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NANOPARTICLES: A COMPREHENSIVE OVERVIEW OF TYPES, SYNTHESIS, AND APPLICATIONS

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ABSTRACT

The special little materials that exist on a nanometer scale, which ranges from 1 to 100 nm, are called nanoparticles (NPs). There are numerous kinds of these NPs. They fall into many classes, including organic, inorganic, and carbon-based nanoparticles, depending on their size, shape, origin, and characteristics. Because of their small size, the NPs have great surface area, reactivity, stability, sensitivity, and other physical and chemical qualities. There are numerous ways to synthesis these NPs. Numerous industrial and environmental fields of application have seen NPs used extensively in recent years, which is thought to be of utmost relevance. Furthermore, the types, preparation, synthesis, advantages and disadvantages of nanoparticles will be covered in this work.

KEYWORDS: Nanoparticles (NPs), magnetic resonance imaging (MRI), antibodies, in vitro and in vivo.

INTRODUCTION

Solid particles or particulate dispersions with sizes between 10 and 1000 nm are called nanoparticles. The medication is bonded, encapsulated, entrapped, or dissolved in a nanoparticle matrix.[1] Because of their nanoscale size, nanoparticles provide enhanced functionality and capacities in the production of semiconductors. They are used as dopants for controlled electrical properties and in processes like chemical mechanical planarization for precise polishing.[2] The nanoparticles with the seeming discretion of the energy level, often referred to as "quantum dots" or "artificial atoms," often share structural similarities with typical semiconductor materials. Alternatively, some NPs are executed as pseudomonas, which are characterized by a core and shell, complex internal systems, and often external working groups.[3] The small droplets are very useful in the production of cosmetics and personal care products since their particle size falls within the range of nanoparticles (100–600 nm). This makes it possible for the cream to be evenly and smoothly applied to the skin's surface. This enhances the cream's capacity to efficiently release the active pharmaceutical components onto the skin's surface in a semisolid form, thereby treating a range of ailments. In addition, the semisolid foundation could be hydrophilic or something else.[4]

The environment's soil, water, and air quality might all be considerably enhanced by nanotechnology. It can enhance pollutant sensing and detection and aid in the development of innovative cleanup methods. The development of effective strategies for lowering pollution emissions and stopping their formation in the first place is made possible by an understanding of the dynamic processes of nanoparticle synthesis and growth (for example, in the combustion system).[5] Since they are inorganic, they have a number of advantages, including improved biocompatibility, widespread availability, tailored distribution, and utility, to name a few, as well as exceptional stability. Two well-known examples of inorganic nanoparticles are titanium dioxide and zinc oxide, which are found in sunscreen and offer protection from UVA and UVB rays. Nanotechnology can improve pollutant sensing and detection and help develop new cleanup techniques. An understanding of the dynamic processes of nanoparticle formation and growth (for instance, in the combustion system) enables the development of efficient methods for reducing emissions of pollutants and preventing their creation in the first place.[6] With more than 30 authorized nanoformulations and more than 100 in clinical trials1, nanoparticle-based medicines have made their way into a variety of therapeutic applications. Additionally, two COVID-19 mRNA vaccines based on lipid nanoparticles (BNT162b2 and mRNA-1273) were developed quickly.[7] Wet chemistry or "bottom-up" routes like hydrothermal, solvothermal, sol-gel, co-precipitation, flow injection syntheses, electrochemical, and laser pyrolysis techniques are among the various ways to create magnetic nanostructures in the form of nanorods, nanowires, and nanocubes, including iron oxide magnetic nanoparticles.[8]

The growth method of nanoparticles dictates their distribution function based on their size, the medium's physical-chemical characteristics, and other factors. Understanding the growth mechanism allows for the management of nanoparticle preparation and the production of nanoparticles with specific dimensions (such as mean diameter, standard deviation, coefficient polydispersity, and others) and properties (such as magnetic moment). The growth mechanism of nanoparticles is a sufficiently intricate process that depends on numerous factors, including temperature, viscosity, medium concentration, and others.[9,10] Both preclinically and therapeutically, intravenously delivered nanoparticles are the best studied of these delivery systems. Given that systemically delivered nanoparticles have direct access to almost every area of the body and so have the greatest potential to impact clinical treatment, the increased interest in intravenous distribution is not surprising. Because of this, systemically administered nanoparticles also encounter particularly challenging issues in the delivery domain (e.g., biological problems).[11,12]

