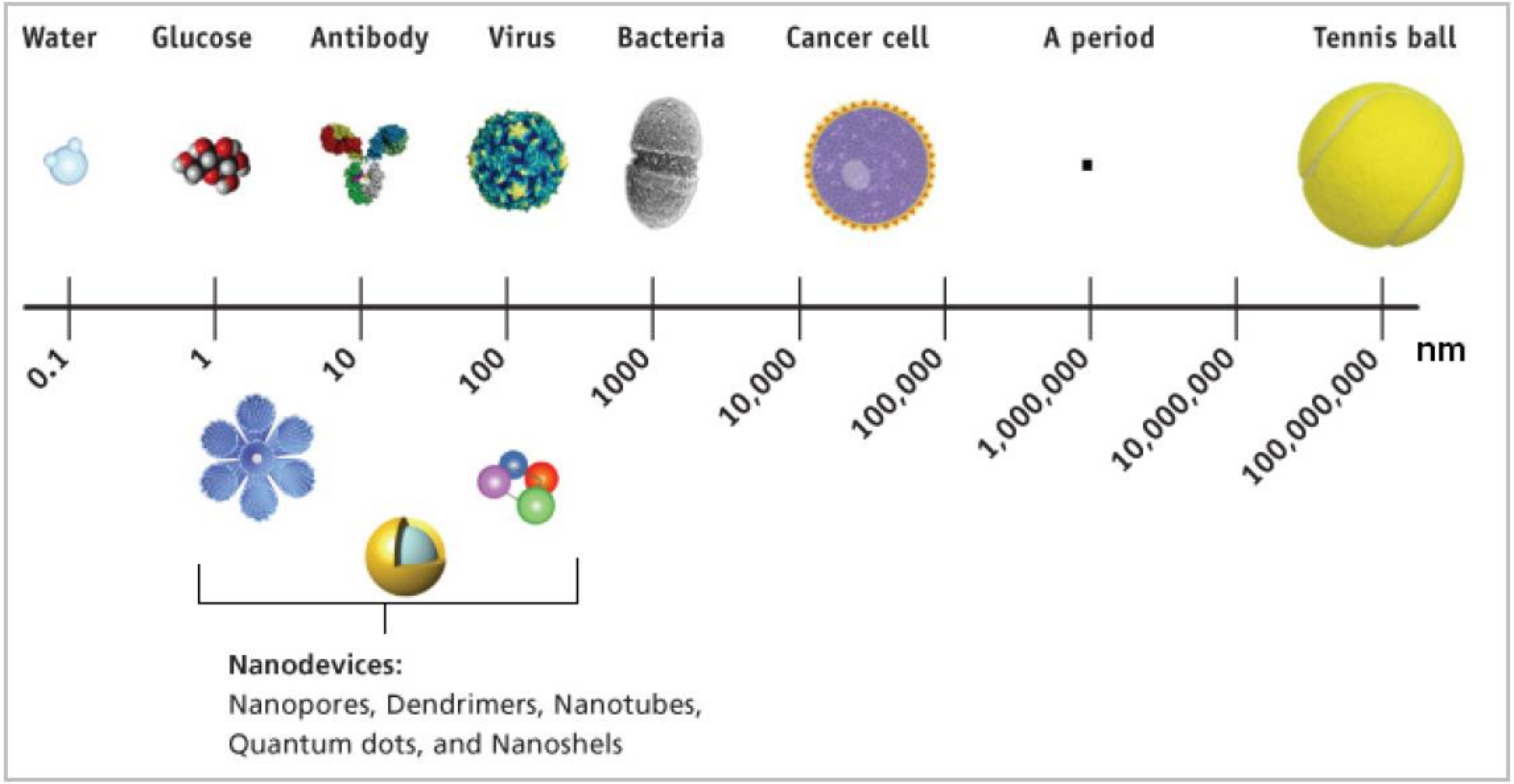
"Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale"[1].

same material (e.g., gold) at the nanoscale can have properties (e.g., optical, mechanical, electrical, etc.) which are very different from (even opposite to!) the properties the material has at the macro scale (bulk). Nanotechnologies are defined thus:

"Nanotechnologies are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale."

Nanometer scale

Nanomaterials are large than single atoms but smaller than bacteria and cells



The nanometre scale

The nanometre scale is conventionally defined as 1 to 100 nm. One nanometre is one billionth of a metre (10^{-9} m). The size range is set normally to be minimum 1nm to avoid single atoms or very small groups of atoms being designated as nano-objects. **Therefore nanoscience and nanotechnologies deal with at least clusters of atoms of 1nm size**.

