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Review Paper

Review On Nanoparticles

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ABSTRACT

Nanotechnology has emerged as one of the most influential scientific advancements of the 21st century, enabling precise manipulation of materials at the nanoscale. Nanoparticles, ranging from 1 to 100 nm, exhibit unique physicochemical and biological properties that make them valuable in diverse scientific and industrial domains. This review provides an overview of the classification, synthesis methods, and applications of nanoparticles. It discusses organic, inorganic, carbon-based, polymeric, and green nanoparticles, highlighting their synthesis through both top-down and bottom-up approaches. Furthermore, the article explores the major biomedical and technological applications, including drug delivery, cancer therapy, antimicrobial treatments, imaging, catalysis, and environmental remediation. The advantages and limitations of nanoparticles are summarized, along with examples of nanoparticle-based drug formulations that have improved therapeutic efficacy and reduced toxicity. Overall, this review emphasizes the potential of nanotechnology in advancing modern medicine, materials science, and sustainable development

INTRODUCTION

Nanotechnology has emerged as one of the most transformative scientific disciplines of the twenty-first century, providing innovative tools to manipulate and control matter at the atomic and molecular scale. It focuses on materials within the size range of 1–100 nanometers, where quantum and surface effects give rise to unique physical, chemical, and biological properties[1]. The rapid advancement of nanoscience has been driven by developments in surface physics, material chemistry, and miniaturization technologies, which have enabled precise synthesis and functionalization of nanomaterials. Various fabrication techniques, such as chemical vapor deposition, laser ablation, and microemulsion methods, have been widely used to produce nanoparticles with controlled size and morphology[2]Additionally, biological and green synthesis methods employing plant extracts and

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microorganisms have offered eco-friendly and cost-effective alternatives for nanoparticle production[3].

Nanoparticles such as gold, silver, zinc oxide, and carbon-based materials exhibit exceptional optical, electrical, and mechanical properties that differ significantly from their bulk counterparts[4].These properties make them highly valuable in various fields, including drug delivery, diagnostics, catalysis, energy storage, and environmental applications. As a result, nanotechnology has become a cornerstone of modern scientific research, bridging the gap between fundamental science and practical applications in medicine, energy, and industry.

Types of Nanoparticles

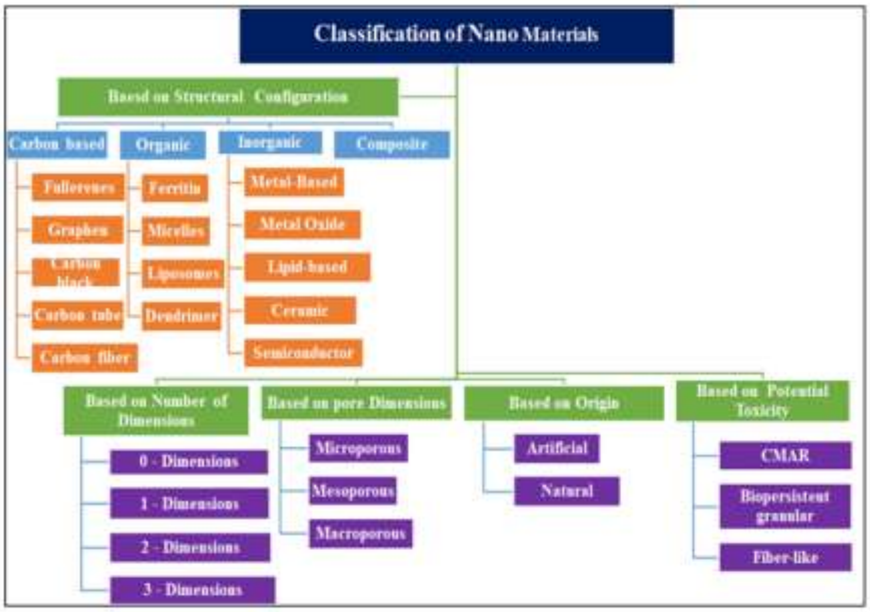
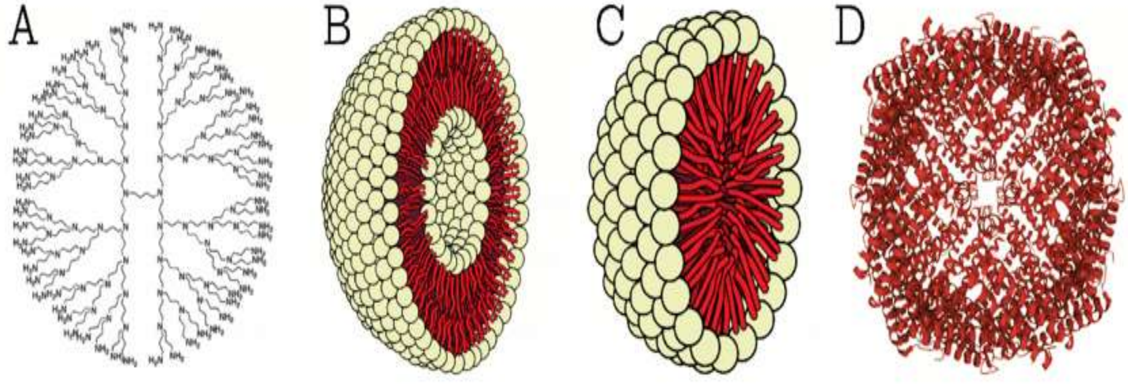


