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Review Article on Nanoparticles

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ABSTRACT:
Nanotechnology is one of the most innovative and popular technology since ages. Nanotechnology is not a modern technology but used since ancient times. There are various applications of nanotechnology in the field of chemistry, physics, biology and medicines. Nanoparticles are considered as most immerging topic in the field of medicines. There are various types of nanoparticles. Silver nanoparticles have been intensely investigated due to their excellent unique properties such as conductivity, chemical stability, catalytic activity, nonlinear optical behavior, and bactericidal activity. Green synthesis or biosynthesis of silver nanoparticles aims for an environmentally friendly manufacturing and uses extracts from organisms, non-toxic reductants and benign substances for particle stability. For silver nanoparticles the chemical reduction method works by reducing Ag ions in an aqueous solution using borohydride, citrate, ascorbate, or elemental hydrogen. When Ag ions are reduced, they form silver atoms (Ago) that will eventually agglomerate into oligomeric clusters and finally lead to colloidal silver nanoparticles.

Keywords: nanotechnology, nanoparticles, metallic nanoparticles, silver nanoparticles.

INTRODUCTION

Nanotechnology deals with the synthesis and applications of nanostructures in different fields such as chemistry, physics, biology, and medicine [1]. Nanoparticles which are produced from metals are called metal nanoparticles, which can also be synthesized using biological sources [2,3]. Silver has been widely used as an antibacterial agent for centuries because of its non-selective toxic biocidal activity [4]. In ancient times, silver nitrate was used to treat ophthalmic infections [5]. Silver metal-based cups and pots were used for storage of water to inhibit the contamination in water. Silver citrate salt has been well known for treatment of skin infections [6]. Since silver is very effective antibacterial, with very less toxicity towards human cells. It has been studied widely against multiple drug resistant bacteria [7]. Although silver is toxic at higher concentrations, many studies have established that a lower concentration of $AgNO_3$ has higher chemical stability, catalytic activity, biocompatibility, and intrinsic therapeutic potential [8].

1.1 History of nanotechnology

The advancement of ideas of nanotechnology is from ancient occasions when ancient people made utilization of normally happening, components of nanoscale [9]. Like, nano-sized carbon particles are incorporated pleasantly to the more permeable shaken surface of giving in dividers so that it can stay implanted for years. The principle of Nanotechnology is not only new for the electronic or post-industrial areas but also in modern nanoscience, it is also considered as newbie as well as has been also used from 4th century [10].
Stained glass windows from medieval places of worship were built many years back, which utilized gold and silver particles of very alternative sized, as shown in figure 1.1 and the procedure which is used to make these excellent masterpieces changed the arrangement and structure of these materials in their nanostate [11].

1.2 History of Nanomaterials

Concept of nanoparticles is from many years ago. Metal nanoparticles are trending from ancient times due to their broad range of activities. Many Researchers and scientist have revealed that metal nanoparticles are developed from Lycurgus cup which shows dichromic effect and also have Damascus steel which were used to make swords in ancient times. This technique was just an accident which leads to formation of nanoparticles and helps to find out their activities [12].

Now days, nanotechnology has become a popular and immerging topic due to its power to analyze nanoscale materials and is also helpful in various fields of nanotechnology [13]. From 500 AD, blades for swords were produce by Damascus steel. These swords were perceived for their flexibility, extraordinary quality, sharpness and good surface pattern. Silver nanoparticles give greenish color on scattering of light and red color when light passed from it. In ancient time, AgNPs concept was used for decoration of different materials using nanotechnology. This concept of AgNPs was not only limited to decoration but its inherent properties helped in exploring the different application of the AgNPs in the field of science. It is now placed in any British Museum [14].

Figure 1.1Ancient cup (Lycurgus cup)

1.3 Types of nanomaterials

Nanomaterials can be made of carbon (fullerenes, nanotubes, etc.,) or inorganic based materials. The latter, include metal oxides (zinc oxide, iron oxide, titanium dioxide, cerium oxide, etc.,), metals (silver, gold, iron, etc.,) and quantum dots (cadmium sulphide and cadmium selenide) [15]. Some of the most commercially used nanomaterials are briefly described below.