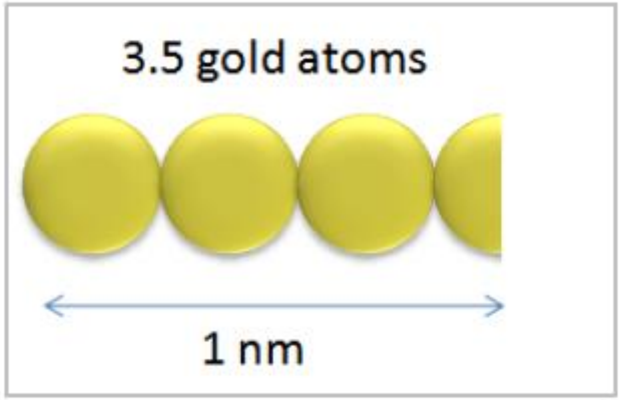


Figure 1. Three and a half gold atoms placed in a row equal to 1nm (assuming a covalent radius of 0.144 nm each). (Image credit: L. Filipponi, iNANO, Aarhus University. Creative Commons ShareAlike 3.0)

Nanoscience is the study of materials that exhibit remarkable properties, functionality and phenomena due to the influence of small dimensions.

- Our **fingernails grow** at the rate of 1 nm per second.

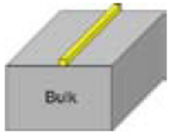
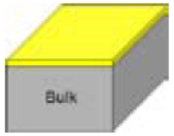
- The **head of a pin** is about 1 million nanometres across.

- A **human hair** is about 80,000 nm in diameter.

- A **DNA molecule** is about 1-2 nm wide.

What is a nanomaterial?

A nanomaterial is an object that has at least one dimension in the nanometre scale (approximately 1-100nm). Nanomaterials are categorised according to their dimensions as shown in **Table 1**:

Nanomaterial Dimension	**Nanomaterial Type**	**Example**
All three dimensions < 100 nm	Nanoparticles, Quantum dots, nanoshells, nanorings, microcapsules	
Two dimensions < 100 nm	Nanotubes, fibres, nanowires	
One dimension < 100 nm	Thin films, layers and coatings	

1. Zero-Dimensional Nanomaterials
2. One-Dimensional Nanomaterials
3. Two-Dimensional Nanomaterials
4. Three-Dimensional Nanomaterials

