

PHYSICS RESEARCH PAPER

TOPIC : NANOSCIENCE AND NANOTECHNOLOGY

PRESENT BY STUDENT OF F.Y BTECH CSE DIV H

GUIDE : PROF.DEEPALI SONAWANE

**NAME : 1. RUTIKA B. BASTWAR
2. SEJAL S. YESHWANTKER**

DIV : H

ROLL NO : 69/55

An Introduction to Nanoscience & Nanotechnology

Abstract

In this paper we present an introduction to the principles and advances made in the fields of nanoscience and nanotechnology including inventions, discoveries and design and study of molecular building blocks (MBBs) studied through nanoscience and applied in nanotechnology. Nanoscience is the study of systems in nanoscale and nanotechnology is the ability to systematically organize and manipulate properties and behavior of matter in the atomic and molecular levels. Through nanoscience and nanotechnology it has become possible to study and create very useful functional devices, materials and systems on the 1 to 100 nanometer (one billionth of a meter) length scale.

The reasons why nanoscale has become so important are presented. Historical aspects of nanoscience and nanotechnology are introduced starting with the famous 1959 lecture by R.P. Feynman. Considering that recent inventions, discoveries and breakthroughs in atomic and molecular aspects of nanoscale systems have been quite frequent, a selected list of recent advances and future prospects familiar to the author are presented here.

Introduction

Even though the scientific community is fascinated with the field of nanoscience, most of the ongoing discussions, definitions and attentions are on nanotechnology. The shortest and most quoted definition of nanotechnology is the statement by the US National Science and Technology Council (NSTC, 2000) which states: *“The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization. The aim is to exploit these properties by gaining control of structures and devices at atomic, molecular, and supramolecular levels and to learn to efficiently manufacture and use these devices”*. In short nanotechnology is the ability to build micro and macro materials and products with atomic precision. Nanoscience is study of properties and behavior of condensed materials in nanoscale, study of natural nanoscale phenomena such as the fascinating field of bio-systems, and investigating the peculiarities of nanosystems (Mansoori, 2005).

The promise and essence of the nanoscale science and technology is based on the demonstrated fact that materials at the nanoscale have properties (i.e. mechanical, optical, chemical,

and electrical, etc.) quite different than the bulk materials. As an example, macromolecules and particles made of a limited number of molecules, in the size range of one to fifty nanometers possess distinct chemical (i.e., reactivity, catalytic potential, etc.), physical (i.e., magnetic, optical, etc.). Some of such properties are, somehow, intermediate between those of the smallest elements (atoms and molecules) from which they can be composed of and those of the macroscopic materials. Compared to bulk materials, it is demonstrated that nanoparticles possess enhanced performance properties when they are used in similar applications. An important application of nanoparticles is recognized to be the production of a new class of catalysts known as nanocatalysts. Significant advances are being made in this field contributing to the production and detailed understandings of the nature (composition, particle size, and structure) and role of nanoparticles as catalysts in improvement of chemical

reactions performances. This is because a catalyst performance is a strong function of its particles sizes and size distributions. Surface morphology, surface to volume ratio, and electronic properties of materials could change appreciably due to particle size changes. There are many present and expected advances in nanoscience and nanotechnology with applications in agriculture, electronics, energy, medicine, etc., which are rapidly increasing (Ghorbanpour, et al., 2015, Mansoori, 2005; Mansoori, et al., 2007; 2016).

The importance of nanoscale:

The Greek word "nano" (meaning dwarf) refers to a reduction of size, or time, by 10^{-9} , which is one thousand times smaller than a micron. One nanometer (*nm*) is one billionth of a meter and it is also equivalent to ten Angstroms. As such a nanometer is 10^{-9} meter and it is 10,000 times smaller than the diameter of a human hair. A human hair diameter is about 50 micron (i.e., 50×10^{-6} meter) in size, meaning that a 50 nanometer object is about $1/1000^{\text{th}}$ of the thickness of a hair. One cubic nanometer (nm^3) is roughly 20 times the volume of an individual atom. A nanosize particle compares to a basketball like a basketball to the size of the earth. Figure 1 shows size ranges for different nanoscale and microscale objects.

It is obvious that nanoscience and nanotechnology, all deal with very small sized objects and systems. Officially, the United States National Science Foundation (Roco, et al., 1999) defined nanoscience / nanotechnology as studies that deal with materials and systems having the following key properties: (1) Dimension: at least one dimension from 1 to 100 nanometers (*nm*). (2) Process: designed with methodologies that shows fundamental control over the physical and chemical attributes of molecular-scale structures. (3) Building block property: they can be combined to form larger structures. Nanoscience, in a general sense, is quite natural in biological sciences considering that the sizes of many bio-entities we deal with (like DNA, RNA, proteins, enzymes, viruses, etc.) fall within the nanoscale range of 1-100 nm.