1.3.1 Natural nanoparticles

Natural nanoparticles (1- 100 nm), are found in aquatic surface and ground water as suspended particles less than 25 nm. In biological systems, examples include DNA, and complex nanostructured proteins such as polysaccharides, viruses, and bacterial exudates that control a range of biological activities. Rock weathering, volcanoes, fires and sea spray are also responsible for producing nano-sized components, other sources include, via microbial activity and through chemical hydrolysis [16].

1.3.2 Anthropogenic nanoparticles

Anthropogenic (incidental or adventitious) nanoparticles have existed since the earliest days of civilization. However, anthropogenic emissions of inorganic nanomaterials have more than doubled the mass of natural nanoparticles into the atmosphere. Recently nanomaterials were referred as ultrafine particles in the air (i.e., Nanomaterials resulting from diesel and gasoline-fueled vehicles and stationary combustion sources), colloids in soil (i.e., clays, organic matter, iron oxides and other minerals important for biogeochemical processes) and also colloids in water (comprising macromolecules, humic and fulvic acids, proteins and peptides, and hydrous iron and manganese oxide) [17, 18].

1.3.3 Carbon based nanomaterials

Carbon based nanomaterials are used in a variety of applications including optics, electronics and biomedicine [19].

1.3.3.1 Fullerenes

Fullerenes are molecules of 60 atoms of carbon (C60). Fullerenes and derivates are very insoluble in biofluids, which limits their application in the medical field. However, they have attracted the attention of many scientists for the variety of interesting applications in this field, and preliminary studies have investigated their role on HIV-Protease inhibition, DNA photocleavage, neuro-protection, apoptosis, among others biological effects [20].

1.3.3.2 Carbon nanotubes

Carbon nanotubes (CNTs) are single-walled (SWCNT) or multi-walled (MWCNT) cylindrical-shaped carbon particles with a diameter of 1 - 10 nm and length of a few micrometers. They are robust but flexible and have been used not only in the manufacturing industry (i.e., aircrafts, sports equipment, etc.,), but also as electron field emitters, nanoprobes in atomic force microscopy, supports for heterogeneous catalysis, microelectrodes in electrochemical reactions, and they are currently being investigated as potential hydrogen storage devices [21].

1.3.4 Metal oxide nanoparticles

Iron oxide nanoparticles are naturally present in high concentrations in the environment.

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Some of their super magnetic properties and generally low toxicity, makes them ideal for nano biotechnological applications and they have been already used as contrast agents for magnetic resonance imaging, drug delivery, gene therapy (efficient delivery of the desired gene and release inside the cell), clinical diagnosis to name a few. Zinc oxide nanoparticles are conventional band gap semiconductors (an energy range in a solid where no electron states exist), and their properties have been investigated due to their potential applications in electronic devices, chemical sensors, solar cells, antimicrobials, water remediation technologies and because of their ability to block UV-A and UV-B rays while being optically transparent, also as sunscreens and cosmetics. Titanium dioxide has received much attention for the application in the fields of photocatalytic activity and photocells due to its stability and low cost [22].

TiO_2 particles can also be used as energy storage devices, and in paints and coatings, sunscreens, etc. TiO_2 can be synthesized in three crystalline phases: rutile, brookite and anatase [23].

1.3.5 Metal nanoparticles

1.3.5.1 Zero-valent iron nanoparticles

The major application of zero-valent iron nanoparticles is in bioremediation technologies due to their size, and primarily due to their ability to degrade and adsorb pollutants, which is partly size dependent. The large volume to surface area enhances their effectiveness and increases the electron transfer required to eliminate toxic atoms [24].

1.3.5.2 Silver nanoparticles

Silver nanoparticles have been intensely investigated due to their excellent unique properties such as conductivity, chemical stability, catalytic activity, nonlinear optical behavior, and bactericidal activity [25]. These properties make them suitable for a variety of applications including inks, microelectronics, and bacterial disinfectant in medical equipment such as catheters, infusion systems and medical textiles. The manufacturing of silver nanoparticles is relatively cheap, and the addition of these particles into goods (i.e., plastics, clothing, creams and soaps) increases their market value due to the consumer valued antimicrobial property. To date, silver is used in more consumer products than any other nanomaterial. Silver nanoparticles, because of their antimicrobial properties, have wide spread applications in hospitals, such as medical bandages and dressings for use in surgery and in dressings for treating burns, as they can be embedded in various materials and textiles. Uses of silver nanoparticles in domestic products are becoming more common in washing machines, fridges and food containers to reduce surface mould growths [26-28].

