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ROLE OF NANOPARTICLES IN CATALYSIS: ENHANCING EFFICIENCY AND SELECTIVITY

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ABSTRACT

The special little materials that exist on a nanometer scale between 1 and 100 nm are called nanoparticles (NPs). These NPs can have many different shapes. They can be divided into several types according to their origin, characteristics, form, and size, such as Organic, Inorganic, and Carbon-based NPs. Because of their small size, the NPs have improved physical and chemical properties, including high surface area, reactivity, stability, sensitivity, etc. There are several ways to synthesis these NPs. Recent years have seen a significant increase in the use of NPs in a variety of industrial and environmental application sectors, which is thought to be quite significant. This critical review article focuses on the uses, preparation process, and classification of NPs.

KEYWORDS: Carbon based NPs, Inorganic NPs, Organic NPs, Nanoparticle.

INTRODUCTION

Particulate materials with at least one dimension smaller than 100 nm are included in the broad class of materials known as nanoparticles (NPs).[1] The Latin word "nanus," which means dwarf or tiny, is the source of the prefix "nano." NPs, or nanoparticles, are the building blocks of nanotechnology.[2] These materials can be one of three dimensions, depending on their overall shape. NPs are formed of three layers since they are not simple molecules.[3] The first layer is (a) the surface, which can be functionalized with a range of small molecules, metal ions, surfactants, and polymers. (b) The shell layer, which is entirely distinct chemically from the core; and (c) The core, which is the main part of the NP and is typically used to refer to the NP itself. They may consist of metal, carbon, metal oxides, or organic materials.[4]

A particularly preferred media for a wider variety of biological applications are nanoparticles. These structures' exterior and primary components can also be designed with human and multimodal uses in mind, including biomaterials recognition, medicinal delivery, biosensing, and bioimaging. Additionally, a wide variety of in vitro and in vivo applications have been made use of nanomaterials.[5]

Different shapes, sizes, and structures can be found in nanoparticles (NPs), including spherical, cylindrical, tubular, conical, hollow core, spiral, flat, and wire. Its form may also be asymmetrical. NPs can have a uniform or uneven surface. In addition, they can exist in crystalline and amorphous forms, which can be single- or multi-crystal solids. Multi-crystal solids can aggregate or remain loose. These NPs' varied sizes and shapes have a major impact on their physio-chemical characteristics. Because of their distinct physical and chemical characteristics, nanoparticles (NPs) have found remarkable success in a wide range of sectors, including medicine, the environment, energy-based research, imaging, chemical and biological sensing, gas sensing, and more.[3]

Metal nanoparticles, also known as nanoparticles derived from metals, can be created through biological means.[6,7] Due to its nonselective harmful biocidal effect, silver has been utilized as an antibacterial agent for centuries.[8] Ocular infections were treated with silver nitrate in antiquity.[9] To prevent water pollution, pots and cups made of silver metal were used to store water. The use of silver citrate salt to treat skin infections is widely recognized.[10]

ADVANTAGES

1. Faster dissolution generally equates with greater bioavailability.
2. Smaller drug doses.
3. Reduction in fed/fasted variability.
4. Less toxicity.
5. Fairly easy preparation.
6. Targeted and drug delivery.
7. Due to their small size Nanoparticles penetrate small capillary and are taken up by the cell which allows for efficient drug accumulation at the target sites in the body.
8. Good control over size and size distribution.

9. Good protection of the encapsulated drug.
10. Retention of drug at the active site.
11. Longer clearance time.
12. Increased therapeutic efficacy.
13. Increased bioavailability.
14. Dose proportionality.[11]

DISADVANTAGES

1. Alveolar inflammation.
2. Limited targeting abilities
3. Discontinuation of therapy is not possible.[11]

CLASSIFICATION OF NANOPARTICLES

The key criteria used to categorize nanoparticles (NPs) are their size, shape, and chemical And physical characteristics.

They fall into three primary categories

A. Organic nanoparticles
B. Inorganic nanoparticles
C. Carbon-based nanoparticles

A. Organic nanoparticles

Organic nanoparticles are solid particles with a diameter between 10 nm and 1 µm that are made of organic substances like lipids or polymers. Among the well-known organic nanoparticles are ferritin, liposomes, dendrimers, and micelles. These non-toxic, biodegradable, and less costly organic nanoparticles are better suited for the biomedical sector.[12] Both liposomes and micelles feature hollow cores, sometimes referred to as nanocapsules, that make them vulnerable to electromagnetic and thermal radiation. Because of these special qualities, organic NPs are a great option for medication administration. They deliver drugs to their intended targets very effectively.[13]

B. Inorganic nanoparticles

The particles that are not composed of carbon are known as inorganic nanoparticles. Metal and metal oxides are included. Inorganic NPs have seen far more commercial and scientific investment than organic NPs.[14]

1. Metal Based Nanoparticles

Metals including aluminum (Al), gold (Au), silver (Ag), cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) can be used to create metal-based nanoparticles. Ag, Au, Cu, Fe, and Zn are the metals that are most frequently utilized. Because transition metals have partially filled d-orbitals, which increase their redox activity, they are determined to be the best options for the production of metal-based NPs. This in turn makes the aggregation of nanoparticles easier. The size of metal-based NPs ranges from 10 to 100 nm. They come in a variety of forms, including spherical and cylindrical ones.

