Understanding Nanoparticles: A Comprehensive Overview of Classification, Types, Characterization, Properties, and Applications

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Abstract:

As per ISO standards, nanoparticles are minuscule materials, measuring between 1 and 100nm, and they come in various forms. They are classified as inorganic organic and carbon-based NPs based on their size, shape, and properties. Because of their small size, NPs display enhanced physical and chemical characteristics like a large surface area, heightened reactivity, stability, and sensitivity. Recently, NPs have found extensive use in numerous industrial and environmental applications, making them of paramount significance. This review article mainly focuses on categorization, its properties, characterization, and wide-ranging applications.

Keywords: Nanoparticles (NPs), Johnson-Kendall-Roberts (JKD) theory, Derjaguin-Landau-Verwey–Overbeek (DLVO), and Derjaguin-Muller-Toporov (DMT) theory.

Introduction:

Nano is derived from the Greek word "Nanos," meaning "dwarf." The IUPAC (International Union of Pure and Applied Chemistry) adopted the word "nano" as a prefix in 1947 to refer to 109 [1]. The prefix "Nano" is commonly used to represent small particles and materials in modern science. In the early stages of nanotechnology, people unknowingly used nanosized objects and nanoscale particles [2]. For example, in ancient Egypt, dyeing hair black was typical. It was previously thought that hair dye was created using plant substances like henna. Recent studies on hair samples obtained from ancient Egyptian burial sites have revealed that the shade used to color the hair was made from a mixture of lead oxide, lime, and water. This dye contained galenite (lead sulfide, PbS), a nanomaterial.

Nanotechnology was also found in ancient Roman cups prepared with gold and silver (50–100 nm) nanoparticles. These Nanoparticles caused a change in the color of cups from green to red depending on the light source. There is also evidence that nanotechnology was used in preparations in Mesopotamia, ancient India, and the Mayan civilization [1]. In treating some diseases, delivering therapeutic agents to the targeting site is the major problem, which shows improper utilization of drugs is due to poor biodistribution, lower effectiveness, undesirable side effects, and lack of selectivity. The development of a controlled drug delivery system can reduce those types of limitations by delivering the drug to the targeted site. However, this system protects against rapid degradation and enhances the targeting site or tissue concentration. Therefore, higher doses of medicines are required to treat such diseases. When there is a problem between the amount or concentration of a drug and its therapeutic action or toxicity, The attachment of drugs to carriers is the most convincing approach in the drug delivery system. Nanotechnology is based on the size reduction of targeting drug formulations for drug delivery systems, which are nanoparticles. The main aim of designing the nanoparticles for the delivery system is to control the particle size and surface properties. Achieving site-specific action at a particular site includes releasing pharmacologically active agents at the desired therapeutic rate and dose [3]. The Nanoparticles may occur in different shapes, sizes, and structures like spherical, spiral, conical, etc. In terms of diameter, the fine particles vary between 100 and 2500nm, while the ultrafine particles range from 1 to 100nm [1]. The current development in nanotechnology has exhibited that the structure of nanoparticles is smaller than 100nm in at least one dimension, which has great potential even as drug carriers [4]. Nanoparticles have unique properties (such as biological and physicochemical) due to their small size. Nanoparticles are tiny due to their small size. They can only be observed through a microscope. In some instances, nanoparticles are amorphous or crystalline in nature [5]. According to the drug delivery system, nanoparticles are poorly soluble in water due to their complex formation. Nanoparticles can be minerals, metallic, or polymers based on a combination of materials. Nanoparticles' attractiveness is due to their unique physical and chemical properties, which have a more extended ability than the other particles to absorb and carry compounds like drugs, probes, etc., catalytically promoting reactions [6]. Nanoparticles have a wide range of applications. They are used in medicines, electronics, cosmetics, and many other industries. For example, nanoparticles are used to develop new drugs targeting cancer cells more effectively. These nanoparticles are mainly coated with collagen, antibodies, and macromolecules. Active and site-specific targeting can be quickly done with nanoparticles. The targeting ligand can be attached to the surface of the nanoparticles to make passive drug targeting possible. Nanoparticles can quickly overcome physiological barriers and resistance and provide effective drug delivery throughout the body. Targeting drug delivery with nanoparticles can reduce toxicity and more efficient drug distribution. Even nanoparticles can get permission to deliver drugs through blood-brain barriers [6]. The interaction and use of components that fall between 10 and 1000 nm in size is another sign of nanotechnology [7]. Now, nanomedicines, made up of suspensions of nanoparticles, have improved the therapeutic index of many parts by lowering their level of toxicity and increasing their pharmacological activity by getting them to a specific cell or tissue that is sick.

Nanotechnology is an integrative field in various fields, such as biomedicine, physics, chemistry, and engineering.The investigation of nanostructure includes gold nanoparticles, paramagnetic nanostructures, nanotubes, and liposomes. Nanotechnology has been a prominent area of research for the past century [7].