Silver nanoparticles embedded into socks, to reduce odours, has been shown to leach silver into the environment from washing. Likewise, silver may leach from anti-fouling membranes, when used as an application in water purification. As environmental sensors, gold and silver have shown potential due to their optical responses when in contact with environmental contaminants such as silver nanoparticles which can be used to detect herbicide. For applications in treatment of contaminated groundwater, zero-valent iron can be used to form underground reactive barriers. Researchers at Ohio State University are experimenting with polymer semiconductors that absorb the sun's energy and generate electricity. They have discovered that adding tiny bits of silver to the plastic boosts the materials electrical current generation [29-32].

1.3.5.3 Gold nanoparticles

Gold nanoparticles are quite stable, inert and their electronic and optical properties can be adjusted. They have been utilised to couple with biomolecules for medical applications. For example, they can detect DNA with high sensitivity and selectivity and have potential applications as contrast agents in cancer diagnosis and therapy, as well as mutations, single nucleotide polymorphisms (SNPs), chromosomal translocations, gene expression and pathogens from clinical samples [33].

1.3.6 Other types of nanoparticles

Quantum dots

Quantum dots (QDs) are semiconductor nanocrystals which show great potential as a new type of labelling and imaging material in biological and biomedical applications because of their unique optical properties, such as tuneable fluorescence, with a broad excitation range [34].

1.4 Properties of nanomaterials

The reduction of a material dimension has pronounced effects on its physical properties, which may be significantly different from the corresponding bulk material.

Some of the physical properties exhibited by nanomaterials are due to: (i) the large number of surface atoms (ii) large surface energy (iii) spatial confinement and reduced imperfections [35].

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A few properties of nanomaterials are discussed below:

1.4.1 Optical property

For the last few decades, metallic nanoparticles have fascinated researchers due to their colorful colloidal solutions. Mie was the first to explain the red color of gold nanoparticles (in 1908) by solving Maxwell's equation for an electromagnetic light wave interacting with small metallic spheres. The color exhibited by metallic nanoparticles is due to the coherent excitation of all the "free" electrons within the conduction band, leading to an in-phase oscillation that is known as the surface plasmon resonance (SPR). Thus, the color of metallic nanoparticles may change with their size due to SPR [36-40].

1.4.2 Magnetic property

Magnetic properties of nanostructured materials are distinctly different from that of bulk materials. Ferromagnetic particles become unstable when the particle size reduces to below a certain size, as the increase in surface energy provides sufficient energy for domains to spontaneously switch polarization directions and become paramagnetic [41]. But this transformed paramagnetism is different from the conventional paramagnetism and thus is referred to as super paramagnetism. In other words, ferromagnetism of bulk materials disappears and is replaced by super paramagnetism in the nanoscale due to the high surface. Magnetic nanoparticles have been receiving considerable attention because of their wide range of applications, such as the immobolization of the proteins and enzymes, bioseparation, immunoassays, drug delivery, and biosensors. Nanoparticles of ferromagnetic materials are of importance because of their reduced sizes that can support only single magnetic domains [42-45].

1.4.3 Mechanical property

The mechanical properties of nanomaterials increase with a decrease in size. Most recent studies have been focused on the mechanical properties of one-dimensional structure such as nanowires. The enhanced mechanical strength of nanowires or nanorods is due to the high internal perfection of the Nanowires [46].

1.5 Silver Nanoparticles (AgNPs)

Nowadays, silver nanoparticles are used in various technologies and have a wide array of consumer products. Silver nanoparticles are trending because its properties are different due to its large surface area to volume ratio, surface energy and special confinement [47]. The superior antibacterial property of silver nanoparticle is due to increased surface area as well as increase potential to produce silver ions [48]. Because of its small size they can accumulate in the cytoplasmic membrane of the bacteria and can cause increase in permeability of the cell wall which leads to bactericidal effect. Also, surface of silver nanoparticles can produce free radicals which further cause damage to cell membrane leads to cell death [49]. They are widely been used because of its antibacterial and antiviral properties, very high catalytic activity and improved enhancement factors for Surface Enhanced Raman Spectroscopy (SERS) [50, 51]. The antibacterial nature of silver is enhanced in the form of nanoparticles. AgNPs has been reported to have the ability to penetrate the bacterial cell wall and damage the cell membrane that further leads to the death of the cell [52]. The presence of protein caps in nanoparticles helps in stabilization and binding to cell surface receptors which results in increase in binding and uptake of drug or genetic material on human cells [53, 54].