The size, shape, and structure of the nanoparticles vary. They range in size from 1 nm to 100 nm and can be spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc., or irregular. Depending on surface differences, the surface may be uniform or uneven. Certain nanoparticles have single or many crystal solids that are either loose or clumped together, and they can be either crystalline or amorphous.[13] Microorganisms biosynthesize nanoparticles by capturing target ions from their surroundings and using enzymes produced by cell activity to convert the metal ions into the element metal. Depending on the site of nanoparticle formation, it can be divided into intracellular and extracellular synthesis.[14,15]

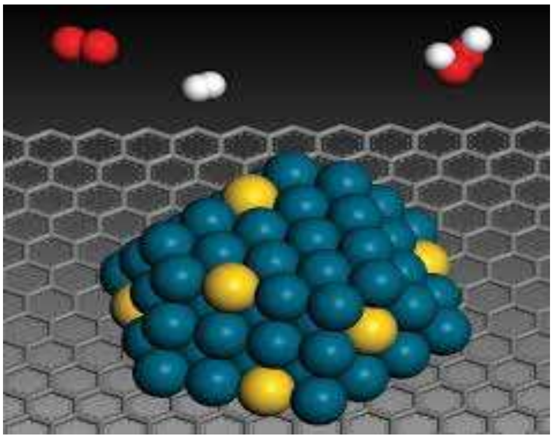

Fig.1.

Preparation of nanoparticles

Nanoparticles can be prepared from a variety of materials such as proteins, polysaccharides and synthetic polymers. The selection of matrix materials is dependent on many factors including.

(a) Size of nanoparticles required.

(b) Inherent properties of the drug, e.g., aqueous solubility and stability.

(c) Surface characteristics such as charge and permeability.

(d) Degree of biodegradability, biocompatibility and toxicity.

(e) Drug release profile desired.

(f) Antigenicity of the final product.[16]

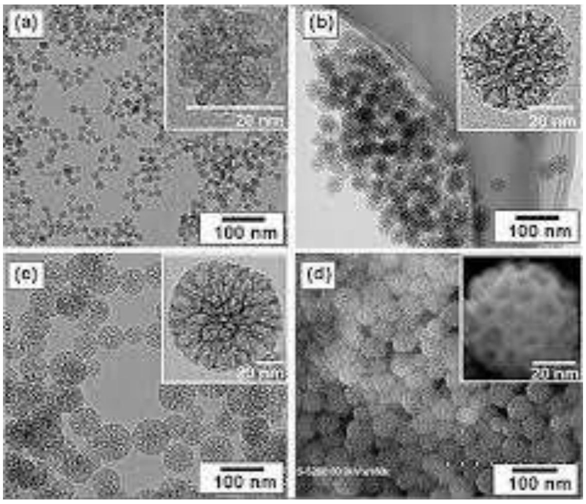

Fig. 2

Types

Silver nanoparticles

Gold nanoparticles

Magnetic nanoparticles

Iron nanoparticles

Copper nanoparticles

Silica nanoparticles

Silver nanoparticles

Many silver atoms or ions are grouped together to produce a silver nanoparticle, which ranges in size from 1 to 100 nm. These nanoparticles can infiltrate and kill bacteria and other microbes because of their small size.[16] The broad-spectrum activity of silver against viruses, fungi, bacteria, and protozoa, both Gram-positive and Gram-negative, has been well-documented.[17] A number of methods have been explored to manufacture silver nanoparticles. The chemical technique is the simplest of them all. Silver nitrate solution can be reduced by ethanol at 70–90 degrees Celsius in an atmosphere to create fine, homogeneous silver nanoparticle.

Fig. 3.

Throughout history, silver in all of its forms has been employed either alone or in conjunction with other technologies as an antibacterial agent.[19] By being used as silver nitrate or silver sulfadiazine in burn and ulcer treatment creams and dressings, food packaging to avoid contamination, household appliances like refrigerators and washing machines, and various industrial applications, this metal has been researched to capitalize on its capacity to inhibit bacterial growth.[20,21,22,23]

Synthesis of silver nanoparticle by chemical methods.