Nanoparticles are complex molecules with three distinct layers, as shown in Figure 1.

a) The surface layer

b) The Core layer

c) The shell layer [7]

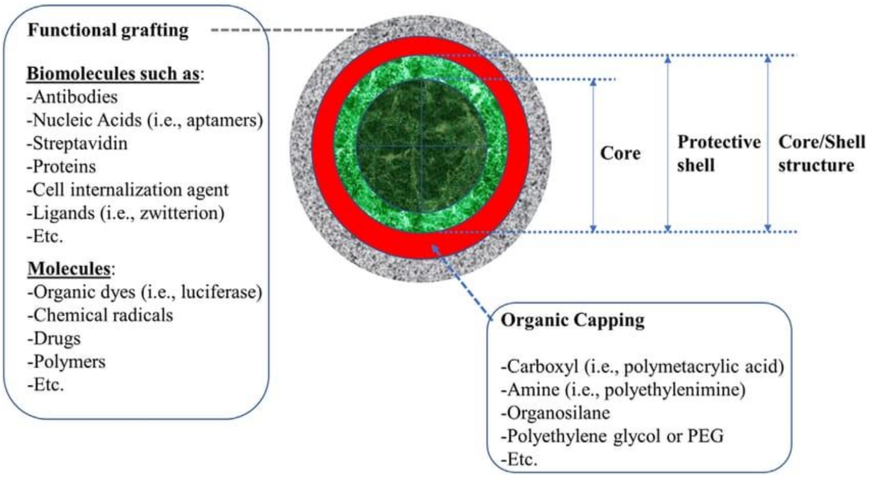

Figure 1: structure of Nanoparticle

There are certain advantages of nanotechnology, including the safety and effectiveness of medicine, that play a significant role in the biotechnology and pharmaceutical industries. Nanoparticles are used in numerous fields, such as histological studies, separation technologies, drug delivery systems, and clinical diagnostic assays.[8] The apparent trends of nanomedicines: Compared to human cells, nanoparticles are smaller but similar to biological macromolecules such as receptors and enzymes [9].

Classification

Nanoparticles are classified based on their physical-chemical properties, size, and morphology. They are broadly characterized into inorganic, organic, and carbon-based Nanoparticles, as shown in Figure 2.