There are various methods to synthesize silver nanoparticles such as chemical reduction, photo reduction, micro emulsion method, radiolytic reduction, beam deposition and sonochemical reduction. AgNPs has been reported to have antibacterial activity against a number of bacterial species [55-58]. Silver nanoparticles (AgNPs) are trending due to their unique biological, chemical, and physical properties [59]. In fact, the slow and regulated release of silver from silver nanoparticles is one of the most striking advantages of these nanoparticles when compared with other bulk metals and their salts [60]. Silver nanoparticles are reported to have potential anticancer and antimicrobial activity [61].

A number of physical and chemical methods have been used for the synthesis of metal nanoparticles. Solution-phase, UV photolysis, Metal vapour deposition, Sonochemical decomposition, Electrochemical techniques, Laser ablation and Microwave plasma synthesis are commonly used physical and chemical techniques for silver nanoparticles production. The synthesis and development of metallic nanoparticles by biosynthetic processes has received much attention as an alternative tool in the field of nanotechnology.

For the past several years, algae, fungi, bacteria, viruses and plants have been used for

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energy-efficient, low-cost and nontoxic production of metallic nanoparticles. Recently, it is reported that this green method can potentially eliminate the various problems faced by the other methods. Green synthesis or biosynthesis of silver nanoparticles aims for an environmentally friendly manufacturing and uses extracts from organisms (i.e. biomolecules), non toxic reductants and benign substances for particle stability. For silver nanoparticles the chemical reduction method works by reducing Ag ions in an aqueous solution using borohydride, citrate, ascorbate, or elemental hydrogen. When Ag ions are reduced, they form silver atoms (Ago) that will eventually agglomerate into oligomeric clusters and finally lead to colloidal silver nanoparticles. Different reductants will yield different colloidal particle sizes. The use of weaker reductants such as citrate (also a capping agent) results in a slower reduction rate (and larger particles) and leads to larger size distributions. To overcome the problem of large size distributions, a two-step-controlled synthesis is used, by firstly utilising a strong reducing agent for the production of small nanoparticles, and secondly narrowing the size distribution with a weaker agent [62].

1.6 Importance of silver nanoparticles

1. The silver nanoparticles are utilized in cosmetic, medical and military applications due to their unique chemical and physical properties. Nanometer sized particles tend to exhibit very different properties than their bulk scaled counterparts.
2. It is used for purification and quality management of air, biosensing, imaging and drug delivery system.
3. Biologically synthesized silver nanoparticles have many applications like coatings for solar energy absorption and intercalation material for electrical batteries, as optical receptors, as catalysts in chemical reactions, for biolabelling, and as antimicrobials
4. Though silver nanoparticles are cytotoxic they have tremendous applications in the field of high sensitivity biomolecular detection and diagnostics, antimicrobials and therapeutics, catalysis and micro-electronics.
5. It has some potential application like diagnostic biomedical optical imaging, biological implants (like heart valves) and medical application like wound dressings, contraceptive devices, surgical instruments and bone prostheses.
6. Many major consumer goods manufacturers already are producing household items that utilize the antibacterial properties of silver nanoparticles. These products include nanosilver lined refrigerators, air conditioners and washing machines.
7. The antibacterial properties of silver nanoparticles have led to several new products such as nanoparticles embedded clothes, dryers, sheets to reduce clothing (socks) odors and antibacterial soap and toothpaste [63-68].

1.7 Why Green Synthesis?

AgNPs can be synthesized using various approaches like chemical, physical, and biological approaches. Also, chemical method requires short time duration for the synthesis of large quantity of nanoparticles [69]. Chemicals used for nanoparticles synthesis are considered as toxic and lead to non-eco-friendly byproducts. Considering eco-friendly practices, bio synthesis take-ups the whole interest, as it is nontoxic and do not leaves any byproducts [70].

