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Nanoparticles: Properties, Applications and Toxicities

Aakanksha Arvind Patil

Rajiv Gandhi Institute of IT and Biotechnology, Bharti Vidyapeeth Deemed to be University (BVDU), Pune, Maharashtra, India

Abstract

This present review provided a detailed overview of the synthesis, properties and applications of Nanoparticles (NPs) exist in different forms. NPs are tiny small in size ranges from 1 to 100 nm. They are classified into different classes based on their properties, shapes or sizes. The different groups include fullerenes, metal NPs, ceramic NPs, and polymeric NPs. NPs possess unique physical and chemical properties due to their high surface area and nanoscale size. Their optical properties are reported to be dependent on the size, which imparts different colors due to absorption in the visible region. Their reactivity, toughness and other properties are also dependent on their unique size, shape and structure. Due to these characteristics, they are suitable candidates for various commercial and domestic applications, which include catalysis, imaging, medical applications, energy-based research, and environmental applications. Heavy metal NPs of lead, mercury and tin are reported to be so rigid and stable that their degradation is not easily achievable, which can lead to much environmental toxicity.

Key words: Nanoparticles (NPs), Nanotechnology, Toxicity and Applications.

1. Introduction

Nanotechnology is a known field of research since last century. Since ‘‘Nanotechnology” was presented by Nobel laureate Richard P. Feynman during his well famous 1959 lecture ‘‘There’s Plenty of Room at the Bottom” (Feynman, 1960), there have been made various revolutionary developments in the field of Nanotechnology. Nanotechnology produced materials of various types at nanoscale level. Nanoparticles (NPs) are wide class of materials that include particulate substances, which have one dimension less than 100 nm at least. Depending on the overall shape these materials can be 0D, 1D, 2D or 3D (Tiwari *et al*., 2012). The importance of these materials realized when researchers found that size can influence the physiochemical properties of a substance e.g. the optical properties. A 20 nm gold (Au), platinum (Pt), silver (Ag), and palladium (Pd) NPs have characteristic wine red color, yellowish gray, black and dark black colors, respectively. These NPs showed characteristic colors and properties with the variation of size and shape, which can be utilized in bioimaging applications (Dreaden *et al*., 2012). As Figure - 1 indicates, the color of the solution changes due to variation in aspect ratio, nanoshell thickness and percentage gold concentration. The alteration of any of the above discussed factor influences the absorption properties of the NPs and hence different absorption colors are observed. NPs are not simple molecules itself and therefore composed of three layers i.e. (a) The surface layer, which may be functionalized with a variety of small molecules, metal ions, surfactants and polymers, (b) The shell layer, which is chemically different material from the core in all aspects, and (c) The core, which is essentially the central portion of the NP and

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usually refers the NP itself (Shin *et al*., 2016). Owing to such exceptional characteristics, these materials got immense interest of researchers in multidisciplinary fields. The NPs can be employed for drug delivery (Lee *et al*., 2011), chemical and biological sensing (Barrak *et al*., 2016), gas sensing, CO_2 capturing (Ramacharyulu *et al*., 2015; Ganesh *et al*., 2017) and other related applications (Shaalan *et al*., 2016).

a) The surface layer, which may be functionalized with a variety of small molecules, metal ions, surfactants and polymers

b) The shell layer, which is chemically different material from the core in all aspects

c) The core, which is essentially the central portion of the NP and usually refers the NP itself

Figure – 1: The color of the solution changes due to variation in aspect ratio, nanoshell thickness and percentage gold concentration

2. Classification of Nanoparticles (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.

Carbon-based NPs

Fullerenes and Carbon Nanotubes (CNTs) represent two major classes of carbon - based NPs. Fullerenes contain nanomaterial that are made of globular hollow cage such as allotropic forms of carbon. They have created noteworthy commercial interest Nanoparticles 909 due to their electrical conductivity, high strength, structure, electron affinity, and versatility (Astefanei *et al*., 2015). These materials possess arranged pentagonal and hexagonal carbon units, while each carbon was sp 2 hybridized. CNTs are elongated, tubular structure, 1 - 2 nm in diameter (Ibrahim, 2013). These can be predicted as metallic or semiconducting reliant on their diameter telicity (Aqel *et al*., 2012). The rolled sheets can be single, double or many walls 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 (Elliott *et al*., 2013). 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 (Saeed and Khan, 2016 Saeed and Khan, 2014), efficient gas adsorbents for environmental remediation (Ngoy *et al*., 2014), and as support medium for different inorganic and organic catalysts (Mabena *et al*., 2011).