Figure no 1 classification of nanoparticles[5]

Organic Nanoparticles

Organic nanoparticles are solid patches with a periphery between 10 nm and 1 µm that are made of organic substances like lipids or polymers [6]. Certain organic nanoparticles, similar to liposomes and micelles, contain a concave sphere and aren't dangerous or biodegradable. It's also apprehensive of the term for light- and heat-sensitive nano capsules[7]. For drug delivery, it is preferable for experimenters to employ organic-grounded NPs due to their unique features. These substances are effective and implicit intercessors for the delivery of a medicine's active factors due to their stability, medicine-carrying capacity, and capacity to adsorb or entrap certain medicines[8].

A. Dendrimers
B. Liposomes
C. Micelles
D. Ferritin



A) Dendrimers B) Liposomes C) Micelles D) Ferritin

Figure 2 types of organic nanoparticles[9]

Inorganic Nanoparticles

Inorganic nanoparticles can be broadly classified based on their composition, structure, and origin. The most widely studied categories include metal nanoparticles, metal oxide nanoparticles, carbon-based nanomaterials, polymeric nanoparticles, and green/biogenic nanoparticles. Each type possesses distinctive physicochemical properties that influence its applications in medicine, engineering, and material science.

Metal Nanoparticles

Metal nanoparticles such as gold (Au), silver (Ag), copper (Cu), and platinum (Pt) are extensively studied due to their optical, catalytic, and antimicrobial properties.

Gold nanoparticles (AuNPs): These are synthesized through chemical reduction or biological methods[10]. The demonstrated intracellular synthesis of gold nanoparticles using alkalotolerant actinomycete species. Gold nanoparticles are widely used in imaging, radio sensitization, and drug targeting[11].

Green and biological synthesis techniques, including the use of Lantana camara leaf extract and marine Streptomyces species, have shown promise in producing stable silver nanoparticles with antimicrobial and antiviral capabilities[12].

Copper nanoparticles (CuNPs): These are used in electronics and catalysis. demonstrated size-controlled deposition of Cu nanoclusters using ultra-high vacuum sputtering and gas aggregation techniques[13].

Platinum nanoparticles (PtNPs): These particles are used as catalysts in renewable energy and fuel cell applications. Pt nanoparticles described embedded on carbon nitride composites for fuel oxidation[14].

Metal Oxide Nanoparticles

Metal oxide nanoparticles, such as zinc oxide (ZnO), titanium dioxide (TiO_2), and iron oxide (Fe_3O_4), are valued for their stability, photocatalytic activity, and biomedical relevance.