Nanoscale is regarded as a magical point on the dimensional scale: Structures in nanoscale (called *nanostuctures*) are considered at the borderline of the smallest of human-made devices and the largest molecules of living systems. Our ability to control and manipulate nanostructures will make it possible to exploit new physical, biological and chemical properties of systems that are intermediate in size, between single atoms, molecules and bulk materials.

There are many specific reasons why nanoscale has become so important some of which are the following (Mansoori, 2005):

(i). Quantum mechanical (wavelike) properties of electrons inside matter are influenced by variations on the nanoscale. By nanoscale design of materials, it is possible to vary their micro and macroscopic properties, such as charge capacity, magnetization and melting temperature, without changing their chemical composition.

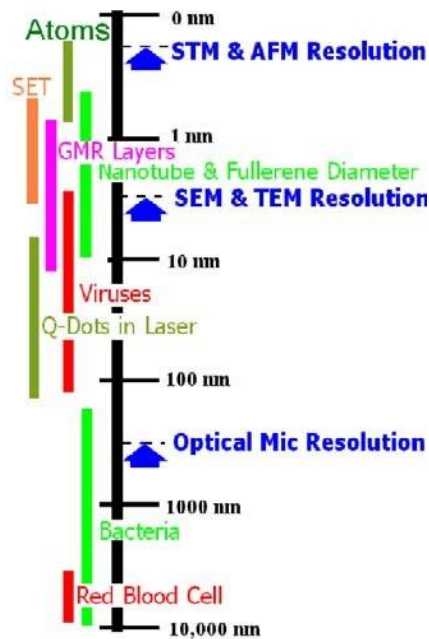


Figure 1. Comparison of size ranges for several entities as compared to some nanotechnology devices and various microscopes resolutions. AFM (atomic force microscope), GMR (giant magneto resistive), Q-DOTS (quantum dots), SEM (scanning electron microscope, SET (single-electron transistor), STM (scanning tunneling microscope), TEM (transmission electron microscope).

(ii) A key feature of biological entities is the systematic organization of matter on the nanoscale. Developments in nanoscience and nanotechnology has allowed us to place man-made nanoscale things inside living cells (Ebrahimi and Mansoori, 2014). It has also made it possible to study micro and macro structure of materials using molecular self-assembly (Xue and Mansoori, 2010). This certainly is a powerful tool in materials science.

(iii) Nanoscale components have very high surface to volume ratio, making them ideal for use in composite materials, reacting systems, drug delivery, and energy storage.

(iv) Macroscopic systems made up of nanostructures can have much higher density than those made up of microstructures. They can also be better conductors of electricity. This can result in new electronic device concepts, smaller and faster circuits, more sophisticated functions, and greatly reduced power consumption simultaneously by controlling nanostructure interactions and complexity.

Historical advances in nanoscience and nanotechnology

Although we have long been aware of many investigators who have been dealing with “nano” sized entities, the historic birth of nanotechnology is commonly credited to Richard P. Feynman. Historically nanotechnology was for the first time formally recognized as a viable field of research with the landmark lecture delivered by Feynman, the famous Noble Laureate physicist on December 29th 1959 at the annual meeting of the American Physical Society (Feynman, 1960). His lecture was entitled “*There’s Plenty of Room at the Bottom - An invitation to enter a new field of physics*”. Feynman stated in his lecture that the entire encyclopedia of Britannica could be put on

the tip of a needle and, in principle, there is no law preventing such an undertaking. Feynman described then the advances made in this field in the past and he envisioned the future for nanotechnology. His lecture was published in the February 1960 issue of Engineering & Science quarterly magazine of California Institute of Technology.

In his talk Feynman also described how the laws of nature do not limit our ability to work at the molecular level, atom by atom. Instead, he said, it was our lack of the appropriate equipment and techniques for doing so. Feynman in his lecture talked about "*How do we write small?*", "*Information on a small scale*", possibility to have "*Better electron microscopes*" that could take the image of an atom, doing things small scale through "*The marvelous biological system*", "*Miniaturizing the computer*", "*Miniaturization by evaporation*" example of which is thin film formation by chemical vapor deposition, solving the "*Problems of lubrication*" through miniaturization of machinery and nanorobotics, "*Rearranging the atoms*" to build various nanostructures and nanodevices, and behavior of "*Atoms in a small*

world" which included atomic scale fabrication as a bottom-up approach as opposed to the top-down approach that we are accustomed to. Bottom-up approach is self-assembly of machines from basic chemical building blocks which is considered to be an ideal through which nanotechnology will ultimately be implemented. Top-down approach is assembly by manipulating components with much larger devices which is more readily achievable using the current technology. It is important to mention that almost all of the ideas presented in Feynman's lecture and even more, are now under intensive research by numerous nanotechnology investigators all around the world.

Feynman in 1983 talked about a scaleable manufacturing system could be made which will manufacture a smaller scale replica of it (Feynman, 1993). That, in turn would replicate itself in smaller scale, and so on down to molecular scale. Feynman was subscribing to the "Theory of Self-Reproducing Automata" proposed by von Neumann the 1940's eminent mathematician and physicist who was interested in the question of whether a machine can self-replicate, that is, produce copies of itself {see (von Neumann, 1966) for details}. The study of man-made self-replicating systems has been taking place now for more than half a century. Much of this work is motivated by the desire to understand the fundamentals involved in self-replication and advance our knowledge of single-cell biological self-replications.