Metal NPs

Metal NPs are purely made of the metals 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 (Dreaden *et al*., 2012). 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.

Ceramics NPs

Ceramics NPs are inorganic nonmetallic solids, synthesized *via* heat and successive cooling. They can be found in amorphous, polycrystalline, dense, porous or hollow forms (Sigmund *et al*., 2006). 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 (Thomas *et al*., 2015).

Semiconductor NPs

Semiconductor materials possess properties between metals and nonmetals and therefore they found various applications in the literature due to this property (Ali *et al*., 2017; Khan *et al*., 2017a). 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 band gap and band edge positions (Hisatomi *et al*., 2014).

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 (Mansha *et al*., 2017). 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 (Rao and Geckeler, 2011). The PNPs are readily functionalize and thus find bundles of applications in the literature (Abd Ellah and Abouelmagd, 2016; Abouelmagd *et al*., 2016).

3. Characterization of NPs

Different characterization techniques have been practiced for the analysis of various physicochemical properties of NPs. These include techniques such as X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), Infrared (IR), SEM, TEM, Brunauer Emmett Teller (BET), and particle size analysis.

Morphological characterizations

The morphological features of NPs always attain great interest since morphology always influences most of the properties of the NPs. There are different characterization techniques for morphological studies, but Microscopic techniques such as Polarized Optical Microscopy (POM), SEM and TEM are the most important of these. SEM technique is based on electron scanning principle, and it provides all available information about the NPs at nanoscale level. Wide literature is available, where people used this technique to study not only the morphology of their nanomaterials, but also the dispersion of NPs in the bulk or matrix. TEM is based on electron transmittance principle, so it can provide information of the bulk material from very low to higher magnification. The different morphologies of gold NPs are studied via this technique. TEM also provides essential information about two or more layer materials. These NPs founded to be exceptionally active as anode in Li-ion batteries.

Structural characterizations

The structural characteristics are of the primary importance to study the composition and nature of bonding materials. It provides diverse information about the bulk properties of the subject material. XRD, Energy dispersive X-ray (EDX), XPS, IR, Raman, BET, and Zieta size analyzer are the common techniques used to study structural properties of NPs. In the case of smaller NPs having size less than hundreds of atoms, the acquisition and correct measurement of structural and other parameters may be difficult. Moreover, NPs having more amorphous characteristics with varied inter atomic lengths can influence the XRD diffractogram. In that case, proper comparison of the diffractograms of bimetallic NPs with those of the corresponding monometallic NPs and their physical mixtures is required to obtain accurate information. EDX, which is normally fixed with field emission scanning electron miscopy (FE-SEM) or TEM device is widely used to know about the elemental composition with a rough idea of % wt. The electron beam focused over a single NP by SEM or TEM through the program functions, to acquire the insight information from the NP under observation. NP comprises of constituent elements and each of them emits characteristics energy X-rays by electron beam irradiation. The intensity of specific X-ray is directly proportional to the concentration of the explicit element in the particle. This technique is widely used by researchers to give support to SEM and other techniques for the confirmation of their elements in prepared materials (Avasare *et al*., 2015;

Iqbal *et al*., 2016). The EDX technique used to determine the elemental composition of ultra-sonochemically synthesized pseudo-flower shaped $BiVO_4$ NPs (Khan *et al*., 2017b). Similarly, by utilizing similar technique the elemental confirmation and graphene impregnation of In2O3/grapheme heterostructure NPs was carried out, which showed C, In and O as contributing elements. This material was synthesized through Conventional Hydrothermal Technique (Mansha *et al*., 2016). More recently Surface Enhanced Raman Spectroscopy (SERS) is evolving as vibrational conformational tool due to its signal enhanced capability via SPR phenomenon. One study reported SERS technique to study the vibrational properties with phonons modes in nanostructured and quantum dots NPS of TiO_2, ZnO and PbS. They concluded that the enhanced spectra can be attributed to the plasmonic resonances in semiconductor (Ma *et al*., 2011).

