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A Systematic Knowledge of Nanoparticles and Nanotechnology – A Review

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Abstract
The main aim is to describe the journey to beautiful and useful word Nano. Nano stands for one billionth. In science & technology, Nano stands for one billionth of meter, 1nm-10^{-9} m. Nanoparticles and nanotechnology words are relatively new but nanoparticles themselves has been around and studied long before the word were used. The beautiful colours of stained glass windows are a result of the presence of small metal oxide clusters in glass, having a size comparable to the wavelength of light. Particles of different sizes scatter different wavelength of light, imparting different colours to the glass. In photography the small colloidal particles of silver are a part of the processes of image formation and water at ambient temperature consists of clusters of hydrogen bonded water molecules. The description of variation of properties of nanoparticle with size, practical application of nanotechnology, uses in defence and biotechnology and as well as disadvantage of nanotechnology are given in this article.

Keywords: Nanoparticles, Nanotechnology, Clusters, Superfluidity, Neurosurgery.

Introduction

Nano is a Greek word, 'Nanos' meaning dwarf [1]. It is a prefix used to describe "one billionth" of something. Richard Feynman, a Nobel Laureate, in 1959 said "Small is beautiful", in his lecture delivered American physical society. He also said that the principles of Physics do not speak against the possibility of manoeuvering things atom by atom. This was his vision and his dream is becoming true.

In fact, nanomaterials and nanotechnology are not the new things. People were using nanomaterials since last 4-5 centuries without knowing that the material they are working with were nanomaterials (Where the size of the particle - 10^{-9}m) as there was no technology available to measure or see this small size. Michel Faraday has synthesized stable gold colloidal particles of nano size in 1857 A.D. A human body is also fitted with nano machines by nature.

On reducing the size particle of a material there is a drastic change in its mechanical, thermal, optical, structural, electrical and other properties and in this way within the same material one can get a range of properties.

Science and technology dealing with particle size of few nanometers are known as nanoscience and nano technology respectively. Some of the nanostructures are quantum dots, carbon nanotubes, conducting polymers based thin films etc. Nanotechnology have applications in all walks of life: electronics, medicine, defence, biotechnology, agriculture, communication, computer, nano machines, devices, sensors etc. and it seems that fictions are being converted into scientific reality.

Since nanometer size grains, fibers and plates have dramatically increased surface area compared to their conventional size materials, the chemistry of these nano sized materials is altered compared to conventional materials. It is known that atoms and molecules possess totally different behaviors than those of bulk materials; while properties of the former are described by quantum mechanics, properties of the latter are governed by classical mechanics. Between these two distinct domains, nanometer range is a gloomy threshold for the transition of material's behavior. For example, ceramics, which normally are brittle can easily be made deformable when their grain is reduced to nanometer range. A gold particle of 1nm across shows red color. Moreover, a small amount of nano size species can interfere with matrix polymer that is usually in the similar size range, bringing up the performance of resultant system to an unprecedented level. These are the reasons why nanotechnology has attracted large amount of federal funding, research activity and media attention.

Thus nanotechnology has been recognized by leading industrialized countries to be of potential key economic significance in the 21st Century[2].

Variation of properties of nanoparticles with size

Nanoparticles are usually considered to be a number of atoms or molecules bonded together with radius of <100 nm. A nanometer is 10^{-9} m or 10 A^0, as particles having a radius of about $\leq$ 1000 A^0 can considered to be nanoparticles. Fig. (1) gives a distinction between molecules, nanoparticles and bulk according to the number of the atoms in cluster and radius of clusters [3,4].

No. of atoms	radius(nm)		
1	1	molecules	
10			
10^2	10	Nanoparticles	
10^3			
10^4			
10^5			
10^6			
		Bulk	

Fig. 1- Distinction Between Molecules, Nanoparticle, And Bulk According To The Number Of Atoms In Cluster And Radius Of Clusters.

This definition based on size is not totally satisfactory because it does not really distinguish between molecules and nanoparticles. For example, a cluster of one nanometer radius (i.e., molecules) has approximately 25 atoms. But many molecules contain more than 25 atoms, particularly biological molecules. For example, the heme molecule $FeC_{34}H_{12}O_4N_4$ which is incorporated in hemoglobin molecules in human blood and transport oxygen to the cells, contains 75 atoms. The unique properties of nanoparticles is that their size is smaller than critical lengths that characterize many physical phenomena. Generally, physical properties of materials can be characterized by some critical length, for example, a thermal diffusion length, or a scattering length. The electrical conductivity of a metal is strongly determined by the distance that electrons travel between collisions with the vibrating atoms or impurities