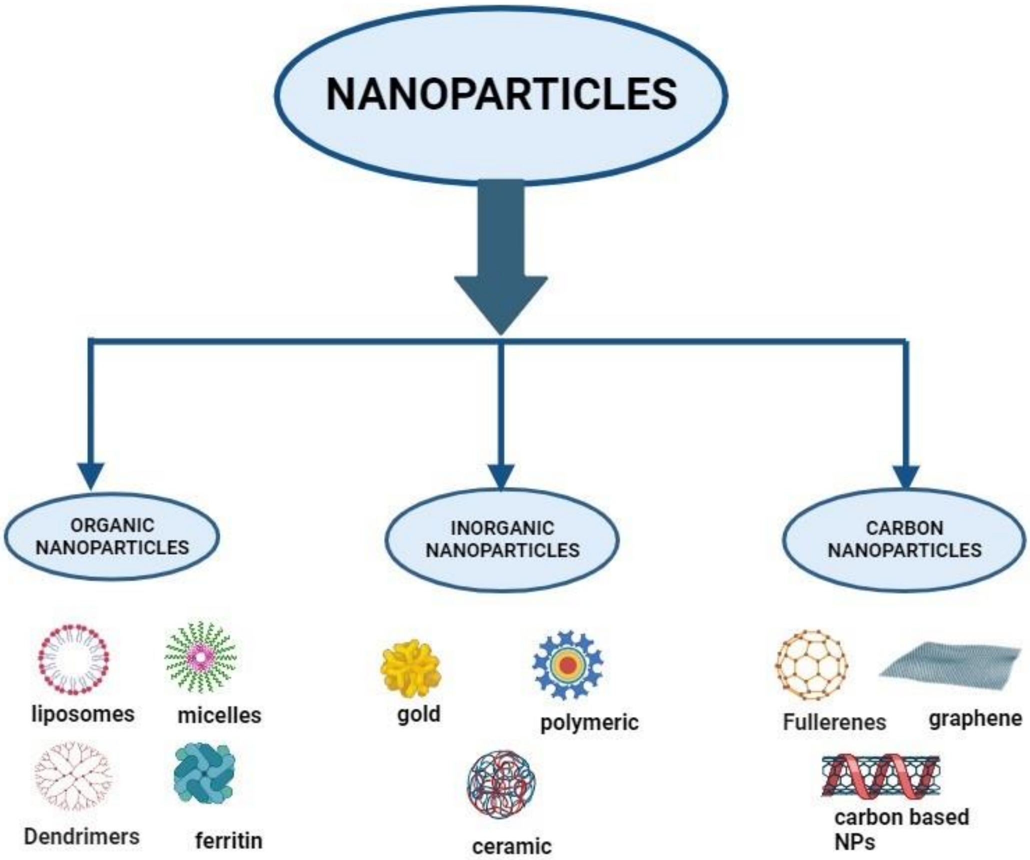

Figure 2: Classification of Nanoparticles

Organic Nanoparticles

Organic Nanoparticles, such as dendrimers, liposomes, micelles, and ferritin, are solid particles of organic compounds like polymers or lipids. They typically have a diameter ranging from 10 Nanometres to 1 micrometer. These Nanoparticles have several advantageous properties, including being environmentally friendly, biodegradable, non-toxic, and cost-effective, making them well-suited for applications in the biomedical field. Two notable types of organic nanoparticles, liposomes, and micelles, have hollow cores called nano capsules. Additionally, they exhibit sensitivity to electromagnetic and thermal radiation. These unique characteristics make organic Nanoparticles an excellent drug delivery option, as they are highly efficient at delivering drugs to specific target locations within the body[10].

Inorganic Nanoparticles

Inorganic Nanoparticles, typically composed of metals or metal oxides, have received significant research and commercial attention. They have tremendous applications in fields such as medicine, electronics, and materials science due to their versatility and unique properties.

Inorganic Nanoparticles are classified into five types:

Metal Nanoparticles

Metal-based Nanoparticles, synthesized from various metals like aluminum, cadmium, copper, gold, and more, exhibit characteristics such as high surface area, small size-to-volume ratio, diverse surface properties, crystalline or amorphous structures, and different shapes and colors. Additionally, their sensitivity and reactivity to environmental factors make them valuable in Nanotechnology, medicine, and materials science. These properties allow for tailored applications in areas like drug delivery, catalysis, and sensors [10].

Metal oxides-based Nanoparticles

Metal oxide-based nanoparticles are like iron (Fe) within sight of oxygen, transforming into iron oxide (Fe_2O_3) and upgrading reactivity. Some typically integrated metal oxide Nanoparticles incorporate zinc oxide (ZnO), Aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3). These changes and blends are critical in different fields, including materials science and catalysis [5].

Ceramic Nanoparticles

Various architectures of earthenware nanoparticles can be arranged, such as thick polycrystalline, vague, porous, and empty features, allowing them to be customized for multiple uses. Particularly interesting are analysts in their benefits in photocatalysis. When colors are photodegraded, they can help accelerate compound reactions and remove contaminants in water. Furthermore, these Nanoparticles can be created by precise physical qualities that medication delivery systems can use. Their assurance in concentrating on diseases, including bacterial infections, glaucoma, and malignancies, provides a potential means of enhancing the effectiveness of medicinal medications while minimizing side effects. Clay's tenability: Because of its nanoparticles, clay is an essential tool in many logical and medical domains[11].

Semiconductor Nanoparticles

Semiconductor Nanoparticles are categorized into groups II-VI, III-V, and IV-VI on the periodic table. These Nanoparticles possess wide bandgaps, which, when tuned, result in various unique properties. Due to their intermediate characteristics between metals and non-metals, they find applications in electronics, photo-optics, photocatalysis, and water splitting. Examples of semiconductor Nanoparticles include GaP, GaN, InP, InAs from group III-V, ZnS, ZnO, CdSe, CdS, CdTe from II-VI, and germanium and silicon from group IV[11].

Polymeric-Nanoparticles

Polymeric Nanoparticles (PNPs) have various applications, including prescription conveyance and diagnostics. Due to their natural personality, they are versatile and appropriate for many utilizations. PNPs enjoy a few benefits, including controlled drug discharge, drug particle security, incorporating treatment with imaging, and allowing specific focus. Moreover, their biodegradability and biocompatibility make them engaging for clinical applications.Analysts are still searching for better approaches to involve these elements in novel applications in Nanomedicine [12].

Carbon-based Nanoparticles:

The carbon-based Nanoparticles are composed as follows:

Fullerenes

Fullerenes are carbon-based Nanoparticles comprised of carbon molecules coordinated in shut enclosures to frame empty circles, ellipsoids, or cylinders. C60, or Buckminsterfullerene, is the most notable and concentrated on fullerene. It is made out of 60 carbon molecules and has a soccer ball-like design.

Grapheme

A two-layered sheet of carbon molecules coordinated in a hexagonal cross-section makes up a solitary layer of graphene, a graphite. It is one of the most intriguing materials in Nanotechnology since it is very meager, lightweight, and has uncommon mechanical, electrical, and warm properties.

Carbon Nanotubes (CNT)

These are barrel-shaped Nanostructures made of graphene sheets that have been wrapped up. They can have single-walled nanotubes (SWCNT) or multi-walled nanotubes (MWCNT), each with its arrangement of properties given its construction.

Carbon

Nanofibers with dimensions in the Nanometer range, carbon Nanofibers are stretched Nanostructures. Their majority consist of undefinable carbon, and they find use in several domains, such as energy capacity, catalysis, and composite materials.

Carbon Black

Particles of unknown carbon that have been finely separated make up carbon dark. It usually results from improper hydrocarbon ignition. Primarily used as a supportive filler in elastic products like tires, carbon dark has excellent mechanical qualities. [10].