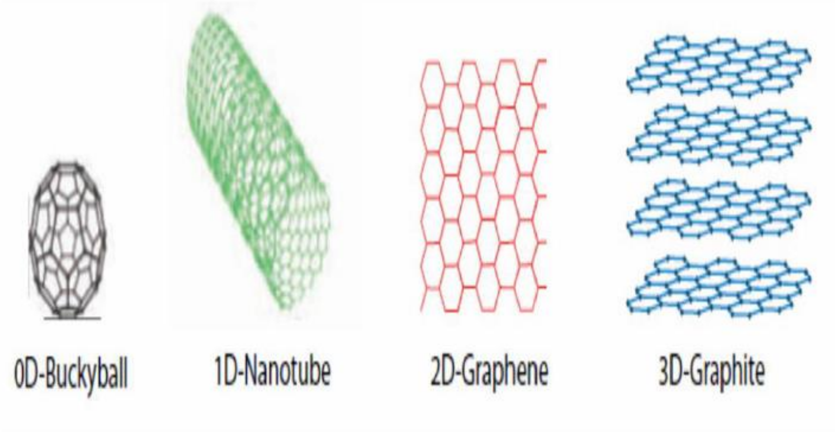
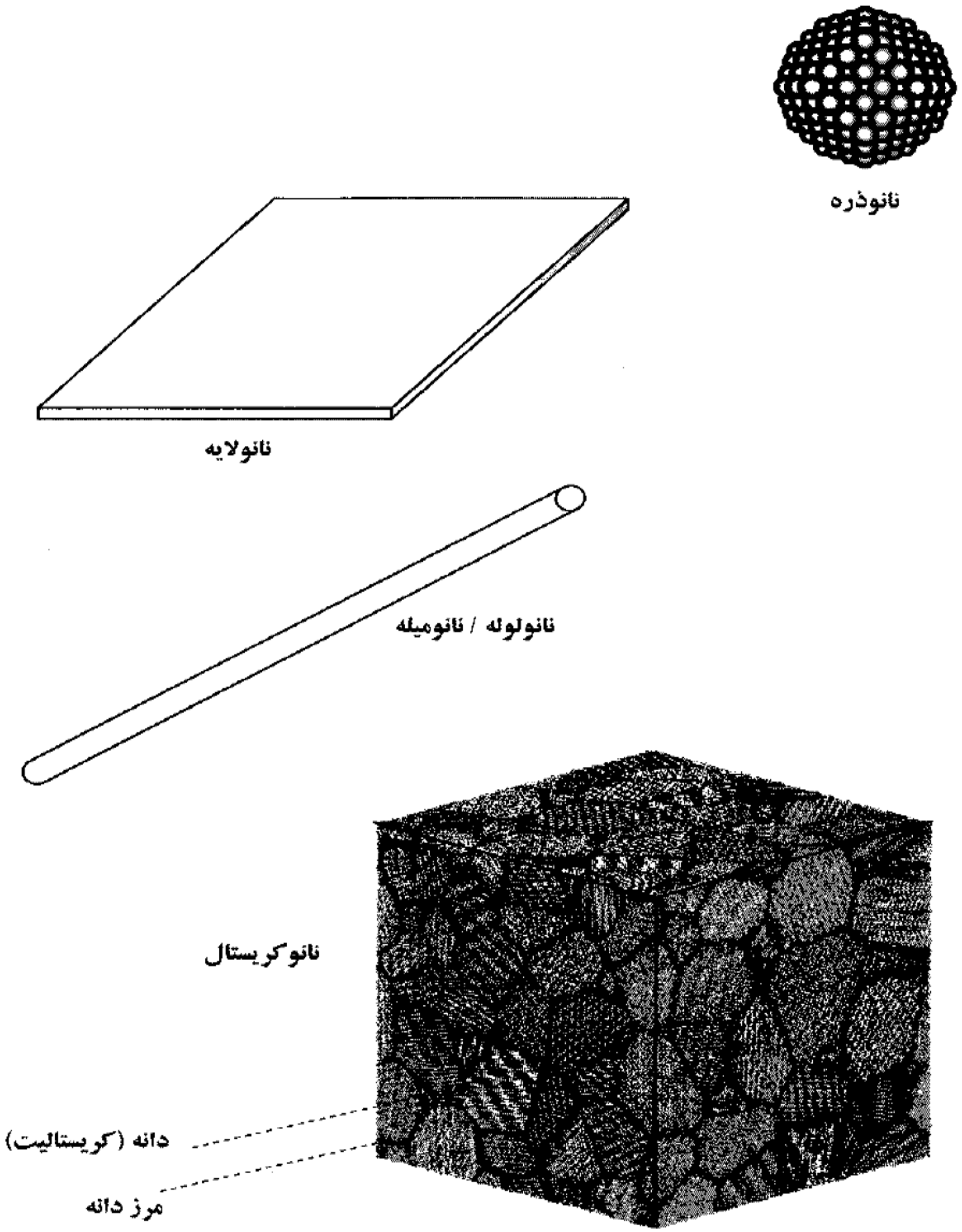


