NANOTECHNOLOGY

SARITA

NANOTECHNOLOGY – A BRIEF INTRODUCTION :

The aim of this paper is to provide some background information on nanoscience and nanotechnology, including definitions; to identify the key properties that make nanomaterials so useful and special in human life and to provide some information about application of nanotechnology to specific fields like energy, environment, medicine etc.

DEFINITION:

A nanometer is 10^{-9} metre. It is so surprising to know that the dot over letter "i" is approximately one million nanometers in diameter.

Nanoscience is the study of phenomena on the nanometer scale. Nanotechnology manipulates matter at the atomic, molecular or macromolecular level of create and control objects on the nanometre scale, with the goal of fabricating novel materials, devices and systems that have new properties and functions because of their small size. The definition of nanotechnology is rather broad and includes both nanotechnology enabled materials (such as carbon nanotubes) and nanotechnology-enabled tools and processes.

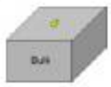
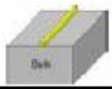
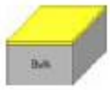
The nanometer scale is commonly indicated as 1-100 nm, but nanoscience and nanotechnology often deal with objects larger than 100 nm. The variability arises from the interdisciplinary nature of nanotechnology, which arises from the convergence of chemistry, physics, material science, engineering, molecular biology, biology and medicine. In daily routine, we deal objects studied are in the 1-100 nm length scale.

Even though nanoscience is often perceived as a science of the future, it is actually the basis for all systems in our living and mineral world. We have hundreds of examples of nanoscience under our eyes daily, such as walk up side down on a ceiling, apparently against gravity, to butterflies with iridescent colours, to fireflies that glow at night. In Nature we encounter some outstanding solution to complex problems in the form of fine nanostructures to which precise functions are associated. In recent years, researchers have had access to new analytical tools to see and study those structures and related functions in depth and further stimulated the research in the nanoscience area, and has catalysed nanotechnology. So in a sense, natural nanoscience is the basis for nanotechnology.

WHAT IS A NANOMATERIAL

Nanotechnology manipulates matter for the deliberate fabrication of nano-sized materials. These are therefore 'intentionally made' through a defined fabrication process. The definition of nanotechnology does not generally include 'non-intentionally made nanomaterials', that is, nano-sized particles or materials that belong naturally to the environment (e.g., proteins, viruses) or that are produced by human activity. The term 'nanomaterial' will be used meaning 'intentionally-made nanomaterial'.

A nanomaterial is an object that has at least one dimension in the nanometre scale. Nanornaterials are categorized according to their dimensions.

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	

What makes 'nano' special'?

'Nano ' means small, very small; but why is this special? There are various reasons why nanoscience and nanotechnology are so promising in material, engineering and related sciences. First, at the nanometre scale, the properties of matter, like 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 electric conductivity, colour, strength, weight, change when the nanoscale level is reached. The same metal can become a semiconductor or an insulator when the nanoscale is reached. The second exceptional property of nanomaterials is that they can be fabricated atom-by-atom, with a process called bottom-up. The information of this fabrication process is embedded in the material building blocks, so that these can self-assemble in the final product. Finally, nanornaterials have an increased surface-to-volume compared to bulk materials. This has important consequences for all those processes that occur at a material surface, such as catalysis and detection.

QUANTUM EFFECT

Nanomaterials don't follow Newtonian physics, which applies to matter at bulk level. At the nanometre scale the properties of matter, like energy, momentum, mass, are not a continuum, like at the bulk level, but are made of specific units, or quanta. Energy, for example, in not absorbed or emitted constantly but only in multiples of specific, non-divisible energy units. Quantum mechanics is the field of physics that describes these quantum effects, which represent nothing but the discrete nature of matter at the smallest level (atomic, nuclear and particulate level). The exceptional properties of nanomaterials are a direct consequence of these Quantum effects. An example of quantum effect in nanosized particles is colour. The gold in a ring is notably yellow, but if gold is shrunk to a nanoparticle (10 nm to 100 nm in size) it becomes red if it is spherical, and colourless if it is shaped in a ring. Moreover, nanoparticles emit a specific colour depending on their nanometre-size, For instance, quantum dots (QD) are semiconducting nanocrystals, about 10 run in size, that are able to 'trap' electrons in small spaces. A QD has a discrete, quantized energy spectrum, which results in the emission of a monochromatic colour.