Their unusual properties include a high surface area to volume ratio, pore size, surface charge, density, and crystalline and amorphous morphologies; also, they are highly reactive and sensitive to a variety of environmental factors, such as heat, moisture, sunlight, and air. They have interesting applications in a variety of disciplines because of these unusual qualities.[15]

2. Metal Oxides Based Nanoparticles

Metal-based NPs have the ability to be transformed into metal oxide-based NPs, which are their corresponding oxides. Metallic oxide-based nanoparticles are distinguished from their metal counterparts by a number of noteworthy characteristics. Iron oxide (Fe2O3), magnetite (Fe3O4), aluminum oxide (Al2O3), cerium oxide (CeO2), silicon dioxide (SiO2), titanium oxide (TiO2), and zinc oxide (ZnO) are a few examples of metal oxide-based nanoparticles (NPs). These metal oxide-based NPs were discovered to be more effective and reactive.[16]

C. Carbon Based Nanoparticles

Carbon-based nanoparticles (NPs) are nanoparticles made of carbon. It is possible for carbon-based nanoparticles (NPs) to be spherical, ellipsoidal, horn-shaped, or tube-shaped. Fullerene and carbon nanotubes (CNTs) are the two main groups of carbon-based NPs. Graphene, nanofibers, and carbon black are additional categories of carbon-based NPs.[17,18]

1. Fullerene

In 1985, the Nobel laureates H. W. Kroto, R. F. Curl, and R. E. Smalley made the discovery of fullerene. There are several atomic clusters (Cn) in the fullerene family, where n > 20. Fullerene C60, the most common fullerene, has sixty carbon atoms. Another name for it is bucky ball. It has a spherical form. After sp2 hybridization, every carbon atom is covalently bonded to every other carbon atom. Every carbon atom found at the points where 12 pentagons and 20 hexagons converge. Fullerenes have a spherical structure consisting of around 28–1500 carbon atoms, with diameters ranging from 4–36 nm for single layers and up to 8.2 nm for multi-layered fullerenes.

2. Carbon Nanotubes (CNTs)

Allotropes of carbon, carbon nanotubes were first identified in 1991 by S. Iijima, a scientist from Japan. Because of their remarkable strength, elasticity, and stiffness, carbon nanotubes (CNTs) have attracted significant economic attention. They exhibit strong electrical and thermal conductivity as well. CNTs are cylindrical structures made of coiled graphene sheets that have a diameter of several nanometers. Their diameter, length, symmetry, and number of layers can all differ. A half-fullerene molecule may close or leave open the ends of carbon nanotubes. They can be roughly categorized into two main groups based on their structural makeup: (a) single-walled carbon nanotubes (SWCNTs), which have a diameter of 1-3 nm and a length of a few micrometers, and (b) multi-walled carbon nanotubes (MWCNTs), which have a diameter of 5-40 nm and a length of approximately 10 μm. On the other hand, 550 nm-long CNTs have also been documented.

3. Graphene

Another allotropic form of carbon is graphene. Its lattice resembles a two-dimensional honeycomb. A sheet of graphene is normally one nanometer thick.

4. Carbon Nanofibers

Graphene sheets also make up carbon nanofibers (CNFs). This graphene arrangement shows layers as stacked plates, cups, or cones. CNFs are very electrically and thermally conductible and have outstanding mechanical qualities. They range in diameter from 10 nm to 500 nm. As a result, these CNFs are used in numerous industries, including photocatalysis, energy devices, sensors, medication delivery, and nanocomposites.

5. Carbon Black

The primary component of carbon black nanoparticles (CBNP), also known as nano powders, is elemental carbon. It is also referred to as "shouen" or "soot." These have a diameter ranging from 20 to 70 nm and are spherical in form. The high level of particle-to-particle contact causes CBNP to aggregate into 500 nm-sized particles. These are commonly found in inks for copy machines and laser printers. They are also employed in the plastics industry as pigments and as preservatives for rubber reinforcing.

APPLICATIONS OF NANOPARTICLES

- Fluorescent biological markers[19,21]
- Gene delivery and Drug[22,23]
- Detection of proteins[25]
- Bio detection of pathogens[24]
- Probing of DNA structure[26]
- Tissue engineering[27,28]
- Tumour destruction via heating (hyperthermia)[29]
- Separation and purification of biological molecules and cells[30]

METHOD OF PREPARATION OF NANOPARTICLE[14]

1. Top-down approach

The bulk material is broken down into nanosized particles using a top-down technique. It's a destructive method. To create the necessary structure with the right qualities, topdown procedures are easier to use and rely either on the removal or division of bulk material or on the downsizing of bulk production processes.

