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An Overview of Nanotechnology and its Possible Medicinal Applications

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ABSTRACT

Physical and chemical properties of a material changed dramatically when the size of the material reduced to nanoscale. These changes are the direct consequences of large surface to volume ratio of the material and quantum confinement effect. The high chemical reactivity of the nanomaterials is due to the large surface to volume ratio. On the other hand, quantum confinement effect is utilized to control the electronic band gap of the material. The electrical and optical properties are directly related to the electronic band gap of the material. By controlling the size, we can synthesize products having different electrical and optical properties with the same material. This tunability of electrical and optical properties is utilized in various applications in the industrial sectors. Nanotechnology has huge potential in the field of health care industry. It can change the whole approach of treatment, diagnosis and monitoring system. The purpose of this paper is to look into the basic simple science behind nanotechnology and its application in medicinal science. Here some possible applications of liposomes, nanopores, carbon nanotubes, nanoshells and dendrimers in the health sector are explored. The effect of nanotechnology on health and environment is also discussed in this paper.

KEYWORDS: Nanotechnology, Quantum size effect, Nanomedicine, Health hazard.

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1. INTRODUCTION

Nano is a Greek word means dwarf. Generally nano indicates a distance of one billionth of a meter i.e. 10^{-9} meter. Most consider nanotechnology to be technology at the sub-micron scale: 1-100's of nanometers. But actually nanotechnology is defined as building and using manmade materials, devices and machines at the nanometer (atomic/molecular) scale, making use of unique, novel properties that occur for structures at those small dimensions. Here manmade is a very important word; otherwise every bio-molecular structure would get the nanotechnology tag. Nanotechnology is a buzz word now a day because of its importance in modern industry and its vast possibilities of future applications. Big industries are taking huge interest in nanotechnology because: (a) it will reduce the device size i.e. miniaturization of the product, (b) it will make the devices work faster, (c) it will make the device lighter, (d) it will also make them cheaper as less materials will be needed for manufacturing, (e) it will be energy efficient and (f) it will produce less waste.

Neils Bohr first explained the basic science behind the atomic stability. After this innovation quantum mechanics developed immensely and in the present time we can say that we understand the science of a single atom quite well. We also have enough knowledge to explain the behavior of bulk material. But we still don't clearly understand the science of a cluster of atoms (say 10^3 atoms). This is why Physicist Richard Feynman introduced the concept of nanotechnology in 1959 in his talk "There's Plenty of Room at the Bottom."

In the present paper, I will first discuss about the technologies to produce the nanocrystal structure, in the second part basic science behind the nanotechnology will be exposed, in the third part some possible medicinal applications of this technology will be discussed and in the final part effects of nanotechnology on environment and health will be explained.

2. FABRICATION OF NANOMATERIALS

There are two basic approach of production of nanostructures (i) top-down approach and (ii) bottom-up approach.

2.1 Top-down approach

In this approach nanomaterials are derived from a bulk structure by progressive removal of materials unless the desired nanomaterial is obtained. Although the method is simple and cost effective, there is a huge loss of materials in removal process. Basically physicists and engineers

prefer this approach. Some examples of this approach are photolithography, scanning lithography, e-beam lithography etc.

2.2 Bottom-up approach

In this approach nanomaterials are obtained starting from molecular or atomic precursors and gradually assembling it until desired structure is formed. This approach is very popular among chemists. The approach has got very high efficiency. Some examples of this approach are wet chemical synthesis, chemical vapor deposition, plasma arcing etc.

3. BASIC SCIENCE

The basic bulk properties like electrical, optical, mechanical etc. of a material are changed dramatically when we reduce the material in nanodimension. This strange behavior can be explained by very simple basic science. There are two reasons why a nanomaterial behaves differently; I will discuss them in details here.

