IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Properties and Applications of Nanomaterials in Electronics for Health – A Review

B.S.Seshagiri Rao* K. Eswara Prasad** K.Satyanarayana Raju***

Department of Physics & Electronic, B.V. Raju College, Vishnupur, Bhimavaram, West Godavari District, Andhra Pradesh, 534202

Abstract: Employments of nanotechnology in gadgets and electrical merchandise that do give rise straightforwardly to natural and human wellbeing concern. This is the utilization of artificially created nanoparticles in 'nanomaterials' to make electronic segments or surface coatings for electrical merchandise. Nanomaterials are usually characterized as materials planned and created to have underlying highlights within any one component of 100 nanometers or less. In hardware, various distinctive nanomaterials are now being utilized economically or are being utilized for innovative work purposes. Probably the most regularly utilized nanomaterials for electronic and electrical hardware are carbon nanotubes and quantum dots nanomaterials are being utilized as surface coatings in certain electrical products, principally in the light of the fact that they have against microbial properties. Items previously showcased as having 'hostile to microbial' nanomaterial coatings incorporate fridges, vacuum cleaners, clothes washers, cell phones and PC mice.

Key words: Nanoparticles (NP). Electronics, Metals.

Introduction:

Nanotechnology resembles a toolbox for the hardware business. It permits to make nano materials with unique properties changed by super fine molecule size, crystallinity, structure or surfaces. These will turn out to be industrially significant to make new items.

The term 'nano' is utilized in science as a prefix meaning one billionth (utilizing billion in its American feeling of a one followed by nine zeros). A 'nanometer' hence implies one billionth of a meter and it is tiny – around 10 particles across. Nanotechnology alludes to advances that are working at the nanometer level (1) and, all things considered, incorporates both a)

procedures used to fabricate items with nano-scale qualities and b) nanomaterials produced by whatever implies. The two viewpoints have significance in the field of present day gadgets.
Nano particles can theoretically be produced artificially from any chemical (2). Such engineered nanomaterials are commonly defined as materials designed and produced to have structural features with at least one dimension of 100 nanometers of less (3). Presently, most nanoparticles that are in use have been made from transition metals, silicon, carbon (carbon nanotubes, fullerenes) and metal oxides (zinc oxide and titanium dioxide). In some cases, engineered nanoparticles exist as nanocrystals composed of a number of compounds such as silicon and metals (as is the case for quantum dots) (4).

Some promising uses of nanomaterials in electronics are

- use of carbon nanotubes in semiconductor chips;
- nanomaterials in lighting advancements (light producing diodes or LEDs and natural light producing diodes or OLEDs), with business utilize expected soon;
- use of 'quantum dots' in lasers, alongside progressing examination into utilization of other nanomaterials in laser innovation;
- utilized in lithium-particle batteries, or which are being investigated for this utilization;
- potential use of carbon nanotubes and other nanomaterials in fuel cells and by the solar industry for use in photovoltaics.
- Research into utilization of nanomaterials to deliver without lead bind, just as the advancement of weld free gathering innovation

Classification of NPs

NPs are broadly divided into various categories depending on their morphology, size and chemical properties. Based on physical and chemical characteristics, some of the well-known classes of NPs are given as below.

1. Carbon-based NPs

Fullerenes and carbon nanotubes (CNTs) speak two significant classes of carbon-based NPs. Fullerenes contain nanomaterial that are made of globular empty pen, for example, allotropic types of carbon. They have made essential business interest because of their electrical conductivity, high strength, structure, electron partiality, and flexibility (5). These materials have masterminded pentagonal and hexagonal carbon units, while every carbon is sp2 hybridized. Fig. 2 shows a portion of the notable fullerenes comprising of C60 and C70 with the distance across of 7.114 and 7.648 nm, separately.