Particle size and Surface area characterization

Different techniques can be used to estimate the size of the NPs. These include SEM, TEM, XRD, AFM, and Dynamic Light Scattering (DLS). SEM, TEM, XRD and AFM can give better idea about the particle size (Kestens *et al*., 2016), but the zeta potential size analyzer/DLS can be used to find the NPs size at extremely low level. In one study, Sikora *et al*. (2015) used DLS technique to investigate the size variation of silica NPs with absorption of proteins from serum. The results showed that size increased with acquisition of protein layer. However, in case of agglomeration and hydrophilicity, DLS might prove incapable of accurate measurement, so in that case we should rely on the high-resolution technique of Differential Centrifugal Sedimentation (DCS). Beside DSC, Nanoparticle Tracking Analysis (NTA) is relatively newer and special technique, which can be helpful in case of biological systems such as proteins, and DNA. In NTA method, we can visualize and analyze the NPs in liquids media that relates the Brownian motion rate to particle size. This technique allows us to find the size distribution profile of NPs with diameter ranging from 10 to 1000 nm in a liquid medium (Filipe *et al*., 2010). This technique produced some good results as compared to DLS and found to be very precise for sizing monodisperse as well as polydisperse samples, with substantially better peak resolution. Gross *et al*. (2016) detected the particle size and concentration of different sized NPs in suspensions of polymer and protein samples and provided an overview on the effect of experimental and data evaluation parameters (Gross *et al*., 2016). Large surface area of nanomaterials offers great room for various applications and BET is the best technique to determine the surface area of NPs materials. This technique is based on adsorption and desorption principle and Brunauer Emmett Teller (BET) theorem. Normally nitrogen gas is used for this purpose.

Optical characterizations

Optical properties are of great concerned in photocatalytic applications and therefore, photo-chemists acquired good knowledge of this technique to reveal the mechanism of their photochemical processes. These characterizations are based on the famous beer-lambert law and basic light principles (Swinehart, 1962). These techniques give information about the absorption, reflectance, luminescence and phosphorescence properties of NPs. It is widely known that NPs especially metallic and semiconductor NPs possess different colors and therefore, best harmonized for photo-related applications. So, it is always interesting to know the value of absorption and reflectance of these materials to understand the basic mechanism for each application. Ultraviolet–visible (UV– Vis), Photoluminescence (PL) and the Null Ellipsometer are the well-known optical instruments, which can be used to study the optical properties of NPs materials. In addition to UV, PL also considers valuable technique to study the optical properties of the photoactive NPs and other nanomaterials. This technique offers additional information about the absorption or emission capacity of the materials and their effect on the overall excitation time of photoexcitons. Thus, it provides significant information about the charge recombination and half-life of the excited materials in their conductance band, which are useful for all photo related and imaging applications. The PL spectrum can be recorded as emission or absorbance depending on the nature of study. Similarly, Wan et al. determined the values of refractive index and extinction coefficient for hollow gold NPs (HGNPs) via spectroscopic ellipsometry. They prepared a series of HG-NPs, with different morphologies and plasmonic properties and the optical constants were calculated. The values were compared with the optical constant values of solid gold NPs, which gave good indication to use these materials in chemical sensing applications due to their sensitive nature as revealed from ellipsometric values (Wan *et al*., 2009).

4. Physicochemical properties of NPs

As discussed earlier, various physicochemical properties such as large surface area, mechanically strong, optically active and chemically reactive make NPs unique and suitable applicants for various applications.

Electronic and optical properties

The optical and electronic properties of NPs are interdependent to greater extent. For instance, noble metals NPs have size dependent optical properties and exhibit a strong UV - visible extinction band that is not present in the spectrum of the bulk metal. This excitation band results when the incident photon frequency is constant with the collective excitation of the conduction electrons and is known as the Localized Surface Plasma Resonance (LSPR). LSPR excitation results in the wavelength selection absorption with extremely large molar excitation coefficient resonance Ray light scattering with efficiency equivalent to that of ten fluorophores and enhanced local electromagnetic fields near the surface of NPs that enhanced spectroscopies. It is well established that the peak wavelength of the LSPR spectrum is dependent upon the size, shape and interparticle spacing of the NPs as well as its own dielectric properties and those of its local environment including the substrate, solvents and adsorbates (Eustis and ElSayed, 2006).

Magnetic properties

Magnetic NPs are of great curiosity for investigators from an eclectic range of disciplines, which include heterogenous and homogenous catalysis, biomedicine, magnetic fluids, data storage Magnetic Resonance Imaging (MRI), and environmental remediation such as water decontamination. The literature revealed that NPs perform best when the size is at such low scale the magnetic properties of NPs dominated effectively, which make these particle priceless and can be used in different applications (Faivre and Bennet, 2016; Priyadarshana *et al*., 2015; Reiss and Hutten, 2005; Zhu *et al*., 1994). The uneven electronic distribution in NPs leads to magnetic property. These properties are also dependent on the synthetic protocol and various synthetic methods such as Solvothermal (Qi *et al*., 2016), co-precipitation, micro-emulsion, thermal decomposition, and flame spray synthesis can be used for their preparation (Wu *et al*., 2008).