3.1 Large surface to volume ratio:

Reactions take place at the surface of a chemical or material; the greater the surface for the same volume, the greater the reactivity. The link to nanotechnology is that as particles get smaller; their surface area to volume ratio increases dramatically. Imagine a cube of sugar, reacting with water as the water dissolves the outside of the sugar. Now imagine the same cube of sugar cut into many little pieces. Each cut makes new outer surfaces for the water to dissolve. For smaller particles of sugar, the same volume of sugar now has much more surface area. A particle with a high surface area has a greater number of reaction sites than a particle with low surface area, and thus, results in higher chemical reactivity. Nanoparticles are special and interesting because their chemical and physical properties are different from their macro counterparts. One prime example of surface area to volume ratio at the nanoscale is gold as a nanoparticle. At the macroscale, gold is an inert element, meaning it does not react with many chemicals, whereas at the nanoscale, gold nanoparticles become extremely reactive and can be used as catalysts to speed up reactions. This increased reactivity for surface area to volume ratio is widely taken advantage of in nature, one biological example being the body's digestive system. Within the small intestine, there are millions of folds and sub-folds that increase the surface area of the inner lining of the digestive tract. These folds allow more nutrients and chemicals to be absorbed at the same time, greatly increasing our body's efficiency and the rate at which we digest food. One important application of surface area to volume ratio is roughness, as

surfaces that are significantly rougher at the microscale and nanoscale have more surface area while taking up the same approximate volume.

3.2 Quantum confinement:

Classical physics laws are applicable to the macro world which can be seen through our naked eyes. In the micro and sub-atomic world quantum mechanics dominates. So, in a nanomaterial we should use the strange physics of quantum mechanics. Nanomaterial is basically a cluster of atoms. To discuss about the electronic energy levels we should first concentrate on a single atom.

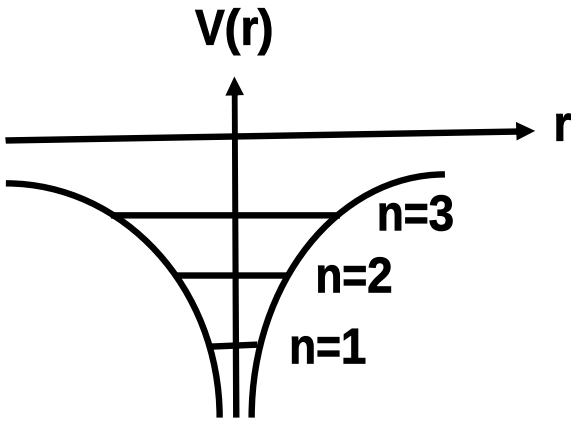

Fig.1 Potential function for a single atom contains the Coulomb interactions between negative electrons and the central nucleus as well as the interaction between the electrons with each other. Discrete energy levels are shown.

Fig.1 shows the potential function V (x) for a single atom contains the Coulomb interactions between negative electrons and the central nucleus as well as the interaction between the electrons with each other. And its solution is of course some discrete energy levels as shown in the figure. Now if we increase the number of atoms the potential function will change its shape as shown in fig.2. For a large bulk cluster this shape looks like a potential well in which potential well length is very much greater than the electronic wave length ($\lambda = h/p$) and the presence of the other atoms broadens the energy levels from the atomic ones.