ZnO nanoparticles: ZnO NPs are frequently used in cancer therapy, drug delivery, biosensing, and electronics. highlighted their applications in cancer diagnosis and treatment[4].

ZnO-doped polymer thin films:The synthesized ZnO NP-based PMMA-coated films with UV curing, demonstrating their utility in optical data storage.[10]

Carbon-Based Nanomaterials: Carbon nanostructures include graphene, carbon nanotubes (CNTs), fullerenes, and carbon nanofibers.

Graphene: High-quality single-layer graphene can be produced through chemical vapor deposition (CVD). reviewed its synthesis and potential in electronics and composite materials[15].

Carbon nanotubes (CNTs): Arc discharge and plasma techniques have been utilized to synthesize branched or nano-channeled CNTs from waste precursors, demonstrating cost-effective methods for large-scale production. Fullerenes critically examined their characterization and environmental implications[16].

Polymeric and Composite Nanoparticles

In both industrial and biomedical applications, polymer-based nanoparticles and hybrid composites have become more significant.

Functional coatings for optical and storage devices are made possible by thin films that combine nanoparticles and polymers, such as PMMA with ZnO[10].

Composites of carbon and polymers: Fuel cell electrocatalytic performance is enhanced by carbon nitride composites decorated with platinum[14].

Biogenic and Green Nanoparticles

Eco-friendly or biologically synthesized nanoparticles use plant extracts, bacteria, fungi, and algae.

Plant-mediated AgNPs: Extracts of Lantana camara promote the green synthesis of silver nanoparticles with minimal toxic…

Microbial synthesis: Actinomycetes and Streptomyces strains have demonstrated efficient intracellular and extracellular production of metallic nanoparticles[12].

Top-Down vs. Bottom-Up Approaches

Nanoparticle synthesis methods fall into two core strategies:

Top-down methods: Techniques like laser ablation, mechanical milling, sputtering and arc discharge reduce bulk materials into nanoscale structures[17].

Microemulsions, sol-gel processes, vapor deposition, and green synthesis assemble nanoparticles from molecular precursors[15].

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Synthesis methods

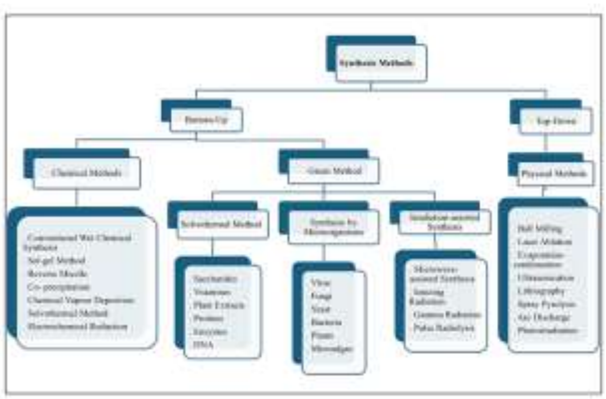

figure 3 Classification of synthesis method physical, chemical, and green synthesis[5]

Top-down method

The destructive process, occasionally appertained to as the top-down system, breaks down bulk accoutrements into bitsy factors that ultimately come nanomaterials. exemplifications of the top-down approach include lithography, thermal corruption bow discharge, ray ablation, sputtering, electron explosion, and mechanical or ball milling[19].

Bottom-up method

The bottom-up or formative approach is the method used to structure material from tittles to clusters to nanoparticles. Sol-gel, spinning, chemical vapour deposit (CVD), pyrolysis, and biosynthesis are the most widely used bottom-up methods for creating nanoparticles [20]. During the bottom-up construction process, nanostructures are made flyspeck by flyspeck or snippet by snippet. This can be accomplished through the development of capitals after a high position of supersaturation. By considering these two methods, colorful scientists have reported a variety of physical and chemical methods[21].