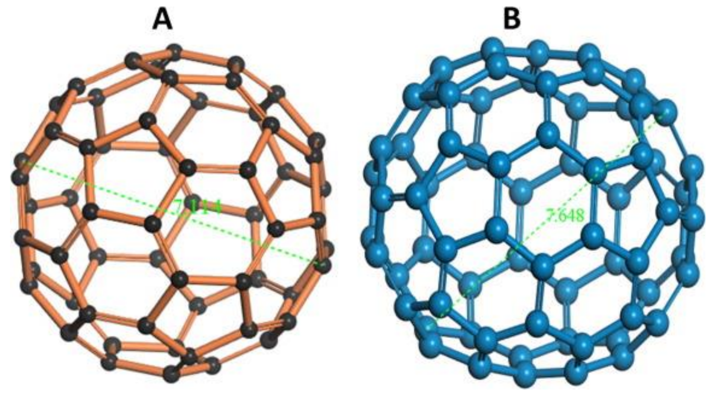

Figure 2. Different forms of Fullerenes/bucky balls (A) C_{60} and (B) C_{70}.

CNTs are elongated, tubular structure, 1–2 nm in diameter (6). These can be predicted as metallic or semiconducting reliant on their diameter telicity (7). These are structurally resemble to graphite sheet rolling upon itself (3). The rolled sheets can be single, double or many walled and therefore they named as single-walled (SWNTs), double-walled (DWNTs) or multi-walled carbon nanotubes (MWNTs), respectively. They are widely synthesized by deposition of carbon precursors especially the atomic carbons, vaporized from graphite by laser or by electric arc on to metal particles. Lately, they have been synthesized via chemical vapor deposition (CVD) technique (8). Due to their unique physical, chemical and mechanical characteristics, these materials are not only used in pristine form but also in nanocomposites for many commercial applications such as fillers (9,10), efficient gas adsorbents for environmental remediation (11), and as support medium for different inorganic and organic catalysts (12).

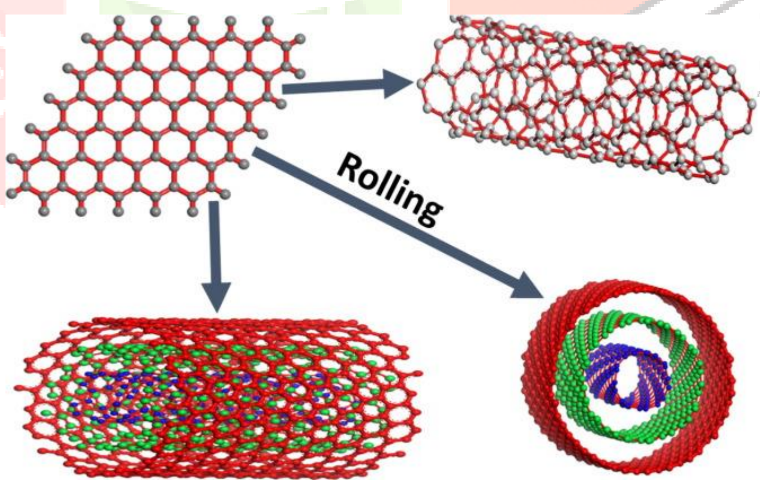

Figure 3. Rolling of graphite layer into single-walled and multi-walled CNTs.

2. Metal NPs

Metal NPs are purely made of the metal precursors. Due to well-known localized surface Plasmon resonance (LSPR) characteristics, these NPs possess unique optoelectrical properties. NPs of the alkali and noble metals i.e. Cu, Ag and Au have a broad absorption band in the visible zone of the electromagnetic solar spectrum. The facet, size and shape controlled synthesis of metal NPs is important in present day cutting-edge materials (13). Due to their advanced optical properties, metal NPs find applications in many research areas. Gold NPs coating is widely used for the sampling of SEM, to enhance the electronic stream, which helps in obtaining high quality SEM images . There are many other applications, which are deeply discussed in applications section of this review.

3. Ceramics NPs

Ceramic NPs are inorganic nonmetallic solids, synthesized via heat and successive cooling. They can be found in amorphous, polycrystalline, dense, porous or hollow forms (14). Therefore, these NPs are getting great attention of researchers due to their use in applications such as catalysis, photocatalysis, photodegradation of dyes, and imaging applications. (15).