Sl no	Type of Nano particle	Active pharmaceutical ingredients	Particle size	Applications
01	Liposome	Abelcet	50-500nm	Cancer treatment, Fungal treatment[13]
02	Micelles	Poly ethylene glycol	10-100nm	Solubility enhancement[14]
03	Ceramics	Titanium carbide	53µm-90µm	Industrial applications[15]
04	Gold	Titanium dioxide	1-100nm	Photo catalyst[16]
05	Dendrimers	Polyether-co polyester	1-15nm	Stability enhancement[17]
06	Carbon based Nano particles	Graphene oxides	<1nm	Biomedical application[18]

Characterization

Particle size

The size of NPs plays a significant role in their cellular uptake rate. Smaller NPs often have better cellular uptake due to their increased surface area-to-volume ratio, allowing for more interactions with cells. This size-dependent internalization mechanism can impact how NPs are processed by the body, affecting factors like their in vivo circulation half-life. The sizes for developing NPs for in vivo applications are between 10 and 100 nanometers. This size range is relevant to their patterns of clearance and distribution within living organisms[8]. SEM and TEM images gauge particles and clusters, while laser diffraction techniques evaluate bulk samples in a solid state[19]. Reducing the size of NPs leads to a larger surface area, enabling faster drug release. However, this can lead to the aggregation of smaller particles during the transportation and storage of Nanoparticle dispersion [12].

Shape

Most NPs designed for drug delivery typically exhibit a spherical morphology. In certain instances, it has been observed that spherical Nanoparticles demonstrate a more significant and swifter rate of endocytosis when contrasted with Nanoparticles of rod or disk shapes [8].

Surface charge

It plays a crucial role in their interaction with cells and uptake. NPs with positive charge tend to undergo greater internalization due to the ionic interactions between positively charged and negatively charged cell membranes. This phenomenon significantly affects their interaction with cells [8]. Typically, a zeta potentiometer is employed to assess the surface charges and their dispersion stability in a solution [19]. Measuring the zeta potential enables us to predict the storage stability of colloidal dispersions. To ensure stability and prevent particle aggregation, it is essential to attain high zeta potential values, whether positive or negative [20].

Surface area

The Nanoparticle's surface area plays a crucial role in its characterization. The surface area to volume ratio significantly impacts the Nanoparticle's performance and properties. Surface area measurement is typically conducted through BET analysis [19]. The extensive surface area of Nanomaterials provides sample opportunities for diverse applications, and the most effective method for evaluating the surface area of Nanoparticles is the Brunauer-Emmett-Teller (BET) technique, which relies on the principles of adsorption and desorption according to the BET theorem [11].

Properties of Nanoparticles

Thermal properties

Nanoparticles (NPs) primarily transfer heat through energy conduction driven by electrons and photons (lattice vibration), accompanied by scattering effects related to these processes. Thermoelectric power, heat capacity, thermal conductivity, and thermal stability contribute to thermal properties. It is commonly acknowledged that solid metals have thermal conductivities significantly higher than those of fluids, differing by orders of magnitude. At room temperature, the thermal conductivity of copper is around 700 times higher than water and approximately 3000 times higher than engine oil. Consequently, fluids with suspended solid metallic particles are anticipated to have significantly improved thermal conductivities compared to formal heat transfer fluids. Their size directly affects the electrical and thermal conductivity of Nanoparticles (NPs). As Nanoparticles (NPs) decrease in size, their surface area-to-volume ratio increases exponentially. One of the two main ways heat is carried is through electron conduction, which significantly impacts heat transmission. Compared to bulk materials, Nanoparticles (NPs) have a higher surface-to-volume ratio, making more electrons accessible for heat transmission.

Furthermore, a process known as micro convection, which results from the Brownian motion of NPs, might further increase the heat conductivity in Nanoparticles. Importantly, this phenomenon happens when solid Nanoparticles are dissolved in a liquid, resulting in a Nanofluid. Numerous experimental and theoretical investigations into the thermal conductivity of particle-containing dispersions have been carried out. However, all previous studies on the thermal conductivity of suspensions have been limited to those containing particles in the millimeter- or micrometer-sized range [21].

Considering this historical background and advancements in synthesizing Nanocrystalline particles, it has been proposed that metallic particles of nanometers can be dispersed in fluids like water, glycol, ethylene, or engine oil, thereby creating a novel group of engineered fluids with significantly enhanced thermal conductivity.

The latest research has provided compelling evidence that these Nano fluids exhibit substantially improved heat transfer coefficients and thermal conductivities compared to fluids that do not contain Nanoparticles. Researchers have found that Nanoparticles (NPs) have a higher heat capacity than equivalent bulk materials by up to 10%. This phenomenon has been noted in NPs made of materials like Al2O3 and SiO2. Vibrational degrees of freedom are the main reason behind this increased heat capacity at room temperature. More specifically, the unique characteristics of the phonon spectra, representing the vibrational energy from oscillating atoms in the crystal, play a crucial role in elucidating the unusual heat capacity behavior in NPs. Nanoparticles commonly demonstrate a significant decrease in temperature compared to their bulk forms. Liquid and vapor interfaces have a lower energy than solid or vapor interfaces, which can explain this phenomenon. The free energy at the surface of a particle decreases as its size decreases, resulting in a reduction in temperature [22].