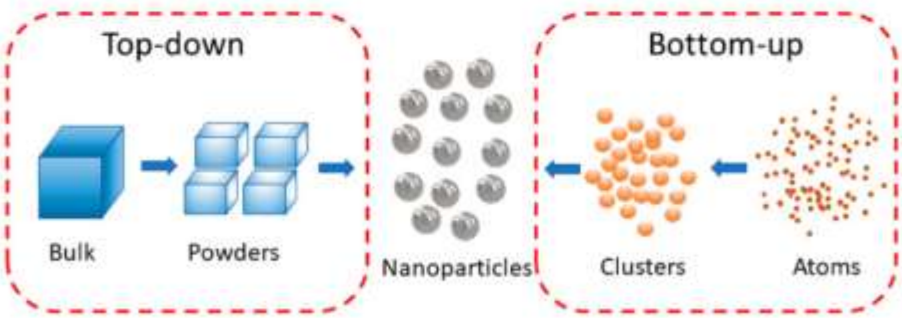

Figure 7 Schematic illustrating the top-down and bottom-up methods for nanoparticle preparation[5]

Advantages and Disadvantages of Nanoparticles

Advantages of Nanoparticles

- Target drug delivery and control release
- Enhanced Diagnostic and Imaging Capabilities
- Antimicrobial and Anticancer Properties
- High Surface Area and Reactivity
- Versatility in Synthesis and Functionalization

Disadvantages of Nanoparticles

- Toxicity and Safety Concerns
- Environmental Impact
- Challenges in Large-Scale Production
- Regulatory and Ethical Limitations
- Stability Issues

Applications of Nanoparticles

Nanoparticles exhibit unique chemical, physical, and biological properties that enable their use across multiple scientific, medical, environmental, and industrial fields. Their customizable size, surface functionality, and biocompatibility make them particularly valuable in drug delivery, diagnostics, imaging, cancer therapy, and antimicrobial treatments.

Drug Delivery and Targeted Therapy

One of the most impactful applications of nanoparticles is in site-specific and controlled drug delivery. Due to their nanoscale size and modifiable surface chemistry, they can encapsulate, adsorb, or conjugate with therapeutic molecules, enabling targeted release.

Gold nanoparticles (AuNPs): Gold nanoparticles facilitate drug transport due to their stability and compatibility. Abdulle explored their role in radiosensitization during radiotherapy[11].

Zinc Oxide nanoparticles (Zno NPs): Their use in cancer drug delivery, cellular imaging, and theranostics. Zinc oxide NPs can be functionalized with ligands to deliver drugs precisely to tumor cells[4].

Polymer-coated nanostructures: Ahmad demonstrated nanoparticle-coated polymer films, which can be adapted for controlled drug release or biosensing platforms[2].

Cancer Diagnosis and Radiotherapy Enhancement

Nanoparticles are widely used in oncology for diagnostic imaging and radiation enhancement.

Abdulle and Chow showed that AuNPs improve contrast during portal imaging and enhance therapeutic dose absorption in nanoparticle-assisted radiotherapy[11].

Anjum emphasized the role of ZnO NPs in imaging, cytotoxic cancer therapy, and drug-tumor targeting[4].

Antimicrobial and Antipathogenic Activity

Many nanoparticles exhibit inherent antibacterial, antifungal, and antiviral properties.

Green-synthesized AgNPs from Lantana camara leaf extract display strong antimicrobial action against pathogenic bacteria further confirmed antimicrobial activity of Ag nanomaterials derived from marine Streptomyces[3,12].

Biogenic gold nanoparticles also demonstrate antimicrobial and biofilm-disrupting capabilities[10].

Biomedical Imaging and Diagnostics

Nanoparticles are integrated into imaging systems due to their optical and magnetic properties.

Gold and metal nanoparticles: Their high electron density and surface plasmon resonance enable their use in photoacoustic imaging, CT scanning, and fluorescence-based systems.[11]

Polymer-nanoparticle films: Ahmad suggested that ZnO-based polymer coatings may be adapted for biosensor diagnostics and optical detection systems[10].

Optical and Data Storage Application

Nanostructures offer enhanced performance in photonics and optoelectronics. developed UV-cured polymer coatings containing zinc oxide nanoparticles for optical data storage.