Some of the other important achievements about which Feynman mentioned in his 1959 lecture include the manipulation of single atoms on a silicon surface, positioning single atoms with a scanning tunneling microscope and the trapping of single, 3 nm in diameter, colloidal particles from solution using electrostatic methods.

In early 60's there were other ongoing research on small systems but with a different emphasis. A good example is the publication of two books on "Thermodynamics of Small Systems" by T.L. Hill in early 1960s. Thermodynamics of small systems is now called "nanothermodynamics" (Hill 1964; 2001; Mansoori, et al, 2005).

In 1960s when Feynman recognized and recommended the importance of nanotechnology the devices necessary for nanotechnology were not invented yet. At that time, the world was intrigued with space exploration, discoveries and the desire and pledges for travel to the moon, partly due to political rivalries of the time and partly due to its bigger promise of new frontiers that man had also not captured yet. Research and developments in small (nano) systems did not sell very well at that time with the governmental research funding agencies and as a result little attention was put in it by the scientific community.

It is only appropriate to name the nanometer scale "the Feynman (ϕ nman) scale" after Feynman's great contribution and we suggested the notation " ϕ " for it like Å as used for Angstrom scale and μ as used for micron scale over ten years ago (Mansoori, 2005).

One Feynman [ϕ] $\equiv$ 1 Nanometer [nm] = 10 Angstroms [$\text{\AA}$] = 10^{-3} Micron [μ] = 10^{-9} Meter [m]

Some key inventions and discoveries

Scanning Tunneling Microscope (STM): Nanotechnology received its greatest momentum with the invention of scanning tunneling microscope (STM) in 1985 by GK. Binnig and H Rohrer, staff scientists at the IBM's Zürich Research Laboratory (Binnig and Rohrer, 1985). That happened forty-one years after Feynman's predictions. To make headway into a realm of molecule-sized devices, it would be necessary to survey the landscape at that tiny scale. Binnig and Rohrer's scanning tunneling microscope offered a new way to do just that. STM allows imaging solid surfaces with atomic scale resolution. It operates based on tunneling current, which starts to flow when a sharp tip is mounted on a piezoelectric scanner approaches a conducting surface at a distance of about one nm (1ϕ). This scanning is recorded and displayed as an image of the surface topography. Actually, the individual atoms of a surface can be resolved and displayed using STM.

Atomic Force Microscope (AFM): After the invention of STM it was quickly followed by the development of a family of related techniques which, together with STM, may be classified in the general category of Scanning Probe Microscopy (SPM) techniques. Of the latter technologies, the most important is undoubtedly the atomic force microscope (AFM) developed in 1986 (Binnig, et al., 1986). Figure 2 shows schematic of two typical AFMs that we use in our laboratory at UIC.

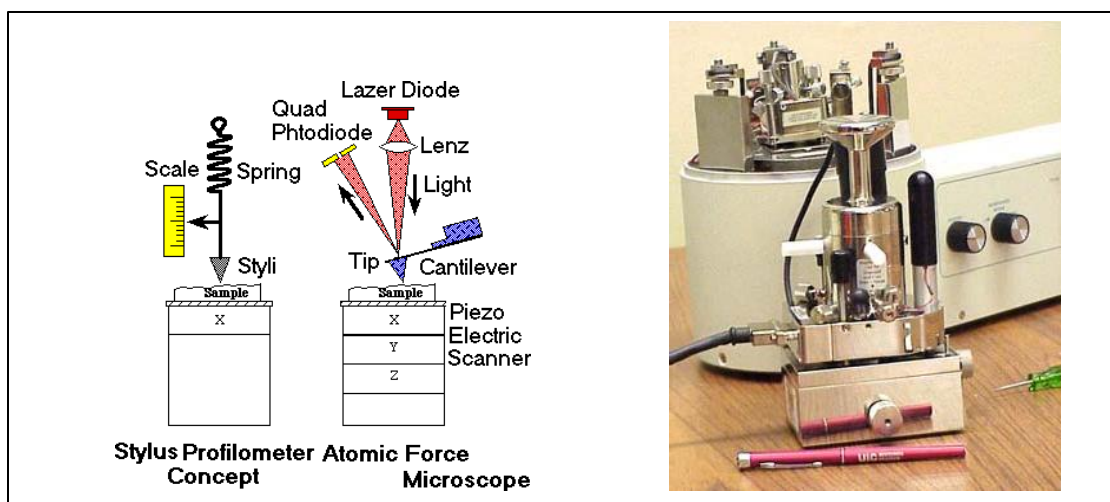


Figure 2: Schematic of a typical AFM and its function as compared with a stylus profilometer. As it is shown an AFM has similarities to a conventional stylus profilometer, but with a much higher resolution in nano scale. In the right-hand side pictures of two AFMs are shown (Mansoori, 2005).