Mechanical properties

The distinct mechanical properties of NPs allow researchers to look for novel applications in many important fields such as Tribology, surface engineering, nanofabrication and nano manufacturing. Different mechanical parameters such as elastic modulus, hardness, stress and strain, adhesion and friction can be surveyed to know the exact mechanical nature of NPs (Guo *et al*., 2014). Beside these parameters surface coating, coagulation, and lubrication also aid to mechanical properties of NPs. NPs show dissimilar mechanical properties as compared to microparticles and their bulk materials. Moreover, in a lubricated or greased contact, the contrast in the stiffness between NPs and the contacting external surface controls whether the NPs are indented into the plan surface or deformed when the pressure at contact is significantly large. This important information could divulge how the NPs perform in the contact situation. Decent controls over mechanical features of NPs and their interactions with any kind of surface are vital for enlightening the surface quality and elevating material removal. Fruitful outcomes in these fields generally need a deep insight into the basics of the mechanical properties of NPs, such as elastic modulus and hardness, movement law, friction and interfacial adhesion and their size dependent characteristics (Guo *et al*., 2014).

Thermal properties

It is well-known fact that metals NPs have thermal conductivities higher than those of fluids in solid form. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil. Even oxides such as alumina (Al_2O_3) have thermal conductivity higher than that of water. Therefore, the fluids containing suspended solid particles are expected to display significantly enhanced thermal conductivities relative to those of conventional heat transfer fluids. Nanofluids are produced by dispersing the nanometric scales solid particles into liquid such as water, ethylene glycol or oils. Nanoparticles to those of conventional heat transfer fluids and fluids containing microscopic sized particles. Because the heat transfer takes place at the surface of the particles, it is desirable to use the particles with large total surface area. The large total surface area also increases the stability suspension (Lee *et al*., 1999).

5. Applications of NPs

Applications in Drugs and Medications

Nano-sized inorganic particles of either simple or complex nature, display unique, physical and chemical properties and represent an increasingly important material in the development of novel nanodevices which can be used in numerous physical, biological, biomedical and pharmaceutical applications (Martis *et al*., 2012; Nikalje, 2015; Loureiro *et al*., 2016). NPs have drawn increasing interest from every branch of medicine for their ability to deliver drugs in the optimum dosage range often resulting in increased therapeutic efficiency of the drugs, weakened side effects and improved patient compliance (Alexis *et al*., 2008). The selection of NPs for achieving efficient contrast for biological and cell imaging applications as well as for photo thermal therapeutic applications is based on the optical properties of NPs. Mie theory and discrete dipole approximation method can be used to calculate absorption and scattering efficiencies and optical resonance wavelength for the commonly used classes of NPs i.e. Au NPs, silica-Au NPs and Au nanorods. All of these biomedical applications require that the NPs have high magnetization value, a size smaller than 100 nm and a narrow particle size distribution (Laurent *et al*., 2010). The detection of analytes in tissue sections can be accomplished through antigen-antibody interactions using antibodies labeled with fluorescent dyes, enzymes, radioactive compounds or colloidal Au (Khlebtsov and Dykman, 2010). Various polymers have been used in drug delivery research as they can effectively deliver the drugs to the target site thus increases the therapeutic benefit, while minimizing side effects. The controlled release of pharmacologically active drugs to the precise action site at the therapeutically optimum degree and dose regimen has been a major goal in designing such devices. Liposomes have been used as a potential drug carrier instead of conventional dosage forms because of their unique advantages which include ability to protect drugs from degradation, target to the site of action and reduce the noxiousness and other side effects. However developmental work on liposome drugs has been restricted due to inherent health issues such as squat encapsulation efficiency, rapid water leakage in the commodity of blood components and very poor storage, and stability. On the other hand, polymeric NPs promise some critical advantages over these materials i.e. liposomes. For instance, NPs help to increase the ratability of drugs or problems and possess convenient controlled drug release properties. Most of the semiconductor and metallic NPs have immense potential for cancer diagnosis and therapy on account of their Surface Plasmon Resonance (SPR) enhanced light scattering and absorption. Au NPs efficiently convert the strong absorbed light into localized heat which can be exploited for the selective laser photo thermal therapy of cancer. Antimicrobial agents are extremely vital in textile, medicine, water disinfection and food packaging. Therefore, the antimicrobial characteristics of inorganic NPs add more potency to this important aspect, as compared to organic compounds, which are relatively toxic to the biological systems. These NPs are functionalized with various groups to overcome the microbial species selectively. TiO_2, ZnO, $BiVO_4$, Cu- and Ni-based NPs have been utilized for this purpose due to their suitable antibacterial efficacies (Akhavan *et al*., 2011; Pant *et al*., 2013; Qu *et al*., 2016; Yin *et al*., 2016).