Mechanical properties

Nanoparticles show distinct mechanical characteristics when compared to bulk materials and microparticles. They offer extensive surface modification capabilities for various devices, enhancing mechanical strength and improving the quality of processes like Nanomanufacturing and Nanofabrication. Different mechanical parameters are used to determine the mechanical properties of nanoparticles, such as modulus, stress, hardness, adhesion, and friction; lubrication and surface coating coagulation are mechanical properties of nanoparticles [23]. Mechanical properties are distinctive characteristics of a particle or material under environmental, diverse, and external forces. When it comes to Nanomaterials, these properties are typically categorized into ten aspects: strength, toughness, brittleness, hardness, fatigue strength, plasticity, rigidity, ductility, elasticity, and yield stress. These factors collectively define how a material behaves and responds to mechanical forces at the Nanoscale level. Non-metallic inorganic materials are typically brittle and lack significant plasticity, elasticity, toughness, and ductility properties. Organic materials are flexible and may not necessarily be brittle or rigid. However, nanoparticles (NPs) display unique mechanical properties at the nanoscale level due to quantum and surface effects that set them apart from bulk materials.

For example, formal FeAl powder, consisting of microparticles [<µm], demonstrates brittleness. In contrast, Nanosized FeAl alloy powder exhibits a desirable combination of ductility and strength, accompanied by improved plasticity. These newly discovered properties are thought to emerge from various interaction forces among Nanoparticles (NPs), either between Nanoparticles themselves or between NPs and a surface. The predominant interaction forces include van der Waals forces, which have three components: Debye, Keesom, and London. Other relevant forces such as electrostatic and electrical and electrostatic double layer forces, lateral normal and normal solvation forces, capillary forces, solvation forces, hydration forces, and structural forces also play a significant role [21].

Several theories have been proposed to elucidate the distinctive mechanical properties arising from interaction forces between Nanoparticles (NPs). These theories encompass the Johnson–Kendall–Roberts (JKR) theory, Derjaguin–Landau–Verwey–Overbeek (DLVO), and Derjaguin–Muller–Toporov (DMT) theory. The DLVO theory, for instance, integrates the influences of electrostatic repulsion to explain the stability of colloidal dispersion by van der Waals's attraction. The DLVO theory successfully elucidates the process in colloidal science, including the aggregation and adsorption of Nanoparticles in aqueous solutions and the forces between charged surfaces in a liquid medium. This theory has limitations in describing the colloidal properties of NPs in an aggregated state.

When dealing with Nanoscale objects, surface forces are predominant in their contact, adhesion, and deformation behaviors [20]. The JKR theory is suitable for high surface energies of large bodies, highlighting strong, short-range adhesion forces. Conversely, the Derjaguin–Landau–Verwey–Overbeek approach is ideal for rigid and small bodies with lower surface energies, emphasizing weak and attractive long-range forces. While the JKR, DMT, and DLVO theories have been extensively utilized to understand the mechanical properties of Nanoparticles, there is an ongoing debate concerning the accuracy of continuum mechanics in describing the behavior of particles or particle collections at the Nanometre scale [24]. Understanding the mechanical characteristics of Nanoparticles (NPs) and how they interact with various surfaces is crucial for enhancing surface quality and improving material removal processes. Achieving significant progress in these domains typically requires a comprehensive understanding of fundamental aspects of NP mechanical properties. This includes parameters such as hardness, elastic modulus behavior during movement, interfacial adhesion, frictional properties, and how these characteristics vary with NP size [21].

Magnetic properties

Nanoparticles' magnetic properties can selectively attach a functional molecule, which can then be targeted, manipulated, and transported to a desired location using the magnetic field produced by a permanent magnet electromagnet[23]. The carriers of magnetic Nanoparticles consist of three main functional parts: a surface coating, a magnetic core, and a functionalized outer coating. The center of the page contains a super magnetic substance in the presence of an external magnetic field, which helps to manipulate the particle. The biologically active drug molecule is a component of the functionalized outer coating. The concentration and magnetic core composition depend on the application. Magnetic compounds incorporate magnetic elements like Fe, Co, or Ni. Crystal structure, magnetic anisotropy, vacancy defects, shape, and size influence the magnetic characteristics of bulk materials. Specifically, the magnetic anisotropy energy is contingent upon the size of the Nanoparticles. When Nanoparticles reduce in size, their magnetic anisotropy energy decreases correspondingly. The magnetic moment flips when this energy equals the thermal energy at the specific size of each Nanoparticle. Nanoparticles exhibit significant magnetization solely as magnetic fields; once the area is removed, they lose their magnetization. This phenomenon is typically observed in small ferromagnetic or ferromagnetic Nanoparticles. However, it's worth noting that some other paramagnetic materials also display magnetization at the nanoscale level.