of the solid, this distance is called the mean free path or the scattering length. If the size of the particles are less than these characteristic lengths, it is possible that new physics or chemistry may occur.
Superfluidity can be understood by the example of the clusters [3,5,6,7]. The clusters of He^4 and He^3 atoms formed by supersonic free-jet expansion of helium gas have been studied by mass spectrometry. One of the more unusual properties displayed by clusters is the observation of superfluidity in He clusters having 64 and 128 atoms. Super-fluidity is the result of the difference in the behavior of atomic particles having half-integer spins called fermions and particles having integer spins called bosons. The difference between them lies in the rules that determine how they occupy the energy levels of a system. Fermions such as electrons are only allowed to have two particles in each energy level with their spins oppositely aligned. On the other hand boson do not have this restriction. This means as the temperature is lowered and more and more of the lower levels become occupied, bosons can all occupy the lowest levels. Fig.2 illustrates the difference.
When all the bosons are in the lowest level, this state is known as Bose-Einstein condensation. In this case the wavelength of each boson is same as every other, and all the waves are in phase. When boson condensation occurs in liquid He^4 at temperature 2.2 K, called lambda(Λ) point, the liquid helium becomes as superfluid and its viscosity drops to zero. Normally when a liquid is forced through a small thin tube, it moves slowly because of the friction with walls, and increasing the pressure at one end increases the velocity. In the superfluid state the liquid moves quickly through the tube, and increasing the pressure at one end does not change the velocity. The transition to the superfluid state at 2.2K is marked by discontinuity in the specific heat known as the lambda transition. The specific heat is the amount of heat energy required to raise the temperature of one gram the material by 1K.

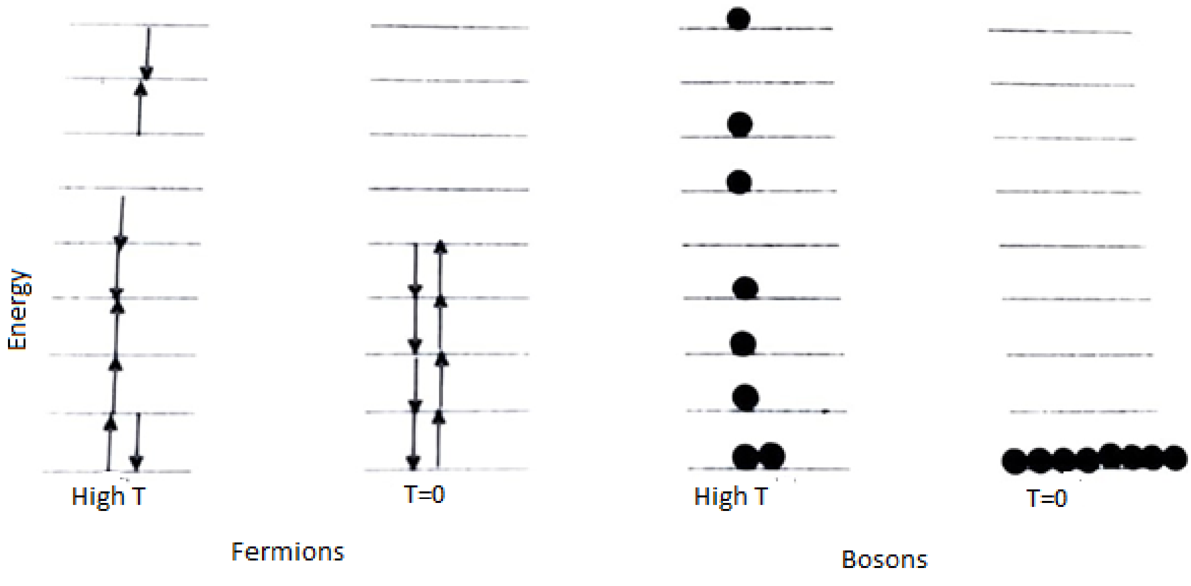

Fig.2 Illustration of how fermions and bosons distribute over the energy levels of a system at high and low temperature.

Thus a number of physical phenomena become pronounced as the size of the system decreases. These include statistical mechanical effects as well as quantum mechanical effects. e.g.,

1. The hardness of copper increase with decreasing grain size.
2. Ohm's law V=IR is not obeyed by a nano scale [8].

3. Bulk gold (inert) can change into nano-gold (highly reactive) under the specific conditions.

The confinement of electrons, holes polarons & bi-polarons due to size reduction gives rise to discrete energy levels and increased band gaps in inorganic materials and polymers. This confinement of carriers is usually known as quantum confinement. Maximum benefit of quantum confinement is experienced when the size of micro-crystallites approaches 1-3nm. The properties which are affected while working at nanoscale are following-