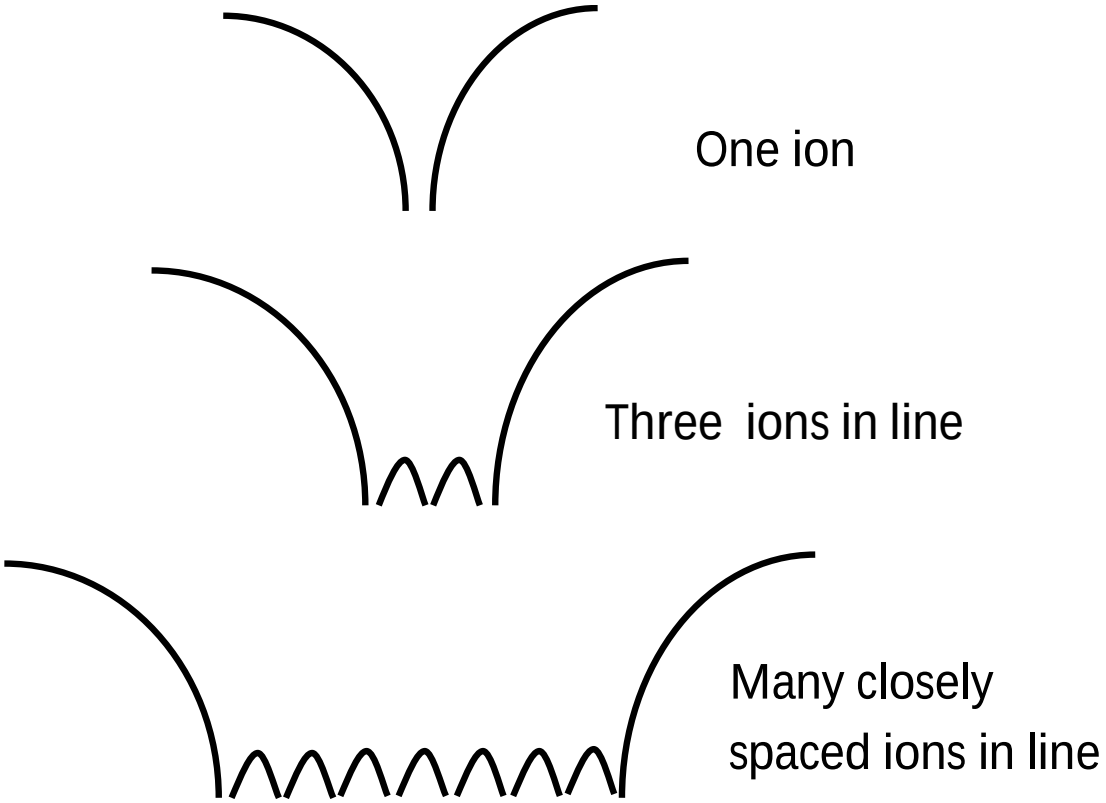

Fig.2 Potential function for single ion, three ions and many closely spaced ions.

But for a nanomaterial, the case is the intermediate one. Here the edges of potential well are still fairly close, and the length of the well is comparable to electronic wavelength (λ=h/p). For simplicity, we take it as an infinite square well problem. This potential can mathematically be written as:

$$V(x) = \infty \text{ when } x<0$$
$$= 0 \text{ when } 0<x<L$$
$$= \infty \text{ when } x>L$$

In the well region Schrödinger equation becomes

$$\frac{\partial^2 \psi(x)}{\partial x^2} + \frac{2mE}{\hbar^2}\psi(x) = 0$$

The solutions are of the form for standing waves and can in general be written as

$\psi(x)= A\cos(kx)+B\sin(kx)$, where $k=(2mE/\hbar^2)^{1/2}$

The full solutions for all energy levels are $E_n = n^2\pi^2\frac{\hbar^2}{2mL^2}$

Where L is the length of the potential well. For the infinite quantum well the possible transition energies ΔE are given by

$$E_m - E_n = \Delta E = (m^2 - n^2)\pi^2 \frac{\hbar^2}{2mL^2}$$

Where, E_m and E_n are the final and initial energy states respectively. From the above discussion we can conclude that transition energy levels are directly proportional to the $1/L^2$.So by changing the quantum well size (i.e. the size of a thin film or nanoparticle) one may fine-tune the energy at which the energy absorption or emission occurs.This strange phenomenon is called quantum confinement effect. Electrical and optical properties of a material solely depend on the transition energy levels of electron. Hence we can tune the electrical and optical properties of an element by controlling its size.

4. MEDICINALAPPLICATIONS:

Nanotechnology is making its mark in every field of our lives. Tremendous amount of researches are going on in almost all the countries in the world. Large amount of money is invested in this field by the industrial sectors. In this section I would provide a brief over view about some current and possible medicinal applications of nanoscience

Some of the challenges of most drug delivery systems include poor bioavailability, *in vivo*stability, solubility, intestinal absorption, sustained and targeted delivery to site of action, therapeutic effectiveness, side effects, and plasma fluctuations of drugs which either fall below the minimum effective concentrations or exceed the safe therapeutic concentrations. However, nanotechnology in drug delivery is an approach designed to overcome these challenges due to the development and fabrication of nanostructures at submicron scale and nanoscale which are mainly polymeric and have multiple advantages. Generally, nanostructures have the ability to protect drugs encapsulated within them from hydrolytic and enzymatic degradation in the gastrointestinal tract; target the delivery of a wide range of drugs to various areas of the body for sustained release and thus are able to deliver drugs, proteins and genes through the oral route of administration. Below I will give some simple future applications of nanotechnology in medicine sector.