Bulk materials have multiple magnetic domain structures, whereas small Nanoparticles or ferromagnetic materials consist of a single magnetic domain structure. As the particle size reaches the minimum critical size or the Nanoscale, changes in magnetization make the formation of domain walls unfavorable and cause the magnetic spins to align unidirectionally. Particles exhibiting this property are termed single domains. As the particle size decreases further, thermal fluctuations affect the reels, rendering them superparamagnetic. This superparamagnetic property is advantageous, enabling individual particles to magnetize when exposed to an external magnetic field. The particle size determines the functionalization essential for various applications [23].

Electronic and optical properties

The electronic and optical properties of Nanoparticles are intricately linked. Noble metal NPs, for instance, showcase optical properties that vary with their size. They exhibit a distinct UV-visible extinction band, a feature absent in the spectrum of the corresponding bulk metal[23].

Semiconductor and Metallic Nanoparticles exhibit fascinating photoluminescence emission, linear absorption, and nonlinear optical properties attributed to LSPR (localized surface Plasmon resonance) effect and quantum mechanics. The LSPR (localized surface Plasmon resonance) effect. LSPR occurs when incident photon frequency aligns with the collective excitation of conductive electrons, resulting in a distinct UV-visible extinction band in noble metal NPs, absent in bulk metals. Typically, the optical properties of Nanoparticles are shaped by their dielectric, size, and shape of the dielectric environment surrounding them. The excitation of LSPR leads to selective absorption at specific wavelengths, featuring an exceptionally high molar excitation coefficient. It also results in resonance Rayleigh light scattering efficiency comparable to ten fluorophores and generates intensified local electromagnetic fields near NP surfaces, making it advantageous for spectroscopic applications. The peak wavelength of the LSPR spectrum is well-known to depend on multiple factors, such as the shape, size, and inter-particle spacing of the Nanoparticle along with their dielectric properties and those of the surrounding environment, including substrates, solvents, adsorbates, and solvents. Gold colloidal Nanoparticles cause the dark colors observed in stained glass doors or windows, while silver (Ag) Nanoparticles typically give a yellowish hue. The presence of free electrons on the surface of Nanoparticles, mainly d electrons in silver and gold, is responsible for the observed coloration. These electrons can move freely within the Nanomaterial, giving rise to this phenomenon. The mean free path for electrons in silver and gold is approximately 50 nm, a size larger than that of these Nanoparticles. This shows that no scattering is expected from the bulk material when interacting with light. Instead, the free electrons in the Nanoparticles create a standing resonance condition, leading to localized surface Plasmon resonance (LSPR) in these Nanoparticles [23].

Applications of Nanoparticles

Nanoparticles play a vital role in various sectors as follows:

Nanotechnology in medicines

Nanotechnology's role in medicine includes a notable application known as drug delivery. This emerging approach uses nanoparticles to directly transport drugs, light, heat, or other substances to specific cell types, like cancer cells, to enhance treatment precision and effectiveness [4]. Nanoparticles have a promising approach for delivering drugs to the brain due to the significant challenge posed by BBB. Drugs can be delivered to the brain via Nanoparticles. The discovery of novel medications for the central nervous system is most significantly inhibited by the blood-brain barrier (BBB). With the help of certain enzymes or efflux mechanisms, the CNS can also lower the concentration of lipid-soluble compounds in the brain [3]. Nanotechnology, known as tissue engineering, can be essential in regenerating and repairing damaged tissues. This advanced approach has the potential to substitute conventional methods like artificial implants and organ transplants. For instance, carbon Nanotube scaffolds have been used for faster bone growth, showcasing the transformative potential of tissue engineering [19]. Their improved absorption and light scattering properties resulting from the LSPR effect make semiconductor and metallic Nanoparticles have great potential for cancer diagnosis and therapy [20]. In particular, medical imaging and drug or gene delivery disciplines have significantly benefited from using Nanoparticles, particularly iron oxide particles like magnetite and its oxidized cousin hematite [2].

In agriculture

Nanoparticles offer the potential to revolutionize agriculture by introducing novel remedies for prevailing agricultural and ecological predicaments. Within agriculture, NPs predominantly serve in two capacities: Nano fertilizers and Nano pesticides. Conventional chemical fertilizers exhibit effectiveness due to leaching and volatilization issues. Consequently, farmers often respond by overusing fertilizers, bolstering crop yield while incurring environmental consequences. Certain NPs demonstrate efficacy against microbes, insects, and nematodes, making them a promising substitute for chemical pesticides and a potentially more economical option than bio-pesticides [20].

Numerous technological innovations created by researchers promise to boost agricultural productivity and simultaneously lower the environmental and resource expenses associated with farming[25].

