International Journal of Research in Engineering, Science and Management
Volume 7, Issue 5, May 2024
https://www.ijresm.com | ISSN (Online): 2581-5792

A Review on Nanoparticle: Structure, Synthesis, Classification and Application

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***Abstract*: This review was concentrated on providing a thorough overview of the characteristics, synthesis, and uses of nanoparticles (NP), which exist in various forms. Nanoparticles are incredibly small particles with sizes between 1 and 100 nm. They are divided into a number of classes according to their sizes, forms, and characteristics. Metal nanoparticles (NP), ceramic NP, polymeric NP, and fullerenes were among the distinct group. Because of their large surface area and nanoscale size, NP have distinct chemical and physical properties. It is known that their optical properties depend on size, which gives different colours because of absorption in the visible area. Their distinct sizes, shapes, and structures also affect their hardness, reactivity, and other qualities. These qualities make them suitable candidates for a variety of applications both domestically and commercially, including energy base research, imaging, medicinal, environmental, and catalysis. Lead, tin, and mercury heavy metal NP are said to be so hard and stable that it is difficult to degrade them, which can have a variety of harmful effects on the environment. Their distinct sizes, shapes, and structures also affect their hardness, reactivity, and other qualities. These characteristics make them suitable candidates for a wide range of domestic and commercial applications, including energy-based research, imaging, medicinal, and environmental applications, as well as catalysis. According to reports, the heavy metal NP of lead, tin, and mercury are so stable and inflexible that it is difficult to degrade them, which can have a variety of harmful effects on the environment.**

***Keywords*: Nanoparticles, Type, Synthesis, Organic nanoparticles, Inorganic nanoparticles.**

1. Introduction

The creation and use of nanostructures in a variety of disciplines, including biology, physics, chemistry, and medicine, is known as nanotechnology [1].

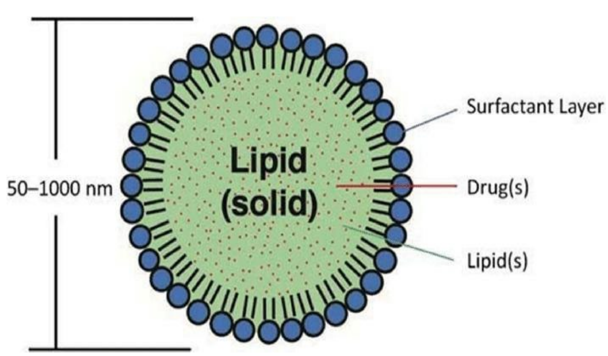

Fig. 1. Structure of nanoparticle

Metal nanoparticles, which can also be created from biological sources, are nanoparticles made of metals [2, 3]. Due to its nonselective harmful biocidal effect, silver has been utilised as an antibacterial agent for centuries [4]. Ocular infections were treated with silver nitrate in antiquity [5]. To prevent water pollution, pots and cups made of silver metal were used to store water. It is commonly recognised that silver citrate salt can be used to treat skin infections [6]. Due to its exceptional antibacterial properties, silver poses minimal hazard to human cells. Its efficacy against drug resistant microorganisms has been extensively researched [7]. Numerous investigations have shown that lower concentrations of AgNO3 have greater chemical stability, catalytic activity, biocompatibility, and intrinsic therapeutic potential, despite the fact that larger concentrations of silver are poisonous [8].

2. Structure of Nanoparticals

Nanoparticles have a complicated structure. They consist of two or three layers.

1. Surface layer: Functionalized with tiny molecules, metal ions, surfactants, or polymers.
2. The shell layer is chemically distinct from the core.
3. The core material is the central section of NPs. [38]-[40].

Need of Nanoparticles:

Controlling particle size, surface characteristics, and the release of pharmacologically active compounds are the main objectives when designing nanoparticles as a delivery system. This allows the medicine to function at a specific spot at the appropriate pace and dosage [9]. Compared to liposomes, polymeric nanoparticles have a few unique advantages. For example, they have beneficial controlled release capabilities and aid in boosting the stability of medications and proteins.[10]

Advantages:

The following are some benefits of employing nanoparticles as a drug delivery system:

1. The ability to easily modify the surface properties and particle size of nanoparticles to accomplish both passive and active medication targeting following parenteral injection.
2. Drugs can be changed on the surface of nanoparticles to change their biodistribution and then clearance,

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resulting in maximal therapeutic efficacy and minimal side effects [11].