Fig. 6. Carbon nanostructures



تقسیم بندی از دیدگاه متالورژی

۱ـ خوشه‌های اتمی و یا نانوذرات

۲ـ نانولایه‌ها

۳ـ نانولوله‌ها و نانومیله‌ها

۴ـ نانوکریستال‌ها

۵ـ نانوکامپوزیت‌ها

Reasons for Special Properties of Nanoscale Materials

1 Increasing the surface area to volume ratio

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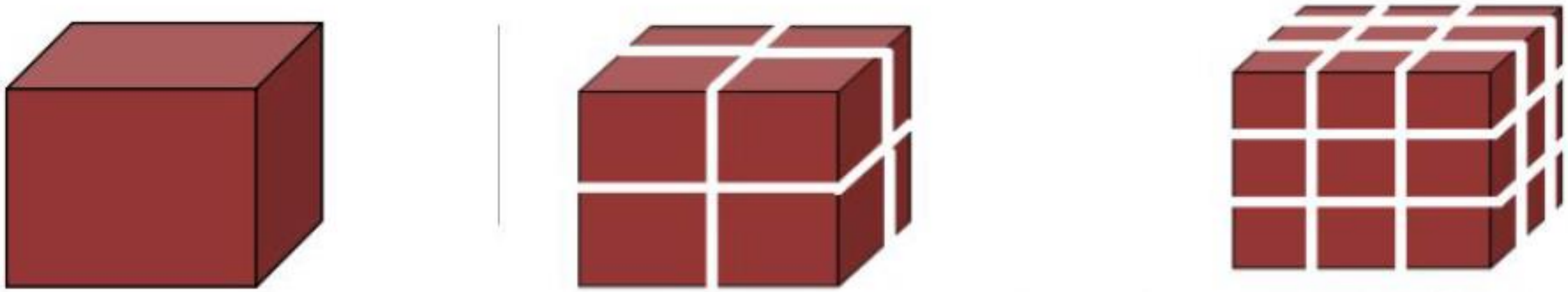
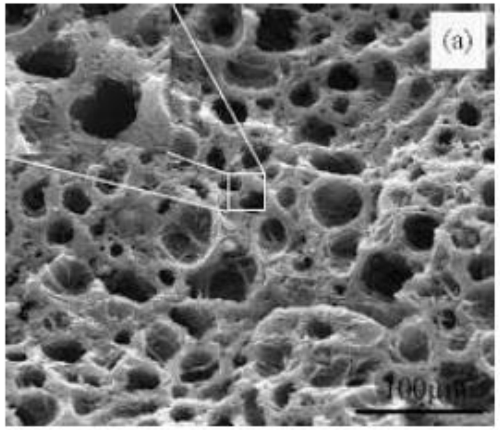
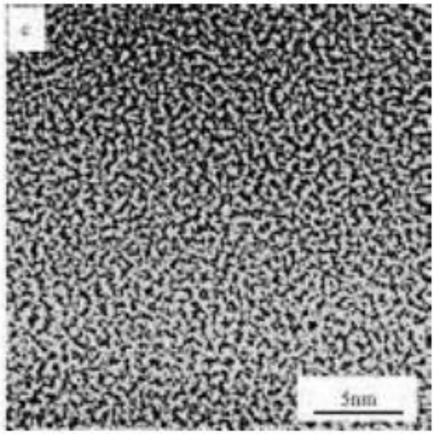


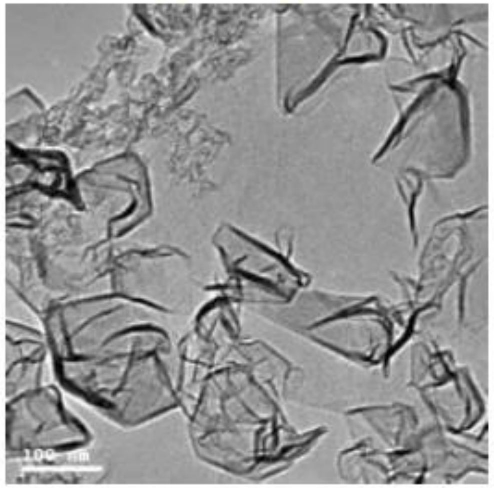
Area = 6 x 1cm^2 = 6 cm^2 **Area= 6 x (1/2cm)^2 x 8 =12 cm^2** **Area= 6 x (1/3cm)^2 x 27 =18 cm^2**