4. Semiconductor NPs

Semiconductor materials possess properties between metals and nonmetals and therefore they found various applications in the literature due to this property (16, 17a). Semiconductor NPs possess wide bandgaps and therefore showed significant alteration in their properties with bandgap tuning. Therefore, they are very important materials in photocatalysis, photo optics and electronic devices (Sun, 2000). As an example, variety of semiconductor NPs are found exceptionally efficient in water splitting applications, due to their suitable bandsgap and bandsedge positions (18).

5. Polymeric NPs

These are normally organic based NPs and in the literature a special term polymer nanoparticle (PNP) collective used for it. They are mostly nanospheres or nanocapsular shaped (19). The former are matrix particles whose overall mass is generally solid and the other molecules are adsorbed at the outer boundary of the spherical surface. In the latter case the solid mass is encapsulated within the particle completely (20). The PNPs are readily functionalize and thus find bundles of applications in the literature (21,22).

6. Lipid-based NPs

These NPs contain lipid moieties and effectively using in many biomedical applications. Generally, a lipid NP is characteristically spherical with diameter ranging from 10 to 1000 nm. Like polymeric NPs, lipid NPs possess a solid core made of lipid and a matrix contains soluble lipophilic molecules. Surfactants or emulsifiers stabilized the external core of these NPs (23). Lipid nanotechnology (24) is a special field, which focus the designing and synthesis of lipid NPs for various applications such as drug carriers and delivery (25) and RNA release in cancer therapy (26).

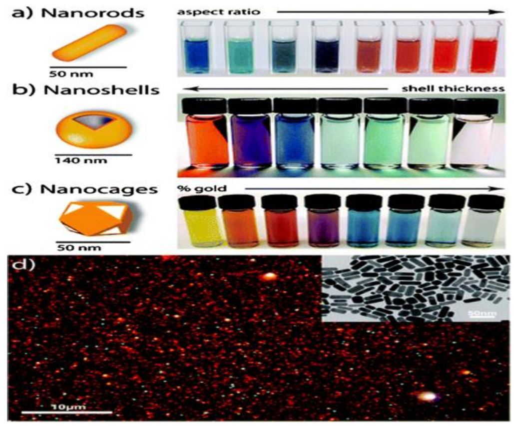

Figure 1
Color dependence of Au NPs on size and shape
(Dreaden et al., 2012).

Nanoparticles (NPs) have become widely used in electronics, agriculture, textiles , medicine, and many other industries and sciences (**Figure 1**) The International Organization for Standardization define NPs as structures whose sizes in one, two, or three dimensions are within the range from 1 to 100 nm [27,28,29,30,31]. Apart from size, NPs may be classified in terms of their physical parameters, e.g., electrical charge; chemical characteristics, such as the composition of the NP core or shell; shape (tubes, films, rods, etc.); and origin: natural NPs (NPs contained in volcanic dust, viral particles, etc.) and artificial NPs, which are the focus of this review [32]. NP toxicity for living organisms, however, is the main factor limiting their use in treatment and diagnosis of diseases. At present, researchers often face the problem and side effects related to their toxicity. In this respect, the choice of an adequate experimental model for estimating toxicity in vitro (cell lines) and in vivo (experimental animals) ones is of paramount importance. NPs can enter the body through inhalation, skin, and digestion, depending on their physicochemical characteristics and mode of their production [33]. The interactive contact with the body, depending on the type of compounds in NPs, can be respiratory, digestive, or through skin or blood [34]. Some of NPs, such as ZnO and TiO_2, have the ability to block UV rays and are extensively used in various health products on the market, which raise concerns about the risk to health, safety and the environment as they are dispersed in the environment. According to primary studies, NPs can enter human body in different ways and they can access vital organs in the body through the blood flow and induce damage to tissues and cells [27, 34, and 35]. Although the mechanism of NPs in this regard is not truly established, researchers have associated the toxicity of NPs to parameters such as particle shape, size, dispersity, surface charge and protein corona effects. Several studies have indicated that NPs activate oxidative stress and expression of genes involved in inflammation [36, 37,38]. NPs can enter the human body through respiration, ingestion, and injection and consequently accumulate into different tissues and organs [39, 40,41,42]. NPs can even reach the brain by breaking the strong connection between cells and passing through the blood–brain barrier (BBB); they attach to the cells containing CXCR6 chemokine receptor and overcome tight injunction in the BBB [43]. The NPs' passage through the membrane, their performance, and their cell metabolism are still being studied and discussed. Thus, herein, we attempt to explain a part of the NPs performance that hopefully can answer whether NPs have destructive and toxic effects on organs, or are they safe enough [32]. Development of safe, biocompatible NPs that can be used for the diagnosis and treatment of human diseases can only be based on a complete understanding of the interactions between all of the factors and mechanisms underlying NP toxicity.