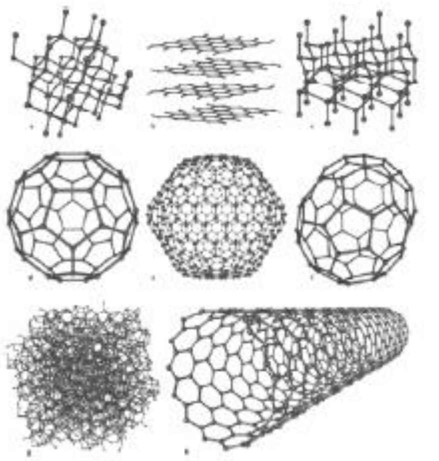
In addition to size, the shape of nanomaterials has an impact on their properties. For instance silver nanoprisrns about 100 run scatter red light while silver nanospheres scatter pale yellow light.

QD and metal nanoparticles hold great promise for nano-enhanced imaging which will bring progress to fields like environmental monitoring, medical diagnostic and treatment. QD are also investigated as novel light sources to improve LED technology.

SAME ATOMS, DIFFERENT MATERIAL

In Nature there are some pure materials that have striking different properties even though they are made of the same atoms. For instance, graphite and diamond: two very popular materials, one used conventionally in pencils and the other in jewellery. These two materials could not be more different: graphite is soft, light, flexible, and conducts electricity while diamond is extremely strong, hard and does not conduct electricity. Both materials are made of atoms of carbon linked through strong bindings (covalent), but in graphite each carbon uses three out of his four electrons to form single bonds with its neighbours, forming a linear sheet, whereas in diamonds each carbon uses all its four electrons to form four single bonds, resulting in a 3-D structure. The different properties of graphite and diamond are a consequence of the different way the carbon atoms in the materials are bonded together. Graphite and diamond are two pure forms of carbon called allotropes.

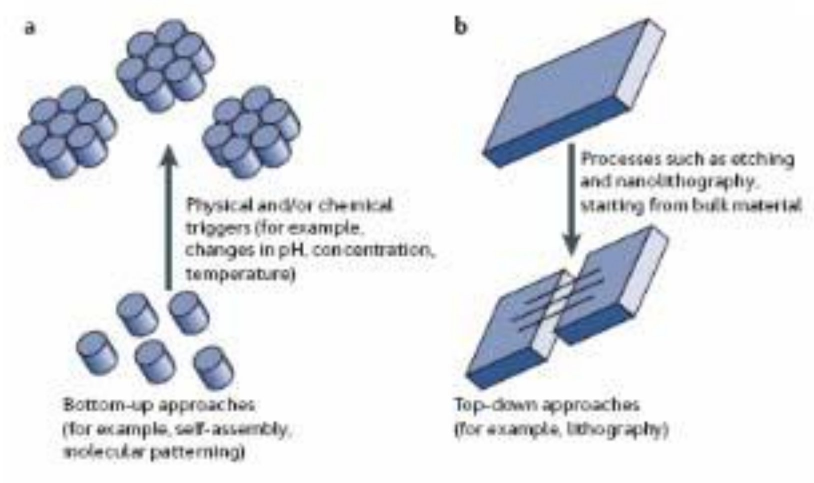
In 1985 a new allotrope of carbon was discovered formed of 60 atoms of carbons linked together though single covalent bonds arranged in a highly symmetrical, closed shell that resembles a soccer ball. This material was officially named Buckminster fullerene and is often referred to as buckyball, fullerene or simply C_{60}. Since its discovery, fullerenes with 70, 80 and even more carbons were discovered. In the early 1990s, an incredibly new carbon form was discovered, carbon nanotubes. These appear like graphite sheets rolled up with fullerene-type end caps, but have totally different properties compared to graphite. This figure shows different forms of carbon allotropes.