Activated carbon – specific surface area up to 3550 m^2/g





Graphene – specific surface area up to 2630 m^2/g



Reasons for Special Properties of Nanoscale Materials

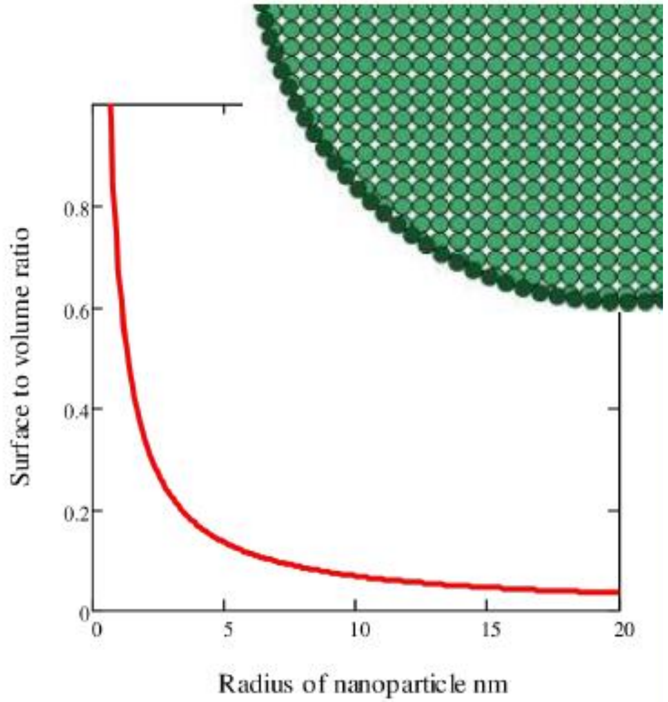
2. Surface tension effect

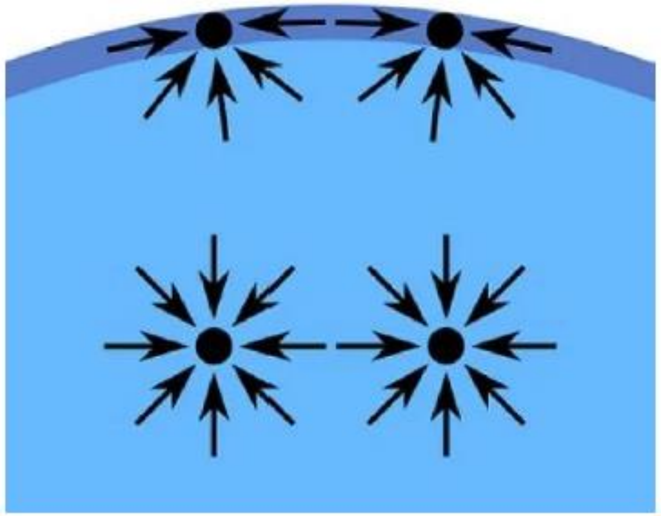
The larger the sample, the smaller the fraction of atoms on the surface.

Atoms on the surface have fewer neighbors than atoms inside

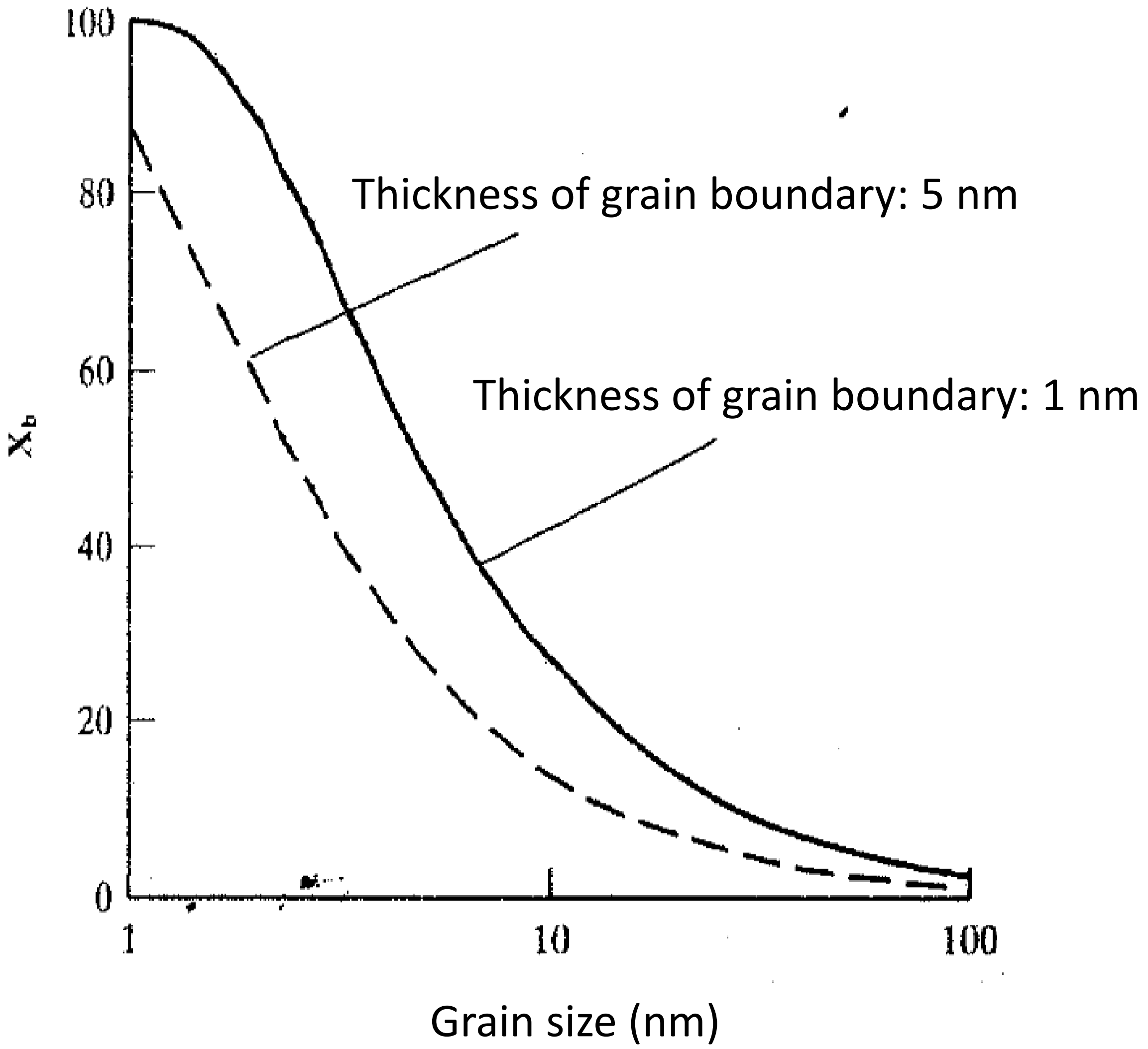
(Students at the edge of the classroom have fewer neighbors than students at the center)