3. The selection of matrix ingredients readily modifies aspects of controlled release and particle Disintegration.
4. One essential aspect in maintaining drug activity is the relatively high drug loading and the medications' ability to be absorbed into the systems without causing any chemical response.
5. Targeting specific sites can be accomplished by the use of magnetic guiding or by affixing targeting ligands to the surface of particle.
6. Liposomes and polymer based nano particulates don't build up in the body, are usually biodegradable, and may not pose any risks.
7. Since smaller capillaries may accommodate smaller nanoparticles, effective drug accumulation at the target sites may be possible.
8. There are other ways to administer the medication, such as parenteral, intraocular, nasal, and oral [12].

Limitations:

1. Despite these benefits, nanoparticles have certain drawbacks. For example, their altered physical characteristics can cause particle aggregation, making it challenging to physically handle them in liquid and dry forms because of their smaller size and greater surface area.
2. Because of their larger surface area and smaller particle sizes, nanoparticles are highly reactive in the cellular environment.
3. Drug loading and burst release are constrained by small particle size. Prior to the clinical application or commercialization of nanoparticles, these pragmatic issues must be resolved [13].

Classifications of nanoparticles:

Nanoparticles (NPs) are mainly classified into various classes based on their morphology, size, physical & chemical properties. They are mainly classified into organic, inorganic and carbon-base NPs.

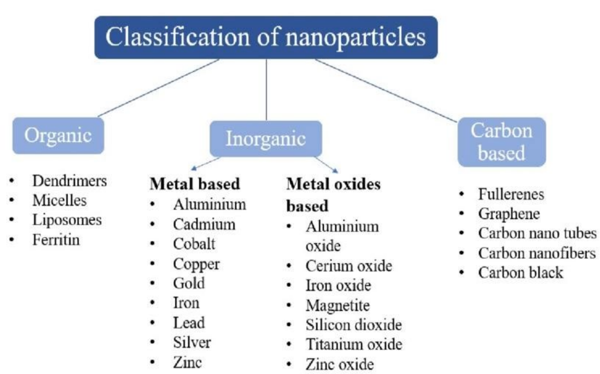

Fig. 2. Classification of nanoparticles

A. Organic Nanoparticle

With a diameter ranging from 10 nm to 1 µm [14], organic nanoparticles are solid particles made up of organic compounds like lipids or polymers. Among the well-known organic nanoparticles are ferritin, liposomes, dendrimers, and micelles.

These organic nanoparticles are less expensive, nontoxic, biodegradable, and more suited for use in the biomedical industry. Both liposomes and micelles are sensitive to electromagnetic and thermal radiations and have a hollow core, sometimes referred to as a nano capsule. Because of these special qualities, organic NPs are the best option for medication delivery. They deliver drugs to their intended targets very effectively.

B. Inorganic Nanoparticles

They can be monometallic, bimetallic, or polymetallic because they are entirely composed of metal precursors [15], [17]. Bimetallic nanoparticles can be manufactured from alloys or constructed in multiple layers (core-shell) [17]. Because of their localised surface plasmon resonance features, these NPs have distinct optical and electrical properties [16]. In addition, some metal nanoparticles have unique thermal, magnetic, and biological properties [14]. This makes them increasingly significant materials for the creation of Nano devices, which can be employed in a variety of physical, chemical, biological, medicinal, and pharmacological applications [18], [19].

All noncarbon and organic materials make up this class of NPs. Semiconductor, ceramic, and metal nanoparticles are common examples of this class. Monometallic, bimetallic, or polymetallic [15], [17] metal precursors are the only ingredients in metal nanoparticles (NPs).

A coreshell structure or an alloy can be used to create bimetallic nanoparticles [17]. These NPs have special optical and electrical capabilities as a result of their localised surface Plasmon resonance features [16]. Furthermore, several metal nanoparticles have distinct biological, magnetic, and thermal characteristics [14]. This makes them materials that are becoming more and more crucial for the creation of nanodevices with a wide range of applications in the physical, chemical, biological, medical, and pharmaceutical domains [18], [19].

C. Metal based Nanoparticles

1) Zero valet iron nanoparticles

Zero valent iron nanoparticles are largely used in bioremediation due to their size-dependent capacity to breakdown and adsorb contaminants. The high volume-to-surface area ratio improves efficacy and boosts electron transport to eliminate hazardous atoms [26].