- Electrical and electronic properties
- Optical properties
- Magnetic properties
- Opto-electronic properties
- Modification of surface topography
- Mechanical strength and stress endurance

Practical application of nanotechnology:

There is a vast of practical application of nanotechnology

- Solid state active devices technology, Very large scale integration (VLSI) electronics, optoelectronics, frequency doubling communication etc.
- Photovoltaics
- Nano -films
- Neno-sensors
- Energy Nano -materials
- Green Nano technology [9]
- Light emitting devices
- Nano electronics
- Molecular electronic components
- Nanoelectromechanical sensors
- Shaping electricity by nano-plastics
- Acquiring body information using nano-crystalline polymer sensors.
- Nano and micro sensors for monitoring environment and Microbiological activity.
- Data storage on molecular tape, data storage on diamond.
- Magnetic memory devices, disc storage magnetic tapes and sheets, cards, magnetic nonlinear optical devices.
- Carbon nano tube electronic components.
- Develop a coated polymer micro sphere containing an antibiotic that can destroy the streptococcus pyogenes bacteria etc. Alain Mac Diarmid (A 2000 Noble laureate for chemistry) has created fibers with a diameter of approximately 4 nanometers (~50,000 time thinner than human hair). His aim is to combine the fields of electronic organic polymers and electronic Nano fibers to develop a new field of “nano electronics”.

Improvement in carbon Nanotubes

Carbon nanotubes have been recognized as fascinating materials with nanometer dimensions promising exciting new areas of carbon chemistry & physics. Carbon nanotubes are today recognized as the strongest material with the theoretical single walled carbon nanotube (SWCNT) estimated as 50 to 100 times stronger than steel. These tubes, therefore, are exciting candidates as a reinforcement for new generation super-strong composites. Based on tremendous stress endurance of such carbon nanotubes, scientists envision a space elevator into space (above one lakh kilometers long) that could rise a satellite in geosynchronous orbit [10]. It will be lightweight and cost effective as well. It may really make science fiction into reality.

The most perfect application using nanotubes may eventually be molecular electronics, Synthesis of carbon nanotubes by reduction of carbon dioxide with metallic as done by Zheng song Lou et al [11] and deposition of tailored structures by R. Vajtai et.al. [12] promises potential application of these single walled structures to fabricate electronic devices, Y, X and T structure tubes may work as 2 or 3 terminal devices and molecular transistors. Y. Saito [13] has demonstrated a systematic study on carbon nanotube emitters using both single walled and multi-walled nanotubes [MWNT]. The advantages of carbon nanotubes as electron field emitters include their small radius, higher aspect ratio, high chemical resistance and strong mechanical strength.

Uses in Defence

The list of possibilities of using nanotechnology in defence is long which include protection armers, invisibility ware, fuel economy, lighter and stronger craft/ships/vehicles manufacturing and radar undetected planes, global information network and submarines by electromagnetic camouflage. These are the most focused applications in nanotechnology to develop Marine, Air force and even battlefield [14].

Biotechnological Applications

Lab on -e-Pill Technology:

The lab on-e-pill can be manufactured to be the size of an aspirin tablet with the help of nanotechnology and can run for up to 40 hours. This is enough time for it to sense chemicals, which might be markets for diseases, as it passes through the intestine.

A New Drug for the Treatment of Burns and Wounds:

Drug Controller General of India (DCGI) has granted permission for the manufacture of a new formulation,' nano-crystalline Silver Gel' developed by Agharkar Research Institute, Pune for the treatment of burns, wound infections, diabetic feet, bed sores, etc.

Quantum Dot Imaging of Cancer in Live Animals:

Artificial High Density Lipo-Protein (HDL) to control Low Density Lipo-Protein (LDL). International Institute for Nanotechnology at North Western University Chigago has fabricated artificial HDL using nanotechnology which when administered into human body causes extra LDL to flush out through urine and avoids heart collapse. The artificial HDL is fabricated with the help of gold nanoparticles. A coated polymer micro been developed which combines an antibiotic that can destroy streptococcus pyogenes bacteria [15,16].

Application in Neuro-surgery:

The most important application of nanotechnology is deciphering brain function. An integrated approach for monitoring neuronal anatomy, chemistry and electronics appears to be ideal in this regard. Carbon neon-tubes (CNT) can monitor both electrical and chemical activity at single neuron level. These CNT can be arranged into arrays for electrical or chemical monitoring for prolonged periods of time. Similarly nanowire electrodes placed in capillaries can be utilized for electrical recording from neurons. Such arrays can also be used for deep brain stimulation for patients with epilepsy. Parkinson's disease, essential tremor, and multiple other application under development [17,18].