Most commonly used examples of this method are as follows:

- Sol- gel
- Spinning
- Chemical Vapour Deposition (CVD)
- Laser pyrolysis
- Template Support Synthesis
- Plasma or flame spraying synthesis
- Atomic or molecular condensation

2. Bottom- Up Approach

An alternate method that uses the build-up approach is called the bottom-up or constructive method. In this process, atoms are the starting point for clusters, which are used to create nanoparticles. This method usually uses the reduction and sedimentation techniques. Because this method may result in less waste, it is thought to be more cost-effective. The most popular examples of this technique are as follows:

- Mechanical Milling
- Nanolithography

- Laser ablation
- Sputtering
- Thermal Decomposition
- Ulsed Electrochemical Etching

PHYSICOCHEMICAL PROPERTIES OF NPS

Large surface area, mechanical strength, optical activity, and chemical reactivity are just a few of the physicochemical characteristics that make NPs special and useful in a variety of applications. The section that follows discusses a few of their significant characteristics.

A. Mechanical properties

Numerous mechanical parameters, including elastic modulus, hardness, stress and strain, adhesion, and friction, can be surveyed to know the precise mechanical nature of NPs. These unique mechanical properties of NPs enable researchers to look for novel applications in many important fields, including tribology, surface engineering, nanofabrication, and nanomanufacturing. NPs' mechanical characteristics differ from those of microparticles and their bulk constituents.[31] Strength, brittleness, hardness, toughness, fatigue strength, plasticity, elasticity, ductility, rigidity, and yield stress are the ten main components of a nanomaterial's mechanical properties.[32]

B. Thermal properties

Energy conduction from photons (lattice vibration) and electrons, as well as the accompanying scattering effects, is the main source of heat transmission in nanoparticles.[33] Thermal conductivity, thermoelectric power, heat capacity, and thermal stability are the main elements of a material's thermal properties. The electrical and thermal conductivity of NPs is directly impacted by their size.[34]

It is common knowledge that metal nanoparticles (NPs) have higher thermal conductivities than solid-state fluids. It is preferable to employ particles with a large total surface area because heat transfer occurs at the particle surface.[35] Additionally, the stability suspension is increased by the high total surface area. It has recently been shown that nanofluids with CuO or Al2O3 NPs in ethylene or water display advanced thermal conductivity.[36]

C. Magnetic properties

Every magnetic compound has a "magnetic element," such as Fe, Co, or Ni, in its formula. There are just three mixed diamagnetic element exceptions that are currently known to exist: Sc3In, ZrZn2, and TiBe2-xCux.[37,40] Elements that are diamagnetic include Pd, Au, and Ag. Everything is changing on a nanoscale. Uneven electrical distribution can cause a number of materials to become magnetic in the form of nanoparticles.[1]

Superparamagnetism is an intriguing size-dependent phenomenon of NPs.[41] When NP size drops, so does the magnetic anisotropy energy per NP. Researchers in a wide range of fields, including data storage magnetic resonance imaging (MRI), biomedicine, heterogeneous and homogenous catalysis, magnetic fluids, and environmental remediation such as water purification, are very interested in magnetic nanoparticles (NPs). According to the literature, NPs function best at sizes between 10 and 20 nm.[42]

D. Electronic and optical properties

NPs' optical and electrical characteristics are more reliant on one another. Noble metal nanoparticles (NPs) possess size-dependent optical characteristics and have a prominent UV-visible extinction band that is absent from the bulk metal's spectra. The localized surface plasma resonance (LSPR) is the name given to this excitation band that arises when the incident photon frequency remains constant due to the collective excitation of the conduction electrons.[43]

Because of the localized surface plasmon resonance (LSPR) effect and quantum confinement, metallic and semiconductor nanoparticles (NPs) have intriguing linear absorption, photoluminescence emission, and nonlinear optical features.[44,45] When the incident photon frequency is constant and the conductive electrons are collectively excited, LSPR phenomena occur. Noble metal NPs have a prominent size-dependent UV–visible extinction band as a result of this phenomena, which is absent from bulk metal spectra. In general, the size, shape, and dielectric environment of NPs affect their optical characteristics.[46]

E. Catalytic properties

Within the subject of chemical catalysis, nano-catalysis—the use of NPs as catalysts—is a rapidly developing area. Differentially from their bulk counterparts, NP catalysts have been shown to have significantly improved or unique catalytic characteristics like reactivity and selectivity. The size, shape, composition, interparticle spacing, oxidation state, and support of

NPs all affect their catalytic qualities.[47] It has been extensively researched how the size of NPs affects catalytic activity. The relationship is inverse, meaning that NPs' catalytic activity increases with their size. The smallest NPs produced the largest normalized current densities, the researchers found.[48]

CONCLUSION

In this review article we have given a brief overview of nanoparticles, classification, method of preparation, applications in various fields and physicochemical properties of NPs. Advances in nanoparticle characterization are necessary for the development of nanoparticle material classes and their use in addressing contemporary global issues. The four characteristics of nanoparticles—size, shape, surface charge, and porosity—have a direct bearing on how well they work and how they affect the environment and human health. It's critical to measure these attributes in order to translate the potential advantages of nanomaterials into targeted applications.

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