In food

Nanoparticles are being more frequently used in food packaging to manage the surrounding atmosphere of the food, thereby preserving its freshness and protecting it from microbial contamination[2]. Nanotechnology is harnessed to enhance food production, processing, protection, and packaging. For instance, using Nanocomposite coatings in food packaging can directly apply antimicrobial agents onto the coated film surface, illustrating how Nanotechnology brings advancements to various aspects of the food industry [19].

Nanoparticles (NPs), despite having potential toxicological issues, offer significant benefits in different food industry processes like food production, preservation, and packaging. Among these, TiO_2 NPs hold a prominent position, showing promise in enhancing food safety and extending shelf life through their photocatalytic antimicrobial properties, making them a captivating choice for food packaging materials[20]. Food fortification using NPs offers a more efficient and effective way to introduce vital nutrients like vitamins and minerals into food items. For instance, Iron-fortified products have utilized Nanoparticles like Fe_2O_3, while CuNPs have enhanced copper levels, a crucial nutrient for metabolizing iron and other essential nutrients[26]. Food storage containers incorporate silver NPs for their antimicrobial properties, effectively safeguarding against bacteria. The "silver Nano poly system' also functions as an antimicrobial and deodorizing agent, enhancing its ability to maintain freshness and hygiene[25].

In electronics

One-dimensional semiconductors and metals' distinctive structural, optical, and electrical attributes position them as crucial foundation components for the next era of electronics, sensors, and photonic materials[2]. The enhanced electrical conductivity of NPs is employed to detect gases such as NO_2 and NH_3. This arises from the augmented Nanoparticle porosity resulting from transferring charges from Nanoparticles to NO_2 as the gas molecules bond with them. This enhances the effectiveness of gas sensors[19]. NPs possess unique electronic and optical characteristics, leading to a broad spectrum of potential applications in imaging and electronics. For example, NPs containing Gd can enhance the imaging precision and reduce the necessary contrast agent dosage in magnetic resonance imaging (MRI)[20]. In recent years, there has been more interest in advancing printed electronics. This interest stems from the appealing alternative they present to conventional silicone methods and their potential to enable cost-effective production of expansive electronic systems for applications such as flexible displays and sensors[11]. The utilization of diverse functional inks containing NPs like organic electronic molecules, metallic NPs, carbon Nanotubes, and ceramic NPs is anticipated to accelerate the adoption of printed electronics as a mass production method for novel electronic devices[11]. NPs have the potential to bring about significant transformations in the electronics sector. They find utility across various electrical applications, including display technologies and storage devices. For instance, incorporating silver NPs and gold NPs in LCD and OLED displays has been explored to enhance image brightness, color, and contrast, thereby improving overall conductivity and display performance[25]. When gold NPs are combined with organic molecules, they give rise to a transistor called a NOMFET (Nanoparticle organic memory Field-Effect Transistor). This type of transistor is remarkable due to its ability to operate in a manner reminiscent of the synapses found in the nervous system[23].

Drug and medication

NPs have garnered growing attention across various medical fields due to their capacity to deliver drugs within the ideal dosage range. This often leads to heightened therapeutic effectiveness, minimized side effects, and enhanced patient adherence. Liposomes have emerged as a promising method for drug transportation, replacing conventional dosage forms, given their distinct benefits.

These advantages encompass safeguarding drugs from degradation, precise targeting of the treatment site, and diminishing both harmful effects and noxiousness[11].

Environment

NPs frequently apply to environmental cleanup due to their adaptability for on-site and off-site usage in water-based systems. Silver NPs, renowned for their antibacterial, antifungal, and antiviral properties, have been widely employed for water disinfection [2]. Nanostructures find significant utility in environmental contexts owing to their high surface-to-mass ratio. They hold significance in the interaction between solids and water, facilitating the absorption of contaminants onto their surfaces. These contaminants might attach during NP formation, co-precipitate with NP creation, or become entrapped through NP aggregation[11].

Nanotechnology's environmental applications cluster into three key spheres:

1) Creating ecologically friendly sustainable items, such as within green chemistry or pollution abatement.

2) The rectification of materials tainted by perilous elements.

3) The deployment of sensors for environmental monitoring [11].

Nanotechnology and NPs enhance water quality and aid in environmental cleanup efforts. Additionally, their viability as ecological sensors for tracking pollutants is increasingly recognized. These NPs can serve as detectors, identifying specific substances like metals and contaminants within the environment [25]. Scientists are employing photocatalytic NPs made of copper tungsten oxide to decompose oil into environmentally friendly substances. Additionally, iron Nanoparticles are being utilized to remediate carbon tetrachloride contamination found in groundwater [23].

Conclusion

Nanotechnology has garnered significant interest, leading to increased investment in research and development from top institutions, industries, and organizations. This review paper has concisely summarized nanoparticles, covering their structure, characterization, properties, and wide-ranging applications in medicine, environmental cleanup, electronics, and more. Due to their adjustable chemical, physical, and biological characteristics, Nanoparticles have become significant in various domains.

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References:

1.Joudeh N, Linke D. Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists. Journal of Nanobiotechnology. 2022 Jun 7;20(1):262.