Medical Applications of Nanoparticles

In medicine, NPs can be used for diagnostic or therapeutic purposes. In diagnosis, they can serve as fluorescent labels for detection of biomolecules and pathogens and as contrast agents in magnetic resonance and other studies. In addition, NPs can be used for targeted delivery of drugs, including protein and polynucleotide substances; in photodynamic therapy and thermal destruction of tumors, and in prosthetic repair [44]. Some types of NPs have been used extensively in drug delivery, diagnosis of diseases and the provision of biologic sensors; several nanometals have been produced and evaluated, but gold and silver are the most widely used. These particles can be prepared in different sizes and shapes, with small particle size distribution. One of the unique features of these particles is their optical behavior change by changing the particle size, meaning that NPs of different sizes exhibit different colors at visible wavelengths. This feature can be used for diagnosis of the disease and eventual drug delivery to facilitate both these processes. The surface variation of these particles is easy to manipulate as various ligands such as sugars, peptides, proteins, and DNA can bind to these particles [45].

Mechanisms of Nanoparticle Toxicity: NP-Cell Interactions

Surface properties of NPs, to be specific hydrophobicity and hydrophilicity, influence a considerable number of natural ecological reactions of these structures, for example, connection with plasma proteins, cell take-up and phagocytosis, incitement of the safe framework and molecule expulsion. The surface properties of nanoparticles bring about various cell reactions, for example, grip, development and separation. The oxidative pressure is instigated by NPs through physicochemical communication in the cell film as they produce particles which are harmful in the cell layer surface and that can be misused to dispense with malignant cell [46]. The higher the breadth of the NPs, the more their collaboration with the outside layer and the higher the degree of cell harmfulness. The cell layer is perplexing and dynamic containing proteins and extracellular polymeric materials.

The Effect of NP on the Protein Conformational Changes

A number of techniques such as nuclear magnetic resonance (NMR) spectroscopy [47], X-ray crystallography [48], circular dichroism spectroscopy [49], isothermal calorimetry [50], differential scanning calorimetry [51], fluorescence spectroscopy [52], and UV-visible spectroscopy [53] have been widely used for analyzing the protein-NP interactions. The NP-induced conformational changes and subsequent corona formation depends on several factors such as, protein type, NP type, size of NP, shape of NP, P^H and the temperature.

The use of materials in nanoscale provides unparallel freedom to modify fundamental properties such as solubility, diffusivity, blood circulation half life drug release characteristics and immunogenity. In the last two decades, a number of NP based therapeutic and diagnostic agents have been developed for the treatment of cancer, diabetes, pain, asthma, allergy, infection and so on. These nanoscale agents may provide more effective and/or more convenient routes of administration lower therapeutic toxicity extend the product life cycle and ultimately reduce health care costs. Therapeutic delivery systems and diagnostic applications of NP allow targeted delivery, controlled release and detection on the molecular scale, may help identify abnormalities such as fragments of viruses, precancerous cells and disease makers that cannot be detected with traditional diagnostics. NP based imaging contrast agents have also been shown to improve the sensitivity and specificity of magnetic resonance imaging.

Other Application of Nanotechnology:

- Chemical sensors, including Hydrogen and glucose sensors;
- Read heads for hard disk drives;
- Transistors, interconnects and integrated circuits (semiconducting and conducting wires); Photo sensors;
- Deposition control systems, a spin off technology for high precision control of particle deposition in the sub-monolayer regime.