AFMs are a combination of the principle of STM and the stylus profilometer. It enables us to study non-conducting surfaces, because it scans van der Waals forces with its "atomic" tips. The main components of AFM are a thin cantilever with extremely sharp ($1-10$ nm [ϕ] in radius) probing tip, a 3D piezo-electric scanner, and optical system to measure deflection of the cantilever. When the tip is brought into contact with the surface or in its proximity, or is tapping the surface, it being affected by a combination of the surface forces (attractive and repulsive). Those forces cause

cantilever bending and torsion, which is continuously, measures via the deflection of the reflected laser beam. 3D scanner moves the sample or, in alternative designs, the cantilever, in 3 dimensions thus scanning predetermined area of the surface. A vertical resolution of this tool is extremely high reaching 0.01 nm [ϕ] is on the order of atomic radius).

Diamondoid Molecules (a.k.a. Nanodiamonds): Diamondoid molecules are saturated hydrocarbons that have diamond-like fused ring structures which can have applications in nanotechnology (Mansoori, et al., 2012). They have the same structure as the diamond lattice, i.e., highly symmetrical and strain free. Diamondoids offer the possibility of producing variety of nanostructural shapes. They have quite high strength, toughness, and stiffness compared to other known molecule. The smallest diamondoid molecule was first discovered and isolated from a Czechoslovakian petroleum in 1933. The isolated substance was named adamantane, from the Greek for diamond. This name was chosen because it has the same structure as the diamond lattice, highly symmetrical and strain free as shown in Figure 3.

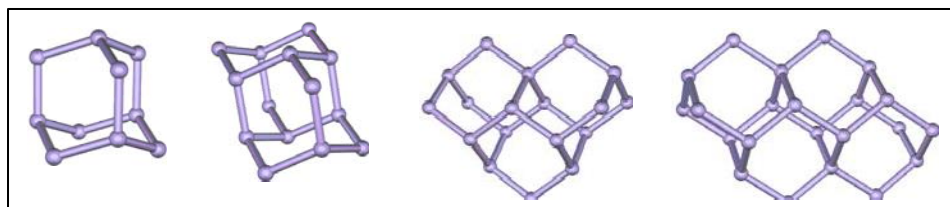


Figure 3: Chemical structures of diamondoid molecules also known as nanodiamonds. These compounds have diamond-like fused ring structures which can have many applications in nanotechnology. They have the same structure as the diamond lattice, i.e., highly symmetrical and strain free. The rigidity, strength and assortment of their 3-d shapes make them valuable molecular building blocks (Mansoori, et al., 2012).

It is generally accompanied by small amounts of alkylated adamantanes: 2-methyl-; 1-ethyl-; and probably 1-methyl-; 1,3-dimethyl; and others. From the nanobiotechnology point of view diamondoids are in the category of organic nanostructures (Mansoori, et al., 2012).

The unique structure of adamantane is reflected in its highly unusual physical and chemical properties. The carbon skeleton of adamantane comprises a small cage structure. Because of this, adamantane, and diamondoid molecules in general, are commonly known as cage hydrocarbons. In a broader sense they may be described as saturated, polycyclic, cage-like hydrocarbons. The diamond-like term arises from the fact that their carbon atom structure can be superimposed upon a diamond lattice. The simplest of these polycyclic diamondoids is adamantane, followed by its homologues diamantane, tria-, tetra-, penta- and hexa-mantane.

Diamondoid molecules are named as the building blocks for nanotechnology (Dahl, et al. 2003; Mansoori, et al., 2012). In Table 1 we report an alphabetical list of applications of diamondoids in biomedicine, materials science, nanotechnology (Mansoori, 2012; 2013; Ramezani and Mansoori, 2007).

Table 1. *Major Applications of Diamondoids and Derivatives*

- Antiviral drug
- Cages for drug delivery
- Crystal engineering
- Designing molecular capsules
- Design of new antidotes
- Diamondoid-DNA nanoarchitectures
- Drug delivery (they can easily pass through blood-brain barrier due to their lipophilicity / hydrophobicity)
- Drug targeting
- Fighting infectious viral diseases (influenza etc.)
- Fighting infectious bacterial diseases (tuberculosis, etc.)
- Fighting infectious parasitic diseases (malaria, etc.)
- Fighting cancer (new antineoplastic agents)
- Gene delivery
- Hypoglycemic action (drugs for diabetes treatment, etc.)
- In designing an artificial red blood cell, called Respirocyte
- In host-guest chemistry and combinatorial chemistry
- MEMS
- Molecular machines
- Molecular probe
- Nanodevices
- Nanorobotics
- Nanofabrication
- Nanocomposites
- Nanomodule
- NEMS
- Neuroprotective effect (for Alzheimer`s disease, etc.)
- Organic MBBs in formation of nanostructures
- Pharmacophore-based drug design
- Polymer, co-polymers
- Positional assembly
- Power cells overcharge protecting compounds
- Preparation of fluorescent molecular probes
- Prodrugs
- Rational design of multifunctional drug systems and drug carriers
- Self-assembly: DNA directed self-assembly, host-guest chemistry
- Shape-targeted nanostructures
- Synthesis of supramolecules with manipulated architecture
- The only semiconductors which show a negative electron affinity
- Microelectronics (thermally conductive films in integrated circuit packaging, low-k dielectric layers in integrated circuit multilevel interconnects, thermally conductive adhesive films, thermally conductive films in thermoelectric cooling devices, passivation films for integrated circuit devices (ICs), and field emission cathodes)