4.1 Liposomes:

Liposomes discovered in mid 1960s were the original models of nanoscaled drug delivery devices[1,2,3,4]. They are spherical nanoparticles made of lipid bilayer membranes with an aqueous interior but can be unilamellar with a single lamella of membrane or multilamellar with multiple membranes. They can be used as effective drug delivery systems. Cancer chemotherapeutic drugs

and other toxic drugs like amphotericin and hamycin, when used as liposomal drugs produce much better efficacy and safety as compared to conventional preparations. These liposomes can be loaded with drugs either in the aqueous compartment or in the lipid membrane. Usually water soluble drugs are loaded in aqueous compartment and lipid soluble drugs are incorporated in the liposomal membrane[5]. The major limitation of liposome is its rapid degradation and clearance by the liver macrophages[6], thus reducing the duration of action of the drug it carries. This can be reduced to a certain extent with the advent of stealth liposomes where the liposomes are coated with materials like polyoxyethylene which prevents opsonisation of the liposome and their uptake by macrophages[7].

4.2 Nanopores:

Nanopores designed in 1997 by Desai and Ferrari[8], consist of wafers with high density of pores(20 nm in diameter). The pores allow entry of oxygen, glucose and other products like insulin to pass through. However, it does not allow immunoglobulin and cells to pass through them. Nanopores can be used as devices to protect transplanted tissues from the host immune system, at the same time, utilizing the benefit of transplantation. β cells of pancreas can be enclosed within the nanopore device and implanted in the recipient's body. This tissue sample receives the nutrients from the surrounding tissues and at the same time remains undetected by the immune system and hence do not get rejected.

4.3 Carbon Nanotubes:

Carbon nanotubes are tubular structures like a sheet of graphite rolled into a cylinder capped at one or both ends by a buckyball. Nanotubes can be single walled carbon nanotube (SWCNT) or multiwalled carbon nanotube (MWCNT) in concentric fashion. Single walled nanotube has an internal diameter of 1-2 nm and multiwalled nanotube has a diameter of 2-25 nm with 0.36 nm distance between layers of MWCNT. These vary in their length ranging from 1 μm to a few micrometers. These are characterized by greater strength and stability hence can be used as stable drug carriers[9,10,11,12]. Cell specificity can be achieved by conjugating antibodies to carbon nanotubes with fluorescent or radiolabelling[13]. Entry of nanotubes into the cell may be mediated by endocytosis or by insertion through the cell membrane. Carbon nanotubes can be made more soluble by incorporation of carboxylic or ammonium groups to their structure and can be used for the transport of peptides, nucleic acids and other drug molecules.

4.4 Nanoshells:

Nanoshells consist of nanoparticles with a core of silica and a coating of thin metallic shell. These can be targeted to desired tissue by using immunological methods. This technology is being evaluated for cancer therapy. Hirsh *et al*[14] used nanoshells which are tuned to absorb infra red rays when exposed from a source outside the body to demonstrate the thermo ablative property of nanoshells. The nanoshells when exposed to near infrared region of the electromagnetic spectrum get heated and cause destruction of the tissue. This has been studied in both *in vitro* and *in vivo* experiments with HER 2 expressing SK-BR-3 human breast carcinoma cells.