The most researched approach to creating Ag NPs is by chemical means.

a) Chemical reduction

b) Electrochemical approaches

c) Pyrolysis and,

d) Irradiation-assisted procedures are the four groups into which chemical processes can be separated.[24]

The most popular and extensively documented synthesis approach for Ag NPs is the chemical reduction of Ag+ species to Ag0 in solution using reducing agents; this method typically has no aggregation, a high yield, and a low preparation cost.[25]

Researchers have looked into the nucleation and growth processes involved in the synthesis of nanoparticles from solutions.[26]

Gold Nanoparticle

In medical applications like medication administration and cancer treatment, gold nanoparticles (Au NPs) work well as radiosensitizers. Au NPs can be used as a contrast agent and dose enhancer in image-guided nanoparticle-enhanced radiotherapy employing kilovoltage cone-beam computed tomography in biomedical and cancer therapeutic applications.[24,25] In immunochemical investigations, gold nanoparticles (AuNPs) are employed to detect protein interactions. To find out if there is DNA in a sample, they are employed as lab tracers in DNA fingerprinting. Additionally, they are employed to detect aminoglycoside drugs such as gentamycin, neomycin, and streptomycin. Gold nanorods are being utilized to identify various bacterial groups and detect cancer stem cells, which is helpful for diagnosing cancer.[26, 27]

Fig. 4.

The resulting AuNPs have special characteristics, including a high surface area to volume ratio, optical and electronic features that depend on size and shape, and surfaces that are easily modified with ligands that contain functional groups like thiols, phosphines, and amines that have an affinity for gold surfaces.[28] Additional moieties, such proteins, oligonucleotides, and antibodies, can be added to the ligands to provide even more functionality by anchoring them with these functional groups. The creation of these gold nanoconjugates has made it possible to conduct a variety of studies, such as material crystallization and programmed assembly.[29, 30]

Magnetic Nanoparticle

It is well known that magnetic nanoparticles such as Fe3O4 (magnetite) and Fe2O3 (maghemite) are biocompatible. They have been actively studied for guided drug delivery, gene therapy, magnetic resonance imaging (MRI), DNA analysis, targeted cancer treatment (magnetic hyperthermia), and stem cell sorting and manipulation.[31]

Fig. 5.

Over the past 20 years, magnetic nanoparticles (MNPs), which range in size from 1 nm to 100 nm, have become a significant nanomaterial for research and technology. Their special qualities, which differ significantly from those of their bulk counterparts, include a high surface-to-volume ratio and size-dependent magnetic properties. MNPs have drawn a lot of interest in a variety of fields, including gyroscopic sensors, data storage, spintronics, catalysts, and neurological stimulation.[32,33,34,35]

Iron nanoparticles

Superparamagnetic metal molecules having a large surface area, magnetic charges, and electrical conductivity are known as iron nanoparticles (10–100 nm). They are easily transformed into their oxidized form and are primarily produced by a reduction reaction between sodium borohydride and ferric chloride solution in an acidic/basic media. In diseases like glioblastoma multiforme, spinal tumors, amyotrophic lateral sclerosis, spinal stenosis, etc., iron nanoparticles track anatomical changes and functionalize cellular trafficking. Iron particles create magnetism as a physical stimulation in subarachnoid delivery, functionalizing the drug surface and delivering the active ingredients straight to the site of action. This reduces the negative effects on the body's off-targeted areas.[36]

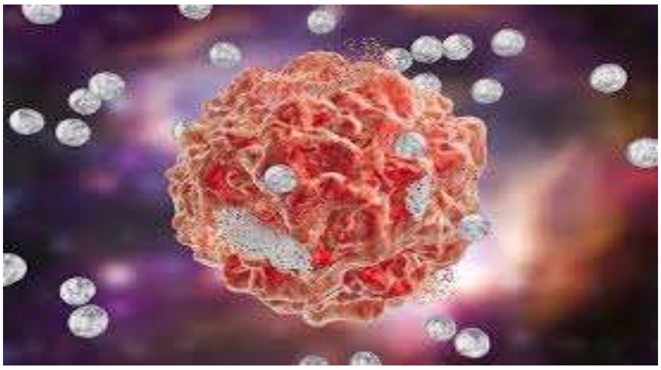

Fig. 6.

IONPs are superparamagnetic and only become magnetized in the presence of a magnetic field because of the core's magnetic characteristics and their small particle size. The use of such particles as contrast agents in magnetic resonance imaging (MRI), where IONPs produce hypointense (dark) signals in T2-weighted MR images, has been demonstrated to benefit from these unique features. As a result, they are the opposite of the traditional Gadolinium (Gd)-based contrast agents, which raise T1 relaxation rates and produce brighter, more positive picture contrast. Ultra-small IONPs have also been shown to exist in recent research.[37, 38]

Copper Nanoparticles

Potential uses for copper nanoparticles include the production of conductive films, antibacterial agents, lubricants, and nanofluids as well as in optics, electronics, and medicine. Copper nanoparticles are preferred over silver because they are less expensive, more stable chemically and physically, and simpler to mix with polymers.