Nano allotropes of carbon:

Fullerene (a.k.a. Buckyballs): Buckminsterfullerene (or fullerene), C₆₀, as is shown in Figure 4 is a nano allotrope of carbon, which was discovered in 1985 by Kroto and collaborators (Kroto, et al., 1985). These investigators used laser evaporation of graphite and they found C_n clusters (with n>20 and even-numbers) of which the most common were found to be C₆₀ and C₇₀. For this discovery, Curl, Kroto and Smalley were awarded the 1996 Nobel Prize in Chemistry. Later fullerenes with larger number of carbon atoms (C₇₆, C₈₀, C₂₄₀, etc.) were also synthesized. Since the time of discovery of fullerenes about three decades ago, a great deal of investigation has gone into these nanostructures. Several more efficient and less expensive method to produce fullerenes have been developed (Eliassi, et al., 2002; Valand and Patel, 2015). Availability of low cost fullerene will pave the way for further research into practical applications of fullerene and its role in nanotechnology.

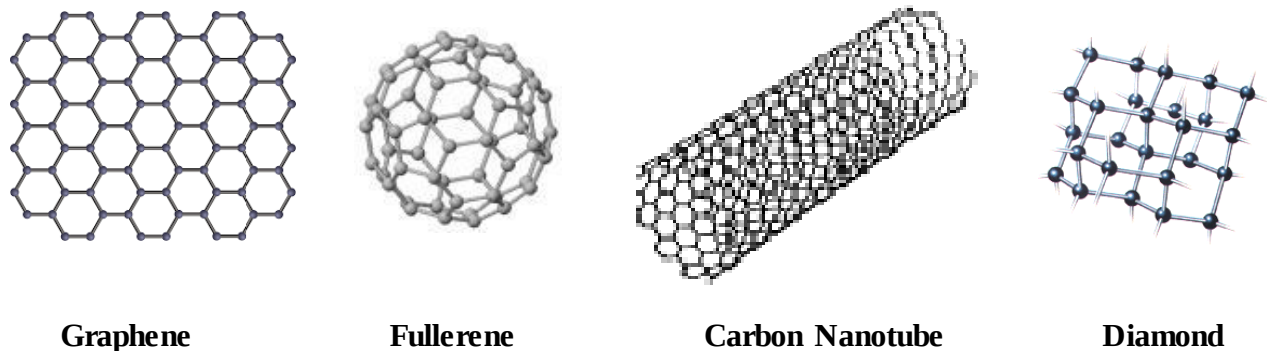


Figure 4: Nano allotropes of carbon.

Carbon Nanotubes: Carbon nanotube was discovered in 1991 (Iijima, 1991) using an electron microscope while studying cathodic material deposition through vaporizing carbon graphite in an electric arc-evaporation reactor under an inert atmosphere during the synthesis of Fullerenes (Iijima and Ichihashi, 1993). The nanotubes produced by Iijima and coworkers appeared to be made up of a perfect network of hexagonal graphite, Figure 4, rolled up to form a hollow tube. The nanotube diameter range is from one to several nanometers which is much smaller than its length range which is from one to a few micrometers. A variety of manufacturing techniques has since been developed to synthesize and purify carbon nanotubes with tailored characteristics and functionalities. Controlled production of single-walled carbon nanotubes is one of the favorite forms of carbon nanotube which has many present and future applications in nanoscience and nanotechnology. Laser ablation chemical vapor deposition joined with metal-catalyzed disproportionation of suitable carbonaceous feedstock are often used to produce carbon nanotubes (Morris and Iniewski, 2013).

Graphene: Graphene is a two-dimensional nano allotrope of carbon, one atom thick composed of, hexagonal lattice (Figure 4). One atom forms each of its vertex, very strong, flexible, transparent, and conductive of electricity. Graphene may be considered as an indefinitely large aromatic molecule, the limiting case of the family of flat polycyclic aromatic hydrocarbons. Graphene was first studied at a theoretical level in 1940s, but it wasn't practically pursued until the 1970s (Morris and Iniewski, 2013). Graphite is made of millions of layers of graphene. In 2003 Geim and Novoselov extracted graphene from graphite using Scotch tape. They published their research the

following year (Novoselov and Geim, 2004). They received the 2010 Nobel Prize for Physics for their investigations on graphene. Graphene is presently considered as a wonder material with many superlatives to its name. Since it is one atom thick, it is the thinnest material in use and quite strong and stiff. Graphene electrical conductivity is reported to be six orders higher than copper and its thermal conductivity is also quite high. It is impermeable to gases and reconciles such conflicting qualities as brittleness and ductility. Electron transport in graphene is described by a Dirac-like equation, which allows the investigation of relativistic quantum phenomena in a bench-top experiment. Presently there are many projects worldwide investigating the potential of graphene for a variety of applications. Graphene research is expanding quite fast and several publications appear in the literature about graphene every day which makes it a real struggle to keep up with the developments. Research on graphene's electronic properties is now quite matured. It is expected that graphene will continue to stand out as a truly unique molecular building block (MBB) in the field of nanotechnology. Research on various properties of graphene is in progress, and it may bring up new phenomena (Morris and Iniewski, 2013).