Conclusion:

Nanoparticles have many biomedical applications owing to their unique characteristics such as size, shape, chemistry and charge. However, the signaling pathways through which NPs can produce toxic effects are needed to be understood better. Recent studies have shown that inflammation, necrosis, ROS and apoptosis are key factors that mediate the mechanism of toxicity of NPs. These results may create a barrier to the use of NPs in diagnosis and in the treatment of diseases for which they are ideally suited. It is important to identify the dose, shape, and the properties of NPs that are responsible for their toxicity in order to reduce their side effects by appropriately modifying the formulation or to use a NP with lower toxicity. The dose of NPs is an important factor in their toxicological profile, along with their accumulation, distribution, metabolism and disposal. In line with this, intravenously injected NPs have a higher toxicity than those administered to the skin. According to the results of various studies, protocols explain which doses and what structures of NPs are more toxic. In general, the problems in the evaluation of NP toxicity are due to the disparity between different toxicological studies performed on the NPs of diverse origins and make-up.

Accordingly, the study of NP toxicity in various applications, especially biomedicine applications such as drug delivery, bio-security and NP toxicity, is very crucial. Consequently, there is a need for the development of accepted and specific protocols to identify the actual particle with its surface surroundings and the composition of NPs that renders them toxic. It is hoped that the increased knowledge of NPs lead to develop safer design with reduced toxicity so that they can be used for treatment of assorted diseases and drug delivery.

References:

1. Whatmore R.W. (2006). Nanotechnology – what is it? Should we be worried? Occupational Medicine – Oxford 56 (5): 295-299.
2. Dreher K.L. (2004). Health and environmental impact of nanotechnology: toxicological assessment of manufactured nanoparticles. Toxicological Sciences 77: 3-5.
3. Oberdörster G., Maynard A., Donaldson K., Castranova V., Fitzpatrick J., Ausman K., Carter J.,Karn B., Kreyling W., Lai D., Olin S., Monteiro-Riviewre N., Warheit D. and Yang H. (2005b). Principles for characterizing the potential human health effects from exposure to nanomaterials: elements of a screening strategy. Particle and Fibre Toxicology 2:8 (6 October 2005).
4. A. Astefanei, O. Núñez, M.T. GalceranCharacterisation and determination of fullerenes: a critical review Anal. Chim. Acta, 882 (2015), pp. 1-21, 10.1016/j.aca.2015.03.025.
5. K.S. IbrahimCarbon nanotubes-properties and applications: a review Carbon Lett., 14 (2013), pp. 131-144,
6. Aqel, K.M.M.A. El-Nour, R.A.A. Ammar, A. Al-WarthanCarbon nanotubes, science and technology part (I) structure, synthesis and characterisation
7. Arab. J. Chem., 5 (2012), pp. 1-23,
8. J.A. Elliott, Y. Shibuta, H. Amara, C. Bichara, E.C. NeytsAtomistic modelling of CVD synthesis of carbon nanotubes and grapheme Nanoscale, 5 (2013), p. 6662,
9. K. Saeed, I. KhanPreparation and characterization of single-walled carbon nanotube/nylon 6,6 nanocomposites Instrum Sci. Technol., 44 (2016), pp. 435-444,
10. K. Saeed, I. KhanPreparation and properties of single-walled carbon nanotubes/poly(butylene terephthalate) nanocomposites Iran. Polym. J., 23 (2014), pp. 53-58,
11. J.M. Ngoy, N. Wagner, L. Riboldi, O. BollandA CO_2 capture technology using multi-walled carbon nanotubes with polyaspartamide surfactant Energy Procedia, 63 (2014), pp. 2230-2248,
12. L.F. Mabena, S. Sinha Ray, S.D. Mhlanga, N.J. CovilleNitrogen-doped carbon nanotubes as a metal catalyst support Appl. Nanosci., 1 (2011), pp. 67-77,
13. E.C. Dreaden, A.M. Alkilany, X. Huang, C.J. Murphy, M.A. El-SayedThe golden age: gold nanoparticles for biomedicine Chem. Soc. Rev., 41 (2012), pp. 2740-2779,
14. W. Sigmund, J. Yuh, H. Park, V. Maneeratana, G. Pyrgiotakis, A. Daga, J. Taylor, J.C. NinoProcessing and structure relationships in electrospinning of ceramic fiber systems J. Am. Ceram. Soc., 89 (2006), pp. 395-407,
15. S. Thomas, B.S.P. Harshita, P. Mishra, S. TalegaonkarCeramic nanoparticles: fabrication methods and applications in drug delivery Curr. Pharm. Des., 21 (2015), pp. 6165-6188,