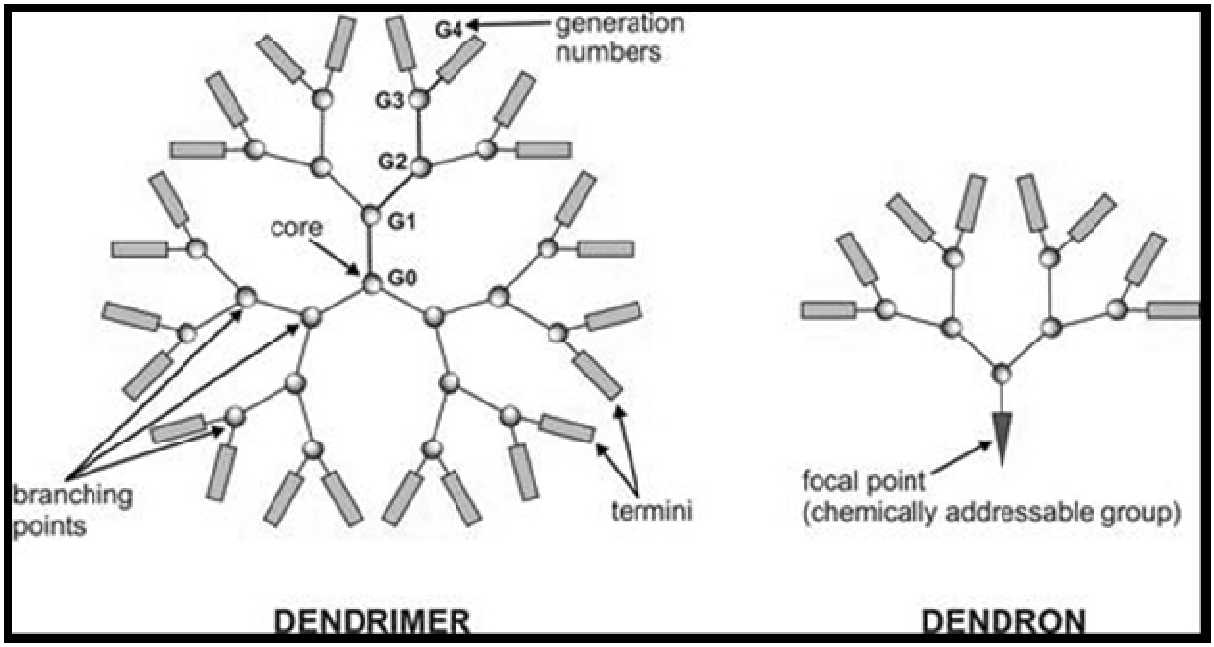

Fig.3 Schematic diagram of dendrimer and a single Dendron.

4.5 Dendrimers:

Dendrimers are nanomolecules with regular branching structures. Fig.3 shows schematic diagram of dendimers. The number of branching determines the size of the dendrimer which can be controlled. The branches arise from the core in shape of a spherical structure by means of polymerisation.This results in formation of cavities within the dendrimer molecule which can be used for drug transport. The ends of the dendrimer molecule can be attached with other molecules for transport[15,16,17,18]. These molecules give the dendrimers various functional applications[19]. Tectodendrimers are complexes of dendrimers, witheach dendrimer module of the complex performing different functions such as targeting, diagnosis of disease state, delivery of drug and

imaging. This extended nanodevice has potential applications in cancer chemotherapy as a mode of targeted drugtherapy[20].

5. EFFECT OF NANOTECHNOLOGY ON HEALTH AND ENVIRONMENT

Nanoparticles, as a result of their extreme microscopic dimension, which gives unique advantage, have potential hazards similar to particulate matter. These particles have the potential to cause varied pathologies of respiratory, cardiovascular and gastrointestinal system. Intratracheal instillation of carbon nanotube particles in mice, has shown that carbon nanotubes have the potential to cause varied lung pathologies like epitheloid granuloma, interstitial inflammation, peribronchial inflammation and necrosisof lung. The toxicity produced by carbon nanotube was found to be greater than that produced by carbon black and quartz[21]. Nanoparticles can enter the central nervous system either directly through axons of olfactory pathway or through systemic circulation that C-60 fullerene can cause oxidative stress and depletion of GSH in brain in fishes by entering through the olfactory bulb[22]. Involvement of olfactory bulb in humans is possible in case of inhalational exposure. Studies done on monkeys and rats have shown accumulation of carbon and manganese nanoparticles in the olfactory bulb through the olfactory pathway[23,24]. This shows that nanoparticle mediated delivery can in future provide a means of alternate route, circumventing the blood brain barrier.

6. CONCLUSIONS

Nanomaterials are advanced materials for various modern applications. In the present paper an overall discussionof the following topics are made:

1) Basic synthesis technologies for the nanomaterials are discussed in brief.
2) Simple science behind the strange behavior of nanomaterials is exposed.
3) Some very important medicinal applications in nanoworld are revisited.
5) Hazards of nanotechnology on health and environment are discussed.

REFERENCES

1. NewRRC, TorchilinVP and WeissigV. Liposomes: Practical Approach 1st ed. Oxford University Press: London; 2003.
2. LasicDD and PapahadjopoulosD.Medical applications of liposomes 4th ed. B. V. Elsevier Science: Amsterdam;1998.

3. AllenTM and CullisPR.Drug Delivery systems: entering the main stream Science 2004; 303: 1818-22.

4. MoghimiSM, HunterAC, MurrayJC.Long-circulating and target-specific nanoparticles: theory to practice Pharmacol. Rev. 2001; 53: 283-318.