Graphene and carbon nanotubes have been incorporated into electronic devices and sensors due to their high conductivity and structural strength [15].

Energy and Catalysis

Nanoparticles are vital in improving fuel cell efficiency, catalysis, and energy conversion systems. Pt nanoparticles in graphene-based composites for catalytic oxidation in fuel cell technology.

Carbon nanotubes (CNTs): Arc discharge–synthesized CNTs from waste PET show potential in electrodes and clean energy devices[14].

Environmental and Industrial Uses

Nanomaterials are being used more and more in waste treatment, coatings, filtration, and sensing. The Metal oxide nanoparticles, such as ZnO and TiO_2, are used in photocatalysis and breaking down pollutants[4].

Carbon nanotube filters create nanochannels for cleaning water and improving the environment[4].

Role in Biosensors and Diagnostics

Functionalized nanoparticles improve the sensitivity and specificity of biosensors. Metal and metal oxide nanoparticles boost signal detection and biochemical interaction in diagnostic systems. Biogenic nanoparticles are low in toxicity, making them suitable for point-of-care testing and lab-on-chip devices[22]

Nanoparticle-Based Drug Formulations

Sr.No	Drug	Formulation / Brand	Indication	Key Advantages	NP System Type	Reference
1.	Doxorubicin	Doxil® (PEGylated liposomal doxorubicin)	Various cancers	Reduced cardiotoxicity; prolonged circulation; increased tumour accumulation (EPR)	PEGylated Liposomes	23
2.	Paclitaxel	Abraxane® (albumin bound paclitaxel)	Breast, lung, pancreatic cancers	Avoids Cremophor toxicity; improved tumour delivery; higher tolerated dose	Albumin bound NPs (~130 nm)	24
3.	Cisplatin	Liposomal / polymeric cisplatin	Various solid tumours	Reduced systemic toxicity; improved tumour targeting; controlled release	Liposomal / Polymeric NPs	25
4.	Curcumin	Various nano formulations	Inflammatory & cancer research	Enhanced solubility and bioavailability; improved delivery	Polymeric / Lipid NPs	26
5.	Insulin	Research PLGA/chitosan NPs (oral/nasal)	Diabetes mellitus	Non invasive ; protection from GI degradation; improved compliance	Polymeric (PLGA, Chitosan)	27
6.	Amphoteric B	AmBisome® (liposomal amphotericin B)	Systemic fungal infections	Reduced nephrotoxicity; improved safety	Liposomal	28
7.	siRNA (Patisiran)	Onpattro® (LNP-siRNA)	hATTR amyloidosis	Systemic siRNA delivery; targeted hepatic uptake; proof of LNP efficacy	Lipid Nano particles	29

8.	Docetaxel	Docetaxel nanocarriers	Breast, lung, prostate cancers	Reduced surfactant toxicity; improved tumour accumulation	Polymeric / Lipid / Albumin NPs	30
9.	Ibuprofen	Nano emulsionns / nano suspensions	Pain and inflammation	Enhanced solubility; reduced gastric irritation; better permeation	Nano emulsion / Vesicular	31
10.	Metho-trexate	MTX-loaded nanoparticles	Cancer, rheumatoid arthritis	Targeted delivery; reduced toxicity; enhanced therapeutic index	Polymeric/ Liposomal/ Inorganic	32

CONCLUSION

Nanoparticles represent a cornerstone of modern nanotechnology, bridging the gap between fundamental research and practical applications across medicine, energy, and industry. Their tunable size, shape, and surface properties enable targeted drug delivery, enhanced imaging, and effective catalytic performance. However, challenges such as toxicity, large-scale production, environmental risks, and regulatory concerns remain key barriers to their widespread use. Continued advancements in green synthesis, surface modification, and biocompatible design are essential for ensuring safe and sustainable applications. As research progresses, nanoparticles are expected to play a pivotal role in developing next-generation materials and therapeutic systems that contribute to improved healthcare and environmental protection.

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