16. S. Ali, I. Khan, S.A. Khan, M. Sohail, R. Ahmed, A. Rehman, M.S. Ur Ansari, M.A. MorsyElectrocatalytic performance of Ni@Pt core–shell nanoparticles supported on carbon nanotubes for methanol oxidation reaction J. Electroanal. Chem., 795 (2017), pp. 17-25,
17. Khan, A. Abdalla, A. QurashiSynthesis of hierarchical WO_3 and Bi_2O_3/WO_3 nanocomposite for solar-driven water splitting applications Int. J. Hydrogen Energy, 42 (2017), pp. 3431-3439,
18. S. SunMonodisperse FePt nanoparticles and ferromagnetic FePt nanocrystal superlattices Science, 80 (287) (2000), pp.
19. T. Hisatomi, J. Kubota, K. DomenRecent advances in semiconductors for photocatalytic and photoelectrochemical water splitting Chem. Soc. Rev., 43 (2014), pp. 7520-7535
20. M. Mansha, I. Khan, N. Ullah, A. QurashiSynthesis, characterization and visible-light-driven photoelectrochemical hydrogen evolution reaction of carbazole-containing conjugated polymers Int. J. Hydrogen Energy (2017),
21. J.P. Rao, K.E. GeckelerPolymer nanoparticles: preparation techniques and size-control parameters Prog. Polym. Sci., 36 (2011), pp. 887-913,
22. N.H. Abd Ellah, S.A. AbouelmagdSurface functionalization of polymeric nanoparticles for tumor drug delivery: approaches and challenges Expert Opin. Drug Deliv., 1–14 (2016),
23. S.A. Abouelmagd, F. Meng, B.-K. Kim, H. Hyun, Y. YeoTannic acid-mediated surface functionalization of polymeric nanoparticles ACS Biomater. Sci. Eng. (2016)
24. M.K. Rawat, A. Jain, S. Singh, W. Mehnert, A.F. Thunemann, E.B. Souto, A. Mehta, S. P. VyasStudies on binary lipid matrix based solid lipid nanoparticles of repaglinide: in vitro and in vivo evaluation J. Pharm. Sci., 100 (2011), pp. 2366-2378, 10.1002/jps.22435
25. S. Mashaghi, T. Jadidi, G. Koenderink, A. MashaghiLipid nanotechnology Int. J. Mol. Sci., 14 (2013), pp. 4242-4282,
26. A. Puri, K. Loomis, B. Smith, J.H. Lee, A. Yavlovich, E. Heldman, R. BlumenthalLipid -based nanoparticles as pharmaceutical drug carriers: from concepts to clinic Crit. Rev. Ther. Drug Carrier Syst., 26 (2009), pp. 523-580
27. M. Gujrati, A. Malamas, T. Shin, E. Jin, Y. Sun, Z.-R. LuMultifunctional cationic lipid-based nanoparticles facilitate endosomal escape and reduction-triggered cytosolic siRNA release Mol. Pharm., 11 (2014), pp. 2734-2744
28. Cheng, R.; Feng, F.; Meng, F.; Deng, C.; Feijen, J.; Zhong, Z. Glutathione-responsive nano-vehicles as a promising platform for targeted intracellular drug and gene delivery. *J. Control. Release* 2011, *152*, 2–12. [Google Scholar] [CrossRef] [PubMed]
29. Sajid, M.; Ilyas, M.; Basheer, C.; Tariq, M.; Daud, M.; Baig, N.; Shehzad, F. Impact of nanoparticles on human and environment: Review of toxicity factors, exposures, control strategies, and future prospects. *Environ. Sci. Pollut. Res.* 2015, *22*, 4122–4143. [Google Scholar] [CrossRef] [PubMed]
30. Dwivedi, A.D.; Dubey, S.P.; Sillanpää, M.; Kwon, Y.-N.; Lee, C.; Varma, R.S. Fate of engineered nanoparticles: Implications in the environment. *Coord. Chem. Rev.* 2015, *287*, 64–78. [Google Scholar] [CrossRef]