5. GregoriadisG and RymanBE, Fate of Protein-Containing Liposomes Injected into RatsEur J Biochem 1972; 24:485-91.

6. McCormack B, and GregoriadisG.Drugs-in-cyclodextrins-in liposomes: A novel concept in drug delivery Int. J. Pharm. 1994; 112: 249–58.

7. SeniorJ, DelgadoC, FisherD, TilcockC, GregoriadisG.Influence of surface hydrophilicity of liposomes on their interaction with plasma protein and clearance from the circulation: studies with poly(ethylene glycol)-coated vesiclesBiochim Biophys Acta 1991;1062: 77-82.

8. DesaiTA, ChuWH, TuJK, BeattieGM, HayekA, FerrariM.Microfabricated immunoisolating biocapsulesBiotechnol Bioeng 1998; 57: 118-20.

9. BianccoA. Carbon nanotubes for the delivery of therapeutic molecules Exp. Opin. Drug Deliv. 2004; 1: 57-65.

10. LopezCF, NielsenSO, MoorePB and KleinML. Understanding nature's design for a nanosyringe. Proc. Natl. Acad. Sci. 2004; 101: 4431-34.

11. AliSS, HardtJI, QuickKL,Kim-HanJS, ErlangerBF, HuangTT, EpsteinCJ and DuganL. A biologically effective fullerene (C60) derivative with superoxide dismutase mimetic properties Free Radical Biol. Med. 2004; 37: 1191-1202.

12. ParkKH, ChhowallaM, IqbalZ and SestiF. Single-walled carbon nanotubes are a new class of ion channel blockers" J. Biol. Chem. 2003; 278: 50212-16.

13. McDevittMR, ChattopadhyayD, KappelBJ, JaggiJS, SchiffmanSR, AntczakC, NjardarsonJT, BrentjensR, ScheinbergDA. Tumor targeting with antibody-functionalized, radiolabeled carbon nanotubes.J Nucl Med. 2007; 48(7):1180-89.

14. HirschLR, StaffordRJ, BanksonJA, SershenSR, RiveraB, PriceRE, HazleJD, HalasNJ, WestJL. Nanoshell-mediated near-infrared thermal therapy of tumors under magnetic resonance guidance.Proc Natl Acad Sci U S A. 2003; 100(23): 13549-54.

15. TomaliaDA and FréchetJMJ. Discovery of dendrimers and dendritic polymers: a brief historical perspective J. Polym. Sci. Part A: Polym. Chem. 2002; 40: 2719-28.

16. TomaliaDA and FréchetJMJ. Dendrimers and other dendritic polymers John Wiley and sons: West Sussex; 2001.

17. HaagR. Supramolecular drug-delivery systems based on polymeric core-shell architectures Angew. Chem. Int. Ed. Engl. 2004; 43: 278-82.

18. MorganMT, CarnahanMA, ImmoosCE, RibeiroAA, FinkelsteinS, LeeSJ and GrinstaffMW.Dendritic molecular capsules for hydrophobic compounds J. Am. Chem. Soc. 2003; 125: 15485-89.

19. MoghimiSM, HunterAC, MurrayJC. Nanomedicine: current status and future prospects.FASEB J. 2005; 19(3):311-30.

20. Baker JR, Quintana A, Piehler L, Banazak-Holl TD, Raczka E. The synthesis and testing of anti-cancer therapeutic nanodevices. Biomed Microdevices 2001; 3:61-69.

21. Lam CW, James JT, McCluskey R, and Hunter RL. Pulmonary toxicity of single-wall carbon nanotubes in mice 7 and 90 days after intratracheal instillation. Toxicol Sci. 2004;77:126-34.

22. OberdorsterE. Manufactured Nanomaterials (Fullerenes, $_{C60}$) Induce Oxidative Stress in the Brain of Juvenile Largemouth Bass.Environ Health Perspect 2004; 112**:** 1058-62.

23. Elder A, Gelein R, Silva V, Feikert T, Opanashuk L, Carter J, Potter R, Maynard A, Ito Y, Finkelstein J, Oberdörster G. Translocation of inhaled ultrafine manganese oxide particles to the central nervous system.Environ Health Perspect 2006; 114: 1172-78.

24. Oberdörster G, Sharp Z, Atudorei V, Elder A, Gelein R, KreylingWand Cox C. Translocation of inhaled ultrafine particles to the brain. Inhal Toxicol 2004; 16:437-45.