Metallic and oxide molecular building blocks (MBBs) of nanotechnology:

Michael Faraday is credited for the first person who recognized the existence of metallic nanoparticles (MNPs), especially gold nanoparticles, in solution in 1857. Later in 1908, Gustav Mie gave a quantitative explanation of MNPs color. MNPs, which are in size between molecular and metallic states possess specific electronic structure which include local density of states; plasmon excitation; quantum confinement; short range ordering; increased number of kinks; a large number of low-coordination sites (such as corners and edges), having a large number of "dangling bonds" and consequently specific and chemical properties and the ability to store excess electrons. Among all MNPs gold nanoparticles and silver nanoparticles have found more extensive and interesting applications in the fields of agriculture, energy and medicine (Hatami and Ghorbanpour, 2014; Ghorbanpour and Hatami, 2015; Mansoori, et al. 2010; Vahabi, et al., 2011; 38, 39).

Considering the existence of variety of metals, we are able to form a large diversity of oxide nanoparticles (ONPs) from such oxides as Al_2O_3 , MgO , ZrO_2 , CeO_2 , TiO_2 , ZnO , Fe_2O_3 , Fe_3O_4 , SnO , just to name a few. Oxides generally possess a vast number of structural geometries with varied electronic structure that can exhibit metallic, semiconductor or insulator character. ONPs can exhibit unique physical and chemical properties due to their limited size and a high density of corner or edge surface sites. For example, during the past two decades, research and development in the area of synthesis and applications of different nanostructured titanium dioxide have become tremendous (Aghdam, et al., 2015; Ghorbanpour, 2015; Ghorbanpour, et al., 2015; Hatami, et al., 2014; Khataee and Mansoori, 2011). TiO_2 nanomaterials can assume the forms of nanoparticles, nanorods, nanowires, nanosheets, nanofibers, and nanotubes. Many applications of TiO_2 nanomaterials are closely related to their optical properties. Examples of applications of nanostructured titanium dioxide include in dye-sensitized solar cells, hydrogen production and storage, sensors, rechargeable batteries, electrocatalysis, self-cleaning and antibacterial surfaces, cancer treatment, photocatalytic removal of various pollutants, TiO_2 -based nanoclays.

Biological molecular building blocks (MBBs) of nanotechnology:

At the same time that physical scientists and engineers have been experimenting with organic and inorganic nanostructures as mentioned above, bio- and medical-scientists and -engineers have been making their own advances with other nanoscale structures known as biological molecular building blocks (MBBs) like cyclodextrins, liposomes, monoclonal antibodies, etc. (Mansoori, 2015; Mansoori, et al., 2007). These nanostructures have specific applications in bio systems/drug-delivery and -targeting. Cyclodextrins, as shown in Figure 5, are cyclic oligosaccharides.

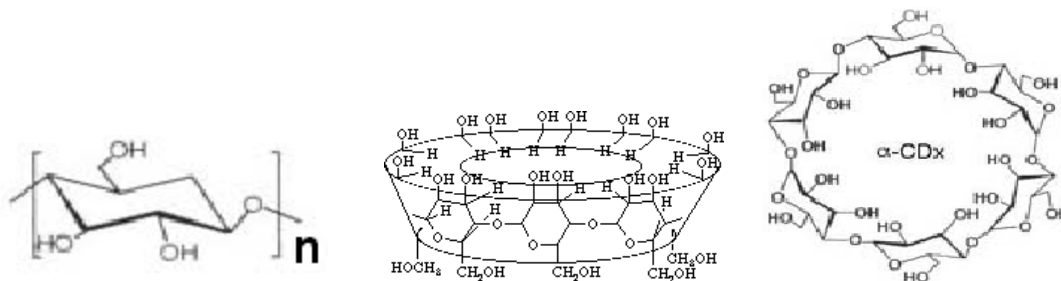


Figure 5: Chemical formula and structure of Cyclodextrins – For $n=6$ it is called α -CDx, $n=7$ is called β -CDx, $n=8$ is called γ -CDx. Cyclodextrins are cyclic oligosaccharides. Their shape is like a truncated cone and they have a relatively hydrophobic interior. They have the ability to form inclusion complexes with a wide range of substrates in aqueous solution. This property has led to their application for encapsulation of drugs in drug delivery (Mansoori, 2005).