2. Kumari S, Sarkar L. A review on Nanoparticles: Structure, classification, synthesis & applications. J. Sci. Res. 2021;65:42-6.

3. Nikam AP, Ratnaparkhiand MP, Chaudhari SP. Nanoparticles–an overview. Int. J. Res. Dev. Pharm. Life Sci. 2014 Sep 15;3:1121-7.

4. Kumari B. A Review on Nanoparticles: Their Preparation method and applications. Ind Res J Pharm Sci. 2018;5(2):1420.

5. Ealia SA, Saravanakumar MP. A review on the classification, characterisation, synthesis of Nanoparticles and their application. InIOP conference series: materials science and engineering 2017 Nov 1 (Vol. 263, No. 3, p. 032019). IOP Publishing.

6. Bhatia S, Bhatia S. Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications. Natural Polymer Drug Delivery Systems: Nanoparticles, Plants, and Algae. 2016:33-93.

7. Amina SJ, Guo B. A review on the synthesis and functionalization of gold Nanoparticles as a drug delivery vehicle. International journal of Nanomedicine. 2020 Dec 7:9823-57.

8. Ganesh K, Archana D, Preeti K. Review article on targeted polymeric Nanoparticles: an overview. Am. J. Adv. Drug Deliv. 2013;3(3):196-215.

9. Couvreur P. Nanoparticles in drug delivery: past, present and future. Advanced drug delivery reviews. 2013 Jan 1;65(1):21-3.

10. Kumari S, Sarkar L. A review on Nanoparticles: Structure, classification, synthesis & applications. J. Sci. Res. 2021;65:42-6.

11. Salavati-Niasari M, Davar F, Mir N. Synthesis and characterization of metallic copper Nanoparticles via thermal decomposition. Polyhedron. 2008 Nov 25;27(17):3514-8.

12. Bhaviripudi S, Mile E, Iii S A S, Zare A T, Dresselhaus M S, Belcher A M and Kong J. CVD Synthesis of Single-Walled Carbon Nanotubes from Gold Nanoparticle Catalysts. J Am Chem Soc., 2007; 129(6): 1516-7.

13. Nsairat H, Khater D, Sayed U, Odeh F, Al Bawab A, Alshaer W. Liposomes: Structure, composition, types, and clinical applications. Heliyon. 2022 May 1.

14. Perumal S, Atchudan R, Lee W. A Review of Polymeric Micelles and Their Applications. Polymers (Basel). 2022;14(12):2510. Published 2022 Jun 20. doi:10.3390/polym14122510

15. Manotham S, Tesavibul P. Effect of particle size on mechanical properties of alumina ceramic processed by photosensitive binder jetting with powder spattering technique. Journal of the European Ceramic Society. 2022 Apr 1;42(4):1608-17.

16. Primo A, Corma A, García H. Titania supported gold nanoparticles as photocatalyst. Physical Chemistry Chemical Physics. 2011;13(3):886-910.19. Ealia SA, Saravanakumar MP. A review on the classification, characterisation, synthesis of Nanoparticles and their application. InIOP conference series: materials science and engineering 2017 Nov 1 (Vol. 263, No. 3, p. 032019). IOP Publishing.

17. Mittal P, Saharan A, Verma R, Altalbawy F, Alfaidi MA, Batiha GE, Akter W, Gautam RK, Uddin MS, Rahman MS. Dendrimers: a new race of pharmaceutical nanocarriers. BioMed Research International. 2021 Feb 15;2021.

18. Maiti D, Tong X, Mou X, Yang K. Carbon-based nanomaterials for biomedical applications: a recent study. Frontiers in pharmacology. 2019 Mar 11;9:1401.

20. Bhaviripudi S, Mile E, Iii S A S, Zare A T, Dresselhaus M S, Belcher A M and Kong J. CVD Synthesis of Single-Walled Carbon Nanotubes from Gold Nanoparticle Catalysts. J Am Chem Soc., 2007; 129(6): 1516-7.

22. Eastman JA. Novel thermal properties of Nanostructured materials. Argonne National Lab., IL (US); 1999 Jan 13.

21. Joudeh N, Linke D. Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists. Journal of Nanobiotechnology. 2022 Jun 7;20(1):262.

23. Khan I, Saeed K, Khan I. Nanoparticles: Properties, applications and toxicities. Arabian journal of chemistry. 2019 Nov 1;12(7):908-31.

24. Mechanical properties of Nanoparticles: basics and applications To cite this article: Dan Guo et al 2014 J. Phys. D: Appl. Phys. 47 013001

25. Anand Pal, Sarita Rani, Jagdish Parshad, Tejpal and Satpal. 2019. Application of Nanoparticles in Applied Science: A review. Int.J.Curr.Microbiol.App.Sci. 8(10): 2318-2325.

26. Altammar KA. A review on Nanoparticles: characteristics, synthesis, applications, and challenges. Front Microbiol. 2023 Apr 17;14:1155622. doi: 10.3389/fmicb.2023.1155622. PMID: 37180257; PMCID: PMC10168541.