Only atoms on the surface can interact with another material and take part in a chemical reaction (increase in reactivity).





The surface layer has excess energy (surface free energy) compared to the bulk. Reducing the particle causes an increase in its surface energy, which leads to a change in properties.


100
80
60
40
20
0
X_b
1
10
100
Thickness of grain boundary: 5 nm
Thickness of grain boundary: 1 nm
Grain size (nm)


ضریب نفوذ
استحکام
چقرمگی
ضریب انبساط حرارتی
سختی
...
تغییر در خواص فیزیکی و
مکانیکی مواد نانوساختار
هدایت حرارتی
هدایت الکتریکی
چگالی
مقاومت به خوردگی
دمای کوری
...

What makes “nano” special

“Nano” means small, very small; but why is this special? There are various reasons why nanoscience and nanotechnologies are so promising in materials, engineering and related sciences. First, at the nanometre scale, the properties of matter, such as energy, change. This is a direct consequence of the small size of nanomaterials, physically explained as quantum effects. The consequence is that a material (e.g., a metal) when in a nano-sized form can assumes properties which are very different from those when the same material is in a bulk form. For instance, bulk silver is non-toxic, whereas silver nanoparticles are capable of killing viruses upon contact. **Properties like electrical conductivity, colour, strength and weight change when the nanoscale level is reached. The same metal can become a semiconductor or an insulator at the nanoscale level.** The second exceptional property of nanomaterials is that they can be fabricated atom-by-atom, with a process called **bottom-up**. The

What makes “nano” special

1 (“Fabrication methods”). Finally, nanomaterials have an **increased surface-to-volume ratio** compared to bulk materials. This has important consequences for all those processes that occur at a material surface, such as catalysis and detection. The properties that make nanomaterials “special” are further discussed in Chapter 4 of Module 1 (“Fundamental ‘nano-effects’”).