Carbon nanotubes can range in length from a few tens of nanometers to several micrometers and can have metallic properties (comparable to, or even better than copper) or can be semiconductors (like silicon in transistors), depending on their sturcutre. Carbon nanotubes can also be modiefied to bind other other molecules, making this material very useful in biological application. The remarkable material properties of carbon nanotubes, such as rigidity, durability, thermal conductivity and electrical conductivity, make these nanomaterials great candidates for wires, interconnectors, sensor elements and molecular electronic devices.

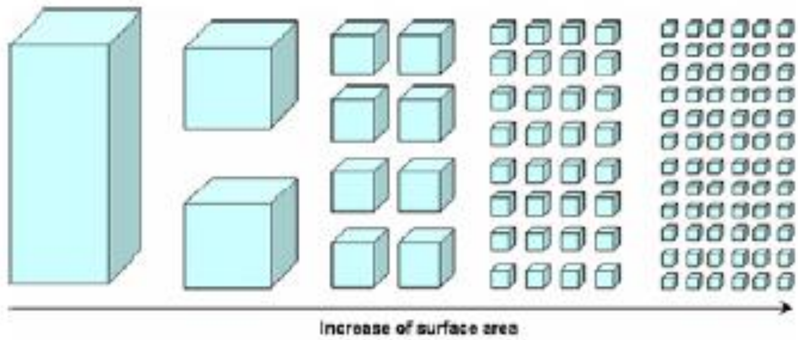
SELF ASSEMBLY :

Fabrication of nanomaterials can be done in two ways be self-assembly, that is, building the nanomateiral 'atom-by-atom' (bottom-up approach) or by 'carving' the nanomateiral out of a bulkier one (top-down approach). The concept of self-assembly derives from observing that, in natural biological processes, molecules self-assemble to create complex structures with nanoscale precision. Example are the formation of the DNA double helix. In self-assembly, sub-units spontaneously organize and aggregate into stable, well defined structures through non covalent interaction. This process is guided by information that is coded into the characteristics of the sub-units and the final structure is reached by equilibrating to the form of lowest free energy.



SURFACE TO VOLUME :

Nanomaterials have an increased surface to volume ratio compared to bulk material. This means that for a given total volume of material, the external surface is greater if it is made of an ensemble of nanomaterial sub-units rather than of bulkmaterial.

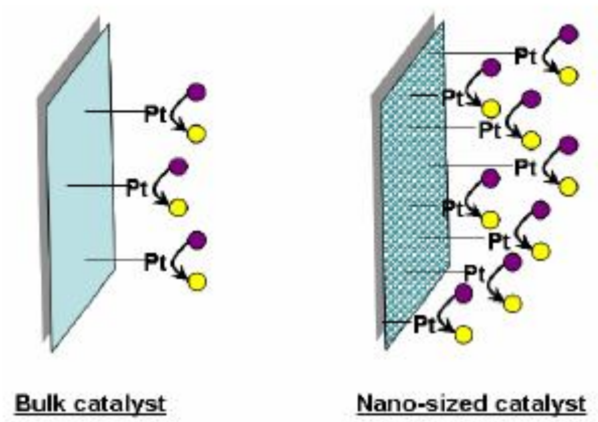


The increased surface-to-volume of nanomaterials impacts the material physical properties such as its melting and boiling points, as well as its chemical reactivity. Reactions that occur at the material surface are particularly affected, such as catalysis reactions, detection reactions, and reactions that require the physical adsorption of certain species at the material's surface to initiate.

Finally, the higher surface-to-volume of nanomaterials allows using less material, which has environmental and economic benefits, as well as fabricating highly miniaturized devices, which can be portable and could use less power to operate.

Catalysis

A catalyst is a substance that increases a chemical reaction rate without being consumed or chemically altered. Nature's catalysts are called enzymes and are able to assemble specific end-products, always finding pathways by which reactions take place with minimum energy consumption. Man-made catalysts are not so energy efficient. They are often made of metal particles fixed on an oxide surface. working on a hot reactant stream (to reduce a phenomenon called 'catalyst poisoning' which occurs when species dispersed in the atmosphere, such as CO, occupy the active sites of the catalysts). One of the most important properties of a catalyst is its 'active surface' where the reaction takes place. The 'active surface' increases when the size of the catalysts is decreased: the smaller the catalysts particles, the greater the ratio of surface-to-volume. The higher is the catalysts active surface, the greater is the reaction efficiency. Research has shown that the spatial organization of the active sites in a catalyst is also important. Both properties (nanoparticle size and molecular structure/distribution) can be controlled using nanotechnology. Hence, this technology holds great potential to expand catalyst design with benefits for the chemical, petroleum, automotive, pharmaceutical and food industry.