31. Ajdari, M.; Ghahnavieh, M.Z. Histopathology effects of nickel nanoparticles on lungs, liver, and spleen tissues in male mice. *Int. Nano Lett.* 2014, *4*, 113. [Google Scholar] [CrossRef]
32. Negahdary, M.; Ajdary, M. The toxicity of gold, silver, and zinc oxide nanoparticles on LDH enzyme in male mice. *Annu. Res. Rev. Biol.* 2014, *4*, 1346–1352. [Google Scholar] [CrossRef]
33. Hornos Carneiro, M.F.; Barbosa, F., Jr. Gold nanoparticles: A critical review of therapeutic applications and toxicological aspects. *J. Toxic. Environ. Health* 2016, *19*, 129–148. [Google Scholar] [CrossRef] [PubMed]
34. Moulton, M.C.; Braydich-Stolle, L.K.; Nadagouda, M.N.; Kunzelman, S.; Hussain, S.M.; Varma, R.S. Synthesis, characterization and biocompatibility of "green" synthesized silver nanoparticles using tea polyphenols. *Nanoscale* 2010, *2*, 763–770. [Google Scholar] [CrossRef] [PubMed]
35. Warheit, D.B.; Laurence, B.R.; Reed, K.L.; Roach, D.H.; Reynolds, G.A.; Webb, T.R. Comparative pulmonary toxicity assessment of single-wall carbon nanotubes in rats. *Toxicol. Sci.* 2004, *77*, 117–125. [Google Scholar] [CrossRef] [PubMed]
36. Hussain, S.; Hess, K.; Gearhart, J.; Geiss, K.; Schlager, J. In vitro toxicity of nanoparticles in BRL 3A rat liver cells. *Toxicol. In Vitro* 2005, *19*, 975–983. [Google Scholar] [CrossRef] [PubMed]
37. Kang, S.J.; Kim, B.M.; Lee, Y.J.; Chung, H.W. Titanium dioxide nanoparticles trigger p53-mediated damage response in peripheral blood lymphocytes. *Environ. Mol. Mutagen.* 2008, *49*, 399–405. [Google Scholar] [CrossRef] [PubMed]
38. Xia, T.; Kovochich, M.; Brant, J.; Hotze, M.; Sempf, J.; Oberley, T.; Sioutas, C.; Yeh, J.I.; Wiesner, M.R.; Nel, A.E. Comparison of the abilities of ambient and manufactured nanoparticles to induce cellular toxicity according to an oxidative stress paradigm. *Nano Lett.* 2006, *6*, 1794–1807. [Google Scholar] [CrossRef] [PubMed]
39. Muller, J.; Huaux, F.; Moreau, N.; Misson, P.; Heilier, J.-F.; Delos, M.; Arras, M.; Fonseca, A.; Nagy, J.B.; Lison, D. Respiratory toxicity of multi-wall carbon nanotubes. *Toxic. Appl. Pharmacol.* 2005, *207*, 221–231. [Google Scholar] [CrossRef] [PubMed]
40. Mutlu, G.k.M.; Budinger, G.S.; Green, A.A.; Urich, D.; Soberanes, S.; Chiarella, S.E.; Alheid, G.F.; McCrimmon, D.R.; Szleifer, I.; Hersam, M.C. Biocompatible nanoscale dispersion of single-walled carbon nanotubes minimizes in vivo pulmonary toxicity. *Nano Lett.* 2010, *10*, 1664–1670. [Google Scholar] [CrossRef] [PubMed]
41. Fard, J.K.; Jafari, S.; Eghbal, M.A. A review of molecular mechanisms involved in toxicity of nanoparticles. *Adv. Pharm. Bull.* 2015, *5*, 447–454. [Google Scholar] [CrossRef] [PubMed]
42. Gualtierotti, R.; Guarnaccia, L.; Beretta, M.; Navone, S.E.; Campanella, R.; Riboni, L.; Rampini, P.; Marfia, G. Modulation of neuroinflammation in the central nervous system: Role of chemokines and sphingolipids. *Adv. Ther.* 2017, *34*, 396–420. [Google Scholar] [CrossRef] [PubMed]
43. Ma, L.; Zou, X.; Chen, W. A new X-ray activated nanoparticle photosensitizer for cancer treatment. *J. Biomed. Nanotechnol.* 2014, *10*, 1501–1508. [Google Scholar] [CrossRef] [PubMed]