From Nanoscience to Nanotechnologies

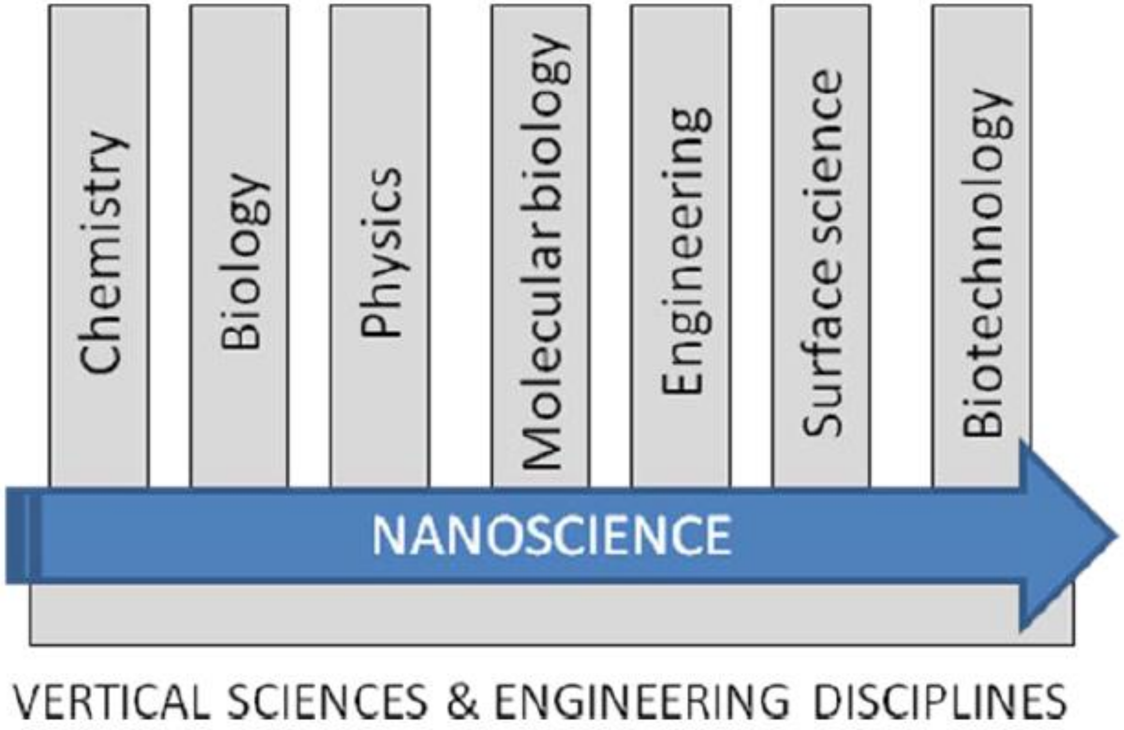


Figure 3. Nanoscience is a horizontal-integrating interdisciplinary science that cuts across all vertical sciences and engineering disciplines. (Image credit: L. Filipponi, iNANO, Aarhus University. Creative Commons ShareAlike 3.0)

Nanotechnology

The application of nanoscience to “practical” devices is called nanotechnologies. Nanotechnologies are based on the manipulation, control and integration of atoms and molecules to form materials, structures, components, devices and systems at the nanoscale. Nanotechnologies are the application of nanoscience especially to industrial and commercial objectives. All industrial sectors rely on materials and devices made of atoms and molecules, thus in principle all materials can be improved with nanomaterials, and all industries can benefit from nanotechnologies. In reality, as with any new technology, the “cost vs. added benefit” relationship will determine the industrial sectors that will mostly benefit from nanotechnologies.