Applications in Manufacturing and Materials

Nanocrystalline materials provide very interesting substances for material science since their properties deviate from respective bulk material in a size dependent manner. Manufacture NPs display physicochemical characteristics that induce unique electrical, mechanical, optical and imaging properties that are extremely looked-for in certain applications within the medical, commercial, and ecological sectors (Ma, 2003; Dong *et al*., 2014; Todescato *et al*., 2016). NPs focus on the characterization, designing and engineering of biological as well as non-biological structures < than 100 nm, which show unique and novel functional properties. The potential benefits of nanotechnology have been documented by many manufacturer at high and low level and marketable products are already being mass-produced such as microelectronics, aerospace and pharmaceutical industries (Weiss *et al*., 2006). Metals NPs such as noble metals, including Au and Ag have many colors in the visible region based on plasmon resonance, which is due to collective oscillations of the electrons at the surface of NPs (Khlebtsov and Dykman, 2010a, 2010b; Unser *et al*., 2015). The resonance wavelength strong depends on size and shape of NPs, the interparticle distance, and the dielectric property of the surrounding medium. The unique plasmon absorbance features of these noble metals NPs have been exploited for a wide variety of applications including chemical sensors and biosensors (Unser *et al*., 2015).

Applications in the Environment

The increasing area of engineered NPs in industrial and household applications leads to the release of such materials into the environment. Assessing the risk of these NPs in the environment requires on understanding of their mobility, reactivity, eco-toxicity and persistency (Ripp and Henry, 2011; Zhuang and Gentry, 2011). The engineering material applications can increase the concentration of NPs in groundwater and soil which presents the most significant exposure avenues for assessing environmental risks (Masciangioli and Zhang, 2003; Golobic *et al*., 2012). Due to high surface to mass ratio natural NPs play an important role in the solid/water partitioning of contaminants can be absorbed to the surface of NPs, co-precipitated during the formation of natural NPs or trapped by aggregation of NPs which had contaminants adsorbed to their surface. The interaction of contaminants with NPs is dependent on the NPs characteristics, such as size, composition, morphology, porosity, aggregation/disaggregation and aggregate structure. The luminophores are not safe in the environment and are protected from the environmental oxygen when they are doped inside the silica network (Swadeshmukul *et al*., 2001). The removal of heavy metals such as mercury, lead, thallium, cadmium and arsenic from natural water has attracted considerable attention because of their adverse effects on environmental and human health. Superparamagnetic iron oxide NPs are an effective sorbent material for this toxic soft material. So, for no measurements of engineered NPs in the environment have been available due to the absence of analytical methods, able to quantify trace concentration of NPs (Mueller and Nowack, 2008). Photodegradation by NPs is also very common practice and many nanomaterials are utilized for this purpose. The high surface area of NPs due to very small size (<10 nm) facilitated the efficient photodegradation reaction (Rogozea *et al*., 2017). The same group has reported the synthesis of variety of NPs and reported their optical, florescence and degradation applications (Olteanu *et al*., 2016a, 2016b; Rogozea *et al*., 2016).

Applications in Electronics

There has been growing interest in the development of printed electronics in last few years because printed electronics offer attractive to traditional silicon techniques and the potential for low cost, large area electronics for flexible displays, sensors. Printed electronics with various functional inks containing NPs such as metallic NPs, organic electronic molecules, CNTs and ceramics NPs have been expected to flow rapidly as a mass production process for new types of electronic equipment (Kosmala *et al*., 2011). Unique structural, optical and electrical properties of one dimensional semi-conductor and metals make them the key structural block for a new generation of electronic, sensors and photonic materials (Millstone *et al*., 2010; Holzinger *et al*., 2014; Shaalan *et al*., 2016). The good example of the synergism between scientific discovery and technological development is the electronic industry, where discoveries of new semiconducting materials resulted in the revolution from vacuumed tubes to diodes and transistors, and eventually to miniature chips (Cushing *et al*., 2004). The important characteristics of NPs are facile manipulation and reversible assembly which allow for the possibility of incorporation of NPs in electric, electronic or optical devices such as ‘‘bottom up” or ‘‘self-assembly” approaches are the bench mark of nanotechnology (O’Brien *et al*., 2001).