44. Guan, X.; Avci-Adali, M.; Alarçin, E.; Cheng, H.; Kashaf, S.S.; Li, Y.; Chawla, A.; Jang, H.L.; Khademhosseini, A. Development of hydrogels for regenerative engineering. *Biotechnol. J.* 2017, *12*, 1600394. [Google Scholar] [CrossRef] [PubMed][Green Version]

45. Dorniani, D.; Hussein, M.Z.B.; Kura, A.U.; Fakurazi, S.; Shaari, A.H.; Ahmad, Z. Preparation of Fe_3O_4 magnetic nanoparticles coated with gallic acid for drug delivery. *Int. J. Nanomed.* 2012, *7*, 5745–5756. [Google Scholar] [CrossRef] [PubMed]
46. Benita, S. *Microencapsulation: Methods and Industrial Applications*; Taylor & Francis: Boca Raton, FL, USA, 2006. [Google Scholar]
47. Mishra, A.K. *Nanomedicine for Drug Delivery and Therapeutics*; Wiley: New York, NY, USA, 2013. [Google Scholar]
48. Ceccon, A.; Tugarinov, V.; Bax, A.; Clore, G.M. Global dynamics and exchange kinetics of a protein on the surface of nanoparticles revealed by relaxation-based solution NMR spectroscopy. *J. Am. Chem. Soc.* 2016, *138*, 5789–5792. [Google Scholar] [PubMed]
49. Pham, N.; Radajewski, D.; Round, A.; Brennich, M.; Pernot, P.; Biscans, B.; Bonneté, F.; Teychené, S. Coupling high throughput microfluidics and small-angle X-ray scattering to study protein crystallization from solution. *Anal. Chem.* 2017, *89*, 2282–2287. [Google Scholar] [CrossRef] [PubMed]
50. Pishkar, L.; Taheri, S.; Makarem, S.; Alizadeh Zeinabad, H.; Rahimi, A.; Saboury, A.A.; Falahati, M. Studies on the interaction between nanodiamond and human hemoglobin by surface tension measurement and spectroscopy methods. *J. Biomol. Struct. Dyn.* 2017, *35*, 603–615. [Google Scholar] [CrossRef] [PubMed]
51. Huang, R.; Lau, B.L. Biomolecule–nanoparticle interactions: Elucidation of the thermodynamics by isothermal titration calorimetry. *Biochim. Biophys. Acta Gen. Subj.* 2016, *1860*, 945–956. [Google Scholar] [CrossRef] [PubMed]
52. Manyanga, F.; Sithole, A.; Rivera, R.; Karamehmedovic, N.; Martin, N. Use of differential scanning calorimetry (DSC) to study the thermodynamics of DNA-based interactions and nucleic acid-based therapeutics. *J. Anal. Pharm. Res.* 2016, *2*, 00013. [Google Scholar]
53. Esfandfar, P.; Falahati, M.; Saboury, A. Spectroscopic studies of interaction between cuo nanoparticles and bovine serum albumin. *J. Biomol. Struct. Dyn.* 2016, *34*, 1962–1968. [Google Scholar] [CrossRef] [PubMed]