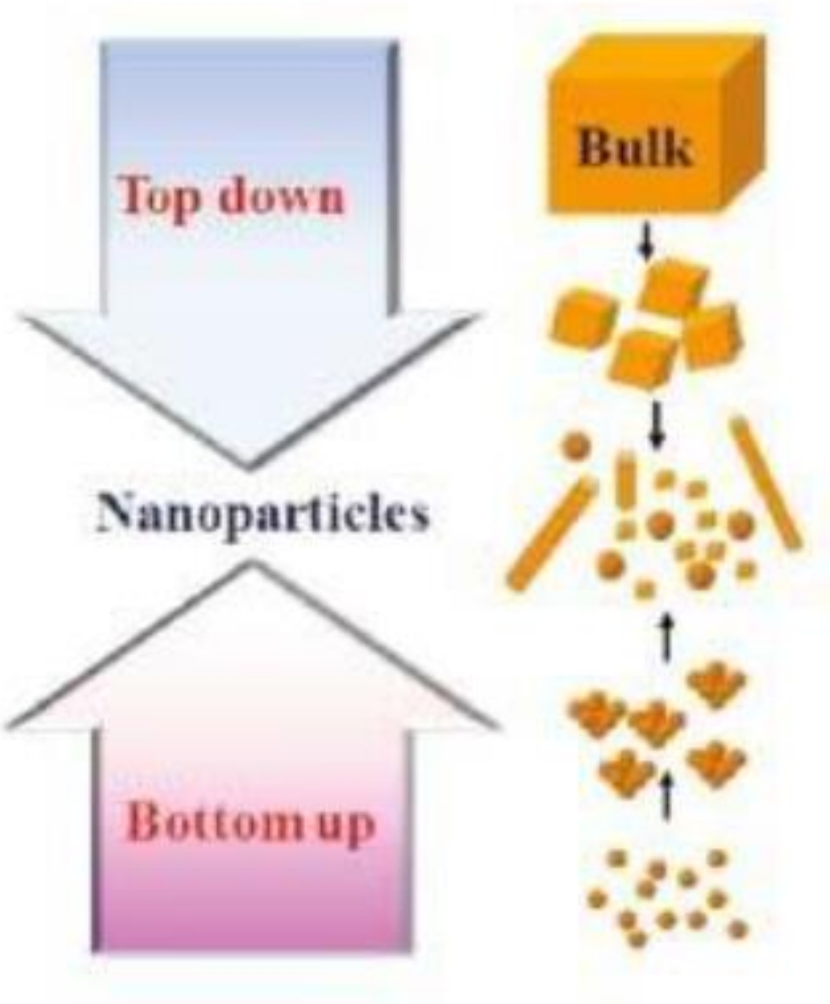


Fig. 5. Schematic illustration of the preparative methods of nanoparticles.

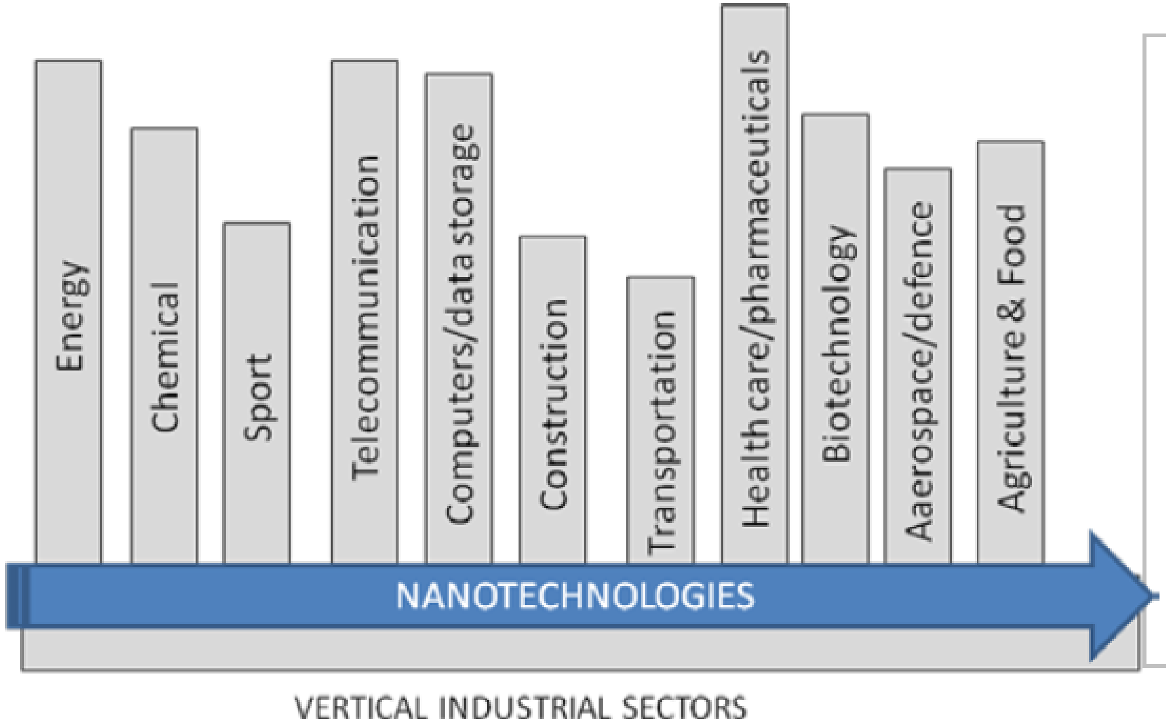


Figure 4. Nanotechnologies are horizontal-enabling convergent technologies which cross all vertical industrial sectors. The different heights of the industrial sectors in the graph are only indicative and are intended to emphasise the fact that the level of impact of nanotechnologies will be different in each industrial sector. (Image credit: L. Filipponi, iNANO, Aarhus University. Creative Commons ShareAlike 3.0)

Thus, **nanotechnologies are horizontal-enabling convergent technologies**. They are "horizontal" because they cut across numerous industrial sectors; they are "enabling" since they provide the platform, the tools to realise certain products; and are "convergent" because they bring together sectors of science that were previously separated.