Their shape is like a truncated cone and they have a relatively hydrophobic interior. They have the ability to form inclusion complexes with a wide range of substrates in aqueous solution. This property has led to their application for encapsulation of drugs in drug delivery. Liposomes, which are also in nanoscale size range as shown in Figure 6, self-assemble based on hydrophilic and hydrophobic properties and they encapsulate drugs inside.

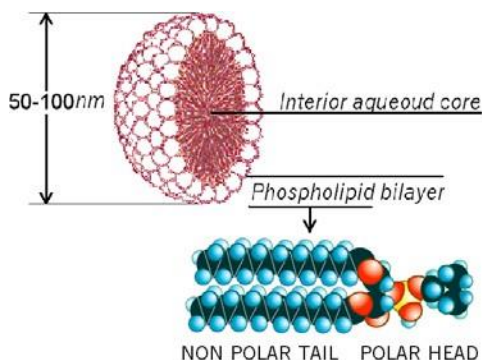
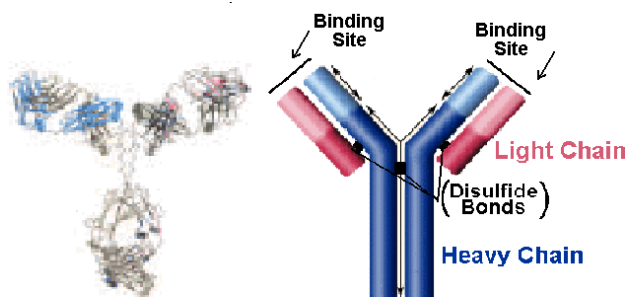


Figure 6: Cross section of a liposome composed of the phospholipid DSPC (Distearoyl phosphatidylcholine) and cholesterol – A spherical bilayer which is quite similar to a micelle. It is made of a bilayer with an internal aqueous compartment. Liposomes vesicles can be used as drug carriers and loaded with a great variety of molecules, such as small drug molecules, proteins, nucleotides and even plasmids (Mansoori, 2005).

Many commercially available anticancer drugs are cyclodextrins or liposome loaded with 100 or less nanometer in diameter. A monoclonal (derived from a single clone) antibody molecule consists of four protein chains, two heavy and two light, which are folded to form a Y-shaped structure (see Figure 7).



Antibody & its Structure

Figure 7: Antibody and its structure (Mansoori, 2005).

It is about ten nanometers in diameter. This small size is important, for example, to ensure that intravenously administered these particles can penetrate small capillaries and reach cells in tissues where they are needed for treatment.

Conclusions and discussion:

The atomic-scale and cutting-edge fields of nanoscience and nanotechnology, which are considered to lead us to the next industrial revolution are likely to have a revolutionary impact on the way things will be done, designed and manufactured in the future.

Results of research and developments in these fields are entering into all aspects of our lives including, but not limited to, aerospace, agriculture, defense, energy, environment, materials, manufacturing, medicine, etc. It is truly an atomic and molecular approach for building biologically, chemically and physically stable structures one atom or one molecule at a time. Presently some of the active nanoscience and nanotechnology research areas include nanolithography, nanodevices, nanorobotics, nanocomputers, nanopowders, nanostructured catalysts and nanoporous materials, molecular manufacturing, nanolayers, molecular nanotechnology, medicine (such as Alzheimer's disease (Nazem and Mansoori, 2008; 2014) and cancer (Ebrahimi and Mansoori, 2014; Mansoori, et al., 2007; 2010) prediction, prevention and treatment through nanotechnology), nanobiology, organic nanostructures to name a few.

We have known for many years that several existing technologies depend crucially on processes that take place on the nanoscale. Adsorption, lithography, ion-exchange, catalysis, drug design, plastics and composites are some examples of such technologies. The "nano" aspect of these technologies was not known and, for most part, they were initiated accidentally by mere luck. They were further developed using tedious trial-and-error laboratory techniques due to the limited ability of the times to probe and control matter on nanoscale. Investigations at nanoscale were left

behind as compared to micro and macro length scales because significant developments of the nanoscale investigative tools have been made only recently.

The above-mentioned technologies, and more, stand to be improved vastly as the methods of nanoscience and nanotechnology develop. Such methods include the possibility to control the arrangement of atoms inside a particular molecule and, as a result, the ability to organize and control matter simultaneously on several length scales. The developing concepts of nanoscience and nanotechnology seem pervasive and broad. It is expected to influence every area of science and technology, in ways that are clearly unpredictable.