2) Silver nanoparticles

Silver nanoparticles have been intensely investigated due to their excellent unique properties such as conductivity, chemical stability, catalytic activity, nonlinear optical behaviour, and bactericidal activity [27]. 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 nonmaterial.

Due to their antibacterial qualities, silver nanoparticles are widely used in hospitals for a variety of purposes. These include medical bandages, surgical dressings, burn treatment dressings, and dressings for surgical sites. In order to prevent surface mould growth, washing machines, refrigerators, and food containers are increasingly using silver nanoparticles in their products [28], [30]. It has been demonstrated that washing socks containing silver nanoparticles reduces the amount of silver that is released into the air. Similarly, when antifouling membranes are applied for water filtration, silver may leak out of them. Gold and silver have demonstrated promise as environmental sensors because of their optical reactions to environmental pollutants, including herbicide detecting silver nanoparticles. Zerovalent iron can be utilised to create subterranean reactive barriers for use in treating contaminated groundwater. Ohio State University researchers are working with polymer semiconductors, which are semiconductors that absorb solar radiation and produce electricity. Researchers have shown that incorporating minuscule silver particles into plastic increases the material's ability to generate electrical current [31-34].

3) Gold nanoparticles

It is possible to modify the electrical and optical properties of gold nanoparticles, which are quite stable and inert. They have been used in medical applications via coupling with biomolecules. For instance, they have the capacity to identify pathogens from clinical samples, mutations, single nucleotide polymorphisms (SNPs), chromosomal translocations, gene expression, and DNA with high sensitivity and selectivity, all of which may find use as contrast agents in cancer diagnosis and treatment [35].

D. Ceramics Nanoparticles

Nonmetallic inorganic solids, or ceramics NP, are created by heating and cooling materials. There are several potential morphologies, including amorphous, polycrystalline, dense, porous, and hollow. Researchers are paying close attention to these NP because of their use in processes including dye photodegradation, catalysis, photocatalysis, and imaging.

E. Semiconductor Nanoparticles

Have properties similar to metals and non-metals, making them suitable in many applications [36]. Because semiconductor nanoparticles have massive band gaps, band gap tuning has a substantial impact on their properties. Photo catalysis, optics, and electronics rely heavily on them. Semiconductor nanoparticles with proper band gap and band edge orientations are extremely efficient at water splitting.

F. Polymeric Nanoparticles

These are mostly organic-based NPs, and they are referred to as polymer nanoparticles (PNPs) in literature. These have the shape of nanospheres or nano-capsulars, depending on how they are prepared. The other molecules are adsorbed at the outside edge of the spherical surface by the former, which are matrix particles with an overall mass that is typically solid. In the latter instance, the solid mass is entirely contained within the particle. Because the PNPs are easily functionalized, a wide range of applications are found in the literature. Polymeric nanoparticles offer numerous benefits, including precise targeting, controlled release, drug molecule protection, and the capacity to integrate imaging and therapy. They are used in diagnostics and medication delivery. Polymeric nanoparticle-based medication delivery is extremely biodegradable and biocompatible.

G. Lipid-based Nanoparticles

Lipid nanoparticles have a spherical form and a diameter of 10 to 100 nm. The structure comprises of a lipid core and soluble lipophilic molecules in the matrix. Surfactants and emulsifiers stabilise the nanoparticles' exterior cores. Nanoparticles are used in biological fields for drug delivery, RNA release, and cancer therapy.

Synthesis of nanoparticles:

Nanoparticles (NPs) can be synthesised using several methods to control their form, size, dimensions, and structure. There are two basic ways for synthesis of NPs: top-down and bottom-up. These methods are further classified according to the operations and reaction circumstances [41]-[45]. (Fig no. 3).