Detection

The detection of a specific chemical or biological compound within a mixture represents the basis for the operation of numerous devices, like chemical sensors, biosensors and microarrays. As with catalysis, a detection reaction occurs at the material surface. The rate, specificity and accuracy of this reaction can be improved using nanomaterials rather than bulk materials in the detection area. The higher surface-to-volume ratio of nanomaterials increases the surface area available for detection with a positive effect on the rate and on the limit of detection of the reaction. In addition, nanomaterials can be designed to have specific surface properties (chemical or biochemical), tailored at a molecular level.

Scaling down using nanomaterials allows packing more detection sites in the same device, thus allowing the detection of multiple analytes. This scaling-down capability, together with the high specificity of the detection sites obtainable using nanotechnology, will allow the fabrication of super-small 'multiplex detection devices'. Devices that can test and detect more than one analyte at the time will lower the cost of the analysis and reduce the number of devices needed to perform the analysis with an obvious economic benefit. Advancements in the field of nanoelectronics will also allow the fabrication of nanosensors capable of continuous, real time monitoring,

CONCLUSION :

In a sense, the study of atoms and molecules is the basis of most scientific disciplines, such as chemistry, biochemistry and physics. Nanomaterials are not all new either: nanocrystals, nano-sized catalysts, magnetic nanoparticles have been long studied for years now, for a variety of applications. Some 'nano-tools' are not that recent either: for instance, the Atomic Force Microscope (AFM) and the Scanning Tunnelling Microscope (STM) techniques were first introduced to the scientific community in the mid 1980s. 'Nanoscience' is therefore an umbrella term that covers traditional disciplines as well as new and emerging ones.

Here, we have been able to uncover enormous potentials of nanoscience and nanotechnology thanks to a new set of analytical and fabrication tools. These have allowed the systematic investigation of nanomaterials and the realization that the exceptional properties of matter at the nano-scale level can be use to build new materials, systems and devices with properties, capabilities and functions that could not be achieved if bulk materials were used. In this context nanotechnology can be thought of as an extension of traditional disciplines towards novel ones that explicitly consider these new properties.

At the same time, in recent years new nanomaterials have been intentionally fabricated or discovered, novel nano-tools have been developed and old ones implemented, and novel properties of the matter at the nano-scale level have been discovered. For these reasons, nanoscience and nanotechnology shouldn't be seen as entirely new but rather 'work-in-progress science'. A 'work' that finds its roots in disciplines, like chemistry and physics, where a lot of fundamental knowledge is well established, and that progresses towards fields and applications where new knowledge is currently being created and collected.

For those reasons, nanotechnology should be seen as an evolution, not a revolution

REFERENCES :

Bibliography and Web Sources

http://www.nanotecbproject.org/

https://hi.wikipedia.org/

https://web.pdx.edu/~pmoeck/phy381/intro-nanotech.pdf

National Nanotechnology Initiative (NN1): http://www.nano.gov

Nanotechnology for the Life Sciences (10 volume set), Challa S. S. R. Kumar (Editor), Wiley- VCH, 2007.

V. Wagner, A. Dullaart. A-K Bock, A. Zweck, The emerging nanomedicine landscape. Nature Biotechnology 2006, 24(10),1211-1217.

Nanofabrication Towards Biomedical Applications: Techniques, Tools, Applications, and Impact, C. S. S. R. Kumar, J. Hermes, C. Leuschner, Wiley-VCH, 2005.

Books :

The Diamond Age - Neal Stephenson, 1995

The Nano Flower, Peter F. Hamlton, 1995

Nanotechnology for Dummies : A Fun and Easy Way to Explore, Earl Boysen and Richard Booker