Applications in Energy harvesting

Recent studies warned us about the limitations and scarcity of fossil fuels in coming years due to their nonrenewable nature. Therefore, scientists shifting their research strategies to generate renewable energies from easily available resources at cheap cost. They found that NPs are the best candidate for this purpose due to their, large surface area, optical behavior and catalytic nature. Especially in photocatalytic applications, NPs are widely used to generate energy from Photoelectrochemical (PEC) and electrochemical water splitting (Mueller and Nowack, 2008; Avasare *et al*., 2015; Ning et al., 2016). Beside water splitting, electrochemical CO_2 reduction to fuels precursors, solar cells and piezoelectric generators also offered advance options to generate energy. Recently, nanogenerators are created, which can convert the mechanical energy into electricity using piezoelectric, which is an unconventional approach to generate energy (Young *et al*., 2012; Fang *et al*., 2013; Nagarajan *et al*., 2014; Lei *et al*., 2015; Sagadevan, 2015; Gawande *et al*., 2016; Li *et al*., 2016; Zhou *et al*., 2016).

Applications in Mechanical industries

As revealed from their mechanical properties through excellent young modulus, stress and strain properties, NPs can offer many applications in mechanical industries especially in coating, lubricants and adhesive applications. Besides, this property can be useful to achieve mechanically stronger nanodevices for various purposes. Tribological properties can be controlled at nanoscale level by embedding NPs in the metal and polymer matrix to increase their mechanical strengths. It is because the rolling mode of NPs in the lubricated contact area could provide very low friction and wear. In addition, NPs offer good sliding and delamination properties, which could also effect in low friction and wear, and hence increase lubrication effect (Guo *et al*., 2014). Coating can lead to various mechanically strong characteristics, as it improves toughness and wear resistance. Alumina, Titania and carbon based NPs successfully demonstrated to get the desirable mechanical properties in coatings (Shao *et al*., 2012; Mallakpour and Sirous, 2015; Kot *et al*., 2016).

6. Toxicity of Nanoparticles (NPs)

Beside many industrial and medical applications, there are certain toxicities which are associated with NPs and other nanomaterials (Khlebtsov and Dykman, 2011, 2010b; Ibrahim, 2013; Bahadar *et al*., 2016) and basic knowledge is required for these toxic effects to encounter them properly. NPs surreptitiously enter the environment through water, soil, and air during various human activities. The advantages of magnetic NPs such as their small size, high reactivity and great capacity, could become potential lethal factors by inducing adverse cellular toxic and harmful effects, unusual in micron-sized counter parts. Studies also illustrated that NPs can enter organisms during ingestion or inhalation and can translocate within the body to various organs and tissues where the NPs have the possibility to exert the reactivity being toxicology effects. The respiratory system represents a unique target for the potential toxicity of NPs due to the fact that in addition to being the portal of entry for inhaled particles, it also receives the entire cardiac output (Ferreira *et al*., 2013). NPs are used in bio applications widely but despite the rapid progress and early acceptance of nanobiotechnology the potential for adverse health effects due to prolong exposure at various concentrations levels in human in the environment has not yet been established. However, the environmental impact of NPs is expected to increase in the future. NPs tend to aggregate in hard water and seawater and are greatly influenced by the specific type of organic matter or other natural particles (colloids) present in fresh water. The state of dispersion will alter the ecotoxicity, but many abiotic factors that influence this, such as pH, salinity, and the presence of organic matters remain to be systematically investigated as part of ecotoxicological studies (Handy *et al*., 2008).

7. Conclusion

In this review, we presented a detail overview about NPs, their types, synthesis, characterizations, physiochemical properties and applications. Through different characterization techniques such as SEM, TEM and XRD, it was revealed that NPs have size ranges from few nanometer to 500 nm while the morphology is also controllable. Due to their tiny size, NPs have large surface area, which make them suitable candidate for various applications. Beside this, the optical properties are also dominant at that size, which further increase the importance of these materials in photocatalytic applications. Synthetic techniques can be useful to control the specific morphology, size and magnetic properties of NPs. Though NPs are useful for many applications, but still there are some health hazard concerns due to their uncontrollable use and discharge to natural environment, which should be consider for make the use of NPs more convenient and environmental friendly.

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