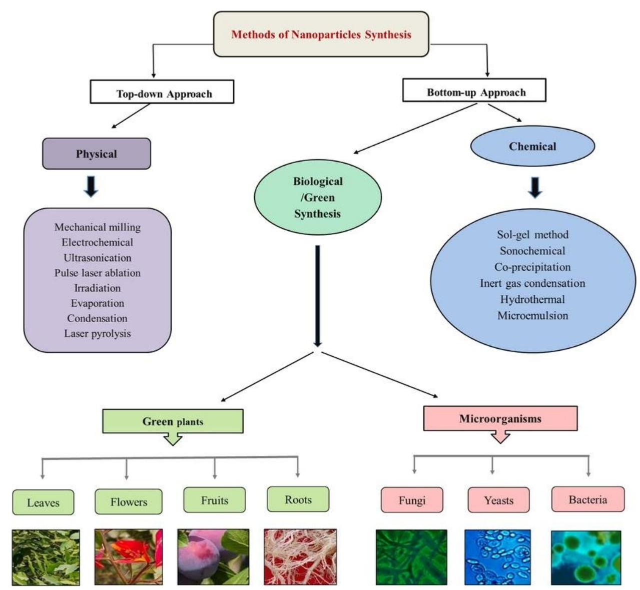

Fig. 3. Methods of preparation of nanoparticles

Top-down Approach:

The top-down technique includes breaking down bulk materials into nanosized particles. This is a damaging method. Topdown techniques are easier and involve removing or dividing bulk material or miniaturizing bulk production processes to achieve desired structures with appropriate attributes. Common methods for producing nanoparticles include mechanical milling, nanolithography, laser ablation, sputtering, and thermal breakdown.

Bottom-up approach:

An alternate method known as the "bottom-up" or "constructive method" uses a build-up strategy in which atoms are the starting point for clusters, which are then used to create nanoparticles. Another strategy that uses the build-up approach in which nanoparticles are assembled from clusters that are derived from atom is known as the bottom-up or constructive method.

This method often uses reduction and sedimentation techniques. This method is thought to be more cost-effective because it can result in less waste. Sol-gel, spinning, green synthesis, chemical vapour deposition (CVD), pyrolysis, and biosynthesis are some of the most often utilised instances of this technique.

Application of nanoparticles:

Nanoparticles have unique physical and chemical properties, including electrical and optical capabilities, mechanical qualities, magnetic properties, and thermal properties. Because of its distinctiveness, it has been used in a variety of applications. Some of the major applications of nanoparticles are listed below:

1. Mechanical industries:

NPs are used in mechanical industries such as coating, lubricants [46], adhesives [47], and nanodevice manufacturing due to their high young modulus, stress, and strain properties. [48] used silver nanoparticles (AgNPs) and a fluorine-free saline monomer, 3-(Trimethoxysilyl) propyl methacrylate (TMSPM), to create a hydrophobic coating on cotton fabric.

2. Medicine:

Nanoparticles have made significant contributions to clinical medicine in areas such as medical imaging and drug/gene delivery. The most prevalent iron oxide particles used in biomedical applications are magnetite (Fe_3O_4) and their oxidised derivative hametite (Fe_2O_3). Because of their antibacterial properties, silver nanoparticles are increasingly being employed in wound dressings, catheters, and other household products. Gold nanoparticles are showing promise in cancer therapy as drug carriers, photothermal agents, contrast agents, and radiosensitizers [49], [51] Over the past few decades, there has been a lot of interest in producing biodegradable nanoparticles as effective medication delivery methods. Polymers are commonly employed in drug delivery research due to their ability to effectively transfer medications to the target region, increasing therapeutic benefit while minimising unwanted effects.

3. Food:

In order to maintain food freshness and prevent microbiological contamination, food packaging is increasingly utilising nanoparticles to regulate the surrounding environment [52]. Since they can directly inject antimicrobial compounds on the coated film surface, inorganic and metal nanoparticles (NPs) are widely utilized nowadays in the food packaging business as alternatives to petroleum plastics [53].

4. Electronic:

One dimensional semiconductors and metals have unique structural, optical, and electrical capabilities, making them essential components for developing new electronic, sensor, and photonic materials.

5. Environmental Remediation:

Nanoparticles are widely used in environmental remediation due to their versatility for both in situ and ex situ applications in aqueous systems. Silver nanoparticles (AgNPs) are widely employed in water disinfection due to their antibacterial, antifungal, and antiviral properties [54]. TiO2 nanoparticles are being studied for waste treatment, air purification [55]. surface cleaning [56]. and water treatment [57].

3. Conclusion

This review article provided an overview of nanoparticles, including structure, classification, synthesis methods, and uses in numerous sectors. While NPs have several applications, their unchecked use and discharge into the environment can pose health hazards. It is important to evaluate these risks to make NP use more beneficial and environmentally friendly.

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