Although the activity of smaller nanoparticles is higher, they may form clusters and lose important characteristics.[39, 40]

Fig. 7

One of the most used materials in the world is copper. Because of its low cost, it is very important in all industries, but especially in the electrical sector. Several techniques have been used to produce and analyze copper nanoparticles. The two key elements that prevent the metal cluster from being used and developed in a new generation of nano-electronic devices are stability and reactivity.[41]

Silica nanoparticles

The most common nanomaterials utilized to construct pH nanosensors are silica nanoparticles. Silica nanoparticles have low toxicity, optically transparent, pH inert, and (some are) biodegradable. More appealingly, the well-established silane technology makes it simple to functionalize their surface. The majority of the time, the pH-sensitive dyes are chemically bound to the silica nanoparticle surface, which helps to protonate and lower the diffusion barrier. Reference dyes that are inert to pH changes are always added to the surface or interior of silica nanoparticles to prevent signal interference and enable ratiometric readout. A ratiometric pH nanosensor was created by the burns group.[42]

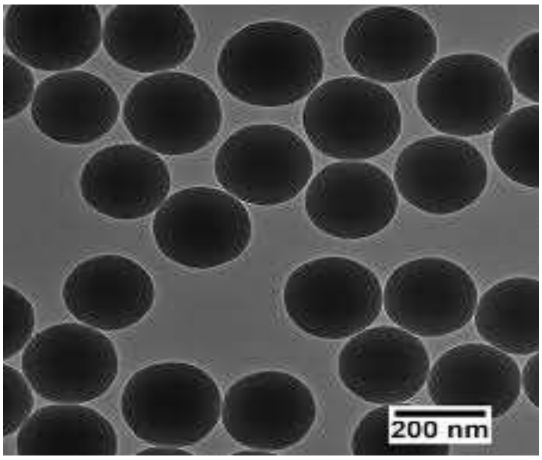

Fig. 8.

Sand and rock contain silicon dioxide ($SiO2$), a common and abundant material that is used to make silica nanoparticles. They are created using a variety of techniques, such as sol-gel synthesis, hydrolysis, and chemical vapor deposition. Like other nanoparticles, silica nanoparticles can be employed in a variety of adsorption and catalytic processes due to their large surface area and chemical durability. They are also helpful for a variety of industrial and structural applications due to their high melting point and resilience to heat and chemical assault. Apart from their physical and chemical characteristics, silica nanoparticles possessing biocompatibility and low toxicity make them appropriate materials for use in biological and medical applications, including tissue engineering, imaging, and drug delivery.[43]

Advantages of nanoparticles

The advantages of using nanoparticles as a drug delivery system include the following:

a) Particle size and surface characteristics of nanoparticles can be easily manipulated to achieve both passive and active drug targeting after parenteral administration.

b) They control and sustain release of the drug during the transportation and at the site of localization altering organ distribution of the drug and subsequent clearance of the drug so as to achieve increase in drug therapeutic efficacy and reduction in side effects.

c) Site-specific targeting can be achieved by attaching targeting ligands to surface of particles or use of magnetic guidance.

d) The selection of matrix ingredients allows for easy modulation of controlled release and particle degrading characteristics. One crucial element in maintaining drug activity is the comparatively high drug loading and the ability to absorb pharmaceuticals into systems without causing any chemical reaction.

e) The system can be administered via oral, nasal, parenteral, intraocular, and other methods.[44]

Disadvantages of nanoparticles

a) Ostwald ripening: because of the high free energy of the nanoparticles, agglomerates and aggregates form.

b) A more intricate operational process

c) A greater likelihood of contamination.

d) Nanoparticles' smaller size and larger surface area make them extremely difficult to handle in both liquid and dry forms; also, their smaller size and larger surface area make them highly reactive to external phase.[45]

CONCLUSION

Nanoparticles' amazing qualities have made them important in a variety of industries in recent years, including agriculture, health care, energy, and the environment. The ability of nanoparticle technologies to transform biologically active chemicals that are labile, poorly soluble, and poorly absorbed into promising deliverable substances gives them enormous potential. An extremely appealing platform for a wide range of biological applications is provided by nanoparticles. These systems' surface and core characteristics can be designed for both single and multimodal uses, such as biosensing, bioimaging, medicinal delivery, and biomolecular recognition. Applications for nanoparticles have previously been many and include both in vitro and in vivo settings. The acute and long-term health impacts of nanomaterials, scalable, reproducible manufacturing processes, and trustworthy metrics for characterizing these materials are just a few of the unresolved difficulties that must be resolved before their full potential can be realized.

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