Quantum dots (Qdots) and Florence resonance energy transfer (FRET) have immense clinical potential. Qdots are nanocrystals which consist of a shell surrounding a core with a diameter<10nm. They produce fluorescence when excited by a light of specific wavelength. The frequency of light produced depends on the size of the crystal. Qdots can be used to label various molecules inside the cells and therefore can locate and track subcellular events e.g. enzymatic reactions. FRET has also been utilized for DNA detection inside cells. These techniques can be combined with nano-arrays for investigating the chemistry and electronics of single neurons. They enhance both special and temporal resolution along with increasing the sensitivity.

Nanotechnology based model have been utilized for understanding nuro-regeneration. Various nano-scaffolds have been developed to tackle some of the issues related to inhibitory environment for neuronal regeneration. Electrospun nanoscaffolds of L-lactic acid have been studied to augment neuronal growth. Self-assembling peptide nanofiber scaffold (SAPNS) deserve a special mention. SPANS is composed of positively and negatively charged amino acids that have the property of self-assembly into interwoven nanofibers of size 10mm. It is shown to promote nerve growth in experimental models of hamster optic nerve injury. It is also associated with both histological and functional recovery.

Nanotechnology offers the promise of paradigm advancement from macro to micro to nano scale neurosurgery. Nano-robots can be utilized to manipulate and repair injured axons utilizing direct fusion or grafts. Prototype platforms have been designed to incorporate cutting blades, electro-kinetic manipulation and cell fusion techniques. Nano-techniques can be utilized for delivering drugs precisely to the target e.g. tumor without opening the skull. The existing neuro-interventional techniques will be useful for these minimally invasive interventions.

Nanotechnology offers endless opportunities for better understanding of neurological processes. Interventions at the cellular and sub cellular are at the heart of improving patient care through nano-neurosurgery. Nanotechnology will bring a revolution in neurosurgery, and benefit millions of patients and their families worldwide.

Nano-cosmetics

Nanoparticles are used as ultraviolet (UV) filters in cosmetic to improve UV resistance-Titanium dioxide because of their unique properties. Nanoparticles when incorporated into cosmetic products, they provide an effective barrier to protect the skin from harmful UV rays. Nanoscale materials transport active ingredients such as pure Vitamin E through the skin. Nano-cosmetics prevent the signs of ageing

Disadvantages of Nanotechnology

Some major disadvantages of nanotechnology are as follows [19]:

- Negative environmental impacts
- Health problems
- Economic imbalance
- ***Decrease in employment**

The toxic effect of nano particles is that once they enter the human body, the various body organs and cells of human body are prone of the toxic effect of nanoparticles. Skin, the covering of human body, is not barrier for nanoparticles. Titanium dioxide and zinc oxide nanoparticles ranging from 10-20 nm and sunscreen product can penetrate the skin to accumulate in hair follicles. Some smaller particles penetrated through the skin are taken by macrophages [20]. Like dust particles, nanoparticles also enter into the lungs through inhale air and taken by macrophages (dust cells). Higher concentration causes inflammation. Experiments with rodents have demonstrated the toxic effect of carbon nanotubes through inhalation. Inhaled nanoparticles have also been associated with adverse effect in the nervous system and cardiovascular system.

Nanoparticles after being absorbed in intestine enter the circulatory system and effect it adversely. Nanoparticles are readily taken up by many types of cells and are expected to cross brain barrier that protects the brain from ill effect of many substances. Studies have shown that nanoparticles cause's oxidative stress in liver, contribute to lung inflammation and activate blood platelets that may contribute of clot formation [20]. High concentration of nanomaterial particles causes morphological changes in vascular endothelia cells and induce cytotoxic effects [21].

Because nanoscale materials are in the same range as hemoglobin and viruses and even smaller than common irritant, such as particular matter and pollen, nanoparticles could pose serious health risk. At the movements, SWCNT tiny tubes of rolled up graphite, are made in gram scale batches that pose little threat to the general public. But, if a cheap large scale production method is devised, SWCNT could be sold by metric tone, will increase the exposures. Nanotubes have been reported causing to lung tissues in mice. Nanoparticles used in paint industry on erosion may pollute environment by the release of nanoparticles. A new study revealed that engineered carbon molecules "bucky Ball's" cause brain damage in fishes.

Potential harmful effect of nanotechnology might arise as a result of nature of nano materials themselves, the characteristic of the products made from them or the aspects of the manufacturing process involved. There is a dire need of a proper evaluation of the risks with respect to the release of nanoparticle their fate in the human body and environment.

Necessity

There is a need to harness nanotechnology and biotechnology in understanding the insight into life process. A strong interface and close interaction among research and development laboratories, academic and industries is essential for taking science and technology outcome to the masses in the form of competitive homegrown technology and products which will lead to economic development [2].

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