Advances in nanoscience and nanotechnology will also help solve other technology and science problems. For example, we have realized the benefits that nanostructuring can bring to (Mansoori, 2005):

- (a) Wear-resistant tires made by combining nanoscale particles of inorganic clays with polymers as well as other nanoparticle reinforced materials.
- (b) Greatly improved printing brought about by nanoscale particles that have the best properties of both dyes and pigments as well as advanced ink jet systems.
- (c) Vastly improved new generation of lasers, magnetic disk heads, nanolayers with selective optical barriers and systems on a chip made by controlling layer thickness to better than a nanometer.
- (d) Design of advanced chemical and biosensors.
- (e) Nanoparticles to be used in medicine with vastly advanced drug delivery and drug targeting capabilities.
- (f) Chemical-mechanical polishing with nanoparticle slurries, hard coatings and high hardness cutting tools.
- (g) Methods of nanotechnology could provide a new dimension to the control and improvement of living organisms.
- (h) Photo-lithographic patterning of matter on the micro scale has led to the revolution in microelectronics over the past few decades. With nanotechnology, it is becoming possible to control matter on every important length scale, enabling tremendous new power in materials design.
- (i) Biotechnology is being influenced by research in nanoscience and nanotechnology greatly. It is anticipated that, for example, this will revolutionize healthcare to produce ingestible systems that will be harmlessly flushed from the body if the patient is healthy but will notify a physician of the type and location of diseased cells and organs if there are problems.
- (j) Micro and macro systems constructed of nanoscale components are expected to have entirely new properties that have never before been identified in nature. As a result, by altering and design of the structure of materials in the nanoscale range we would be able to systematically and appreciably modify or change selected properties of matter at macro and micro scales. This would include, for example, production of polymers or composites with most desirable properties which nature and existing technologies are incapable of producing.
- (k) Robotic spacecraft that weigh only a few pounds are being flown out for various exploratory missions.
- (l) Nanoscale traps will be constructed that will be able to remove pollutants from the environment and deactivate chemical warfare agents. Computers with the capabilities of current workstations will be the size of a grain of sand and will be able to operate for decades with the equivalent of a single wristwatch battery.
- (m) There are many more observations in the areas of agricultural applications (Ghorbanpour, et al., 2015; Ghorbanpour and Hadian, 2015; Ghorbanpour and Hatami, 2015) inks and dyes, protective coatings, dispersions with optoelectronic properties, nanostructured catalysts,

high reactivity reagents, medicine, electronics, structural materials, and energy conversion, conservation, storage and usage (Mansoori, et al., 2016) which are also worth mentioning.

(n). Many large organic molecules are known to forming organic nanostructures of various shapes as shown in Figures 3 and 8 the driving force of which is the intermolecular interaction energies between such macromolecules (Mansoori, 2002; Priyanto, et al., 2001; Rafii-Tabar and Mansoori, 2004).

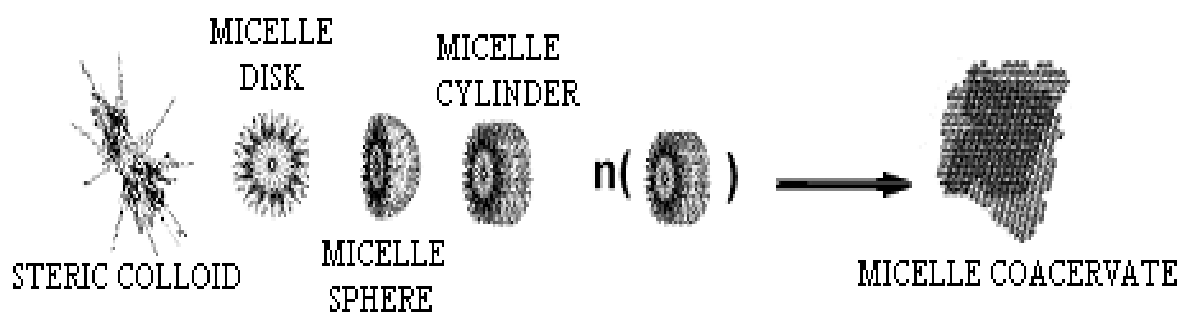


Figure 8: Organic nanostructure self-assemblies of various shapes
(Mansoori, 2002; Priyanto, et al., 2001)

There has been an appreciable progress in research during the past few years on organic nanostructures, such as thin film nanostructures, which have excellent potential for use in areas that are not accessible to more conventional, inorganic nanostructures. The primary attraction of organic nanostructures is their potential for molding, coating, and the extreme flexibility that they have in being tailored to meet the needs of a particular application. The organic nanostructures materials are easily integrated with conventional inorganic nanostructures (like semiconductor devices), thereby providing additional functionality to existing photonic circuits and components. Some progress has been made in understanding the formation and behavior of organic nanostructures that might be formed to serve as elements of nanomaterials and also on synthetic strategies for creating such structures (Mansoori, 2002; Priyanto, et al., 2001; Rafii-Tabar and Mansoori, 2004). The ultimate goal is to achieve a better understanding of the fundamental molecular processes and properties of these nanostructures which are dominated by grain boundaries and interfaces. In understanding the behavior and the properties of these nanostructures the potential for technological applications will be considered.

Many other unpredictable advances resulting from nanotechnology are inevitable. Thus, the future prospects for nanotechnology actually represent a revolutionary super-cutting-edge field that is expected to eventually become the foundation for such currently disparate areas as, and many others that we cannot even foresee at this time. It is then no wonder that it is considered to lead the humanity to the next industrial revolution.