Thus, there is an increase in demand of “green nanotechnology.” For the synthesis of nanoparticles, various biological approaches have been reported using micro-organisms like bacteria, fungi and plants [71]. AgNPs are considered as very effective antimicrobial agent who exhibits low toxicity [72]. Green synthesis is a better platform for nanoparticle synthesis as they are free from toxic chemicals and also provide natural capping agents. Use of plant extracts also reduces the cost of microorganism’s isolation and culture media, which enhance the cost competitive feasibility over nanoparticles synthesis by microorganisms [73]. So green chemistry has several advantages such as it is an economic, efficient, and ecofriendly process. It is also energy-efficient and cost-effective. Also results in healthier workplaces and communities, protecting human health and the environment and leads to lesser waste and safer products [74].

1.9 Nano-material a potential antimicrobial agent

Nanotechnology and nano-medicine have drastically improved the areas of disease diagnosis, drug design and drug delivery. The metal nanoparticles (NPs) have been widely explored to target bacteria as an alternative to antibiotics. The mechanism of nanomaterial against bacteria is still unknown. The size of bacteria is in picometers where as that of nano-material is in several nanometers even though there is a great difference in the size, nano-material has been proved to be effective against the bacteria. Thus, it is mainly because of the larger surface area possessed by smaller particles that help in the attachment to the large bacterial surface. This proves that size is an important criterion and for these reasons, nanoparticles are regarded as a real improvement in antimicrobial area. Another reason for exploring NPs as an antimicrobial agent is the mode of action used by NPs in killing the bacteria. They make direct contact with the bacterial cell wall without penetrating the cell which is different than the conventional antibiotics used, Therefore NPs are unaffected by the resistance mechanisms of the bacteria. Hence, NPs based materials possessing the antibacterial activity is the recent trend in the nano-medicine for treatment against bacterial infections [79].

1.10 Metal nanoparticles

Since ancient times different metals bas been used against several microbes. The metallic nanoparticles explored till date are silver (Ag), gold (Au), copper (Cu), aluminum (Al), titanium (Ti). iron (Fe), zinc (Zn). Nanotechnology in pharmaceuticals has attracted many researchers due to its numerous advantages. Different metal nanoparticles and their derivatives have been used for potential antimicrobial effects. Metals and metal oxides that shows antimicrobial activity are Ag, silver oxide (Ag_2O), titanium dioxide (TiO_2), silicon (Si), copper oxide (CuO), zinc oxide (ZnO), Au, calcium oxide (CaO) and magnesium oxide (MgO). ZnO nanoparticles are known to naturally inhibit the growth of a wide range of Gram-positive and Gram-negative bacterial strains as well as the spores without the use of additional antibiotics. ZnO affects bacterial cell activities such as glycolysis, transmembrane proton translocation, and acid tolerance [80]. ZnO is presumed to reduce the bacteria viability; by generation of hydrogen peroxide or by the accumulation of the particles on the bacterial surface due to the electrostatic forces, the exact mechanism followed by ZnO is still unknown [81]. TiO_2 is another metal oxide that is well explored for antimicrobial applications which is mainly because of its shape and size [82]. TiO_2 follows a different mechanism it generates reductive oxygen species (ROS) that causes DNA damage [83]. Prased et al studied TiO_2 nanoparticles along with several antibiotics against methicillin resistant Staphylococcus aureus (MRSA). It was observed that TiO_2 nanoparticles improved the antimicrobial effect of the antibiotics against MRSA [84]. Similarly gold nanoparticles (AuNps) have also been repmted by Jiang et at for its antibacterial activity against several bacteria such as Micrococcus luteus, Staphylococcus. aureus (S. aureus). Pseudomonas aeruginosa (P.aeruginosa), Escherichia coli (E. coli), Aspergillus fiunigates, and Aspergillus niger. It was reported that AuNps follow different mechanism other than ROS-related process. AuNps follows two step mechanisms: a) it attaches the bacterial membrane then modifying membrane potential followed by decreasing ATP level b) inhibiting tRNA that binds to the ribosome [85].

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