

Review on Nanoparticles

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Abstract- Nanotechnology has become a rapidly advancing field with wide applications in pharmaceuticals and biomedicine. Among its innovations, nanoparticles are of particular interest because of their unique physiochemical properties that improve drug delivery. This review highlights the introduction, classification and essential properties of nanoparticles, emphasizing their significance in targeted and controlled drug delivery systems. Their role in enhancing therapeutic efficacy and reducing side effects is discussed along with common synthesis approaches. The advantage of nanoparticles, such as site-specific action and improved bioavailability, are outlined in contrast to limitations like stability issues and toxicity concerns. The article also traces the evolution of nanoparticle research and its growing impact on healthcare applications. Finally, future perspectives are explored, with a focus on personalized medicine and advanced therapeutic strategies. Overall, nanoparticles represent a promising platform with strong potential to transform the future of drug delivery.

Index Terms- Bioavailability, Carbon nanotubes, Drug delivery, Nanoparticles, Nanotechnology.

I. INTRODUCTION

According to International Organization for Standardization (ISO), Nanoparticles may be defined as nano-objects whose external dimensions all fall within the nanoscale range, and where the longest and shortest dimensions are relatively similar in size. When there is a significant difference in these dimensions—usually more than three times—alternative terms like nanofibers or nanoplates are often used instead of simply calling them nanoparticles.

Nanoparticles (NPs) come in a wide range of shapes, sizes, and structural forms. They may appear as spheres, cylinders, cones, tubes, hollow cores, spirals, or have irregular shapes. Their size typically ranges from 1 to 100 nanometers.[1]

These particles possess distinctive characteristics because of their tiny size and the ability to modify their surface with various molecules. As a result of their small dimensions and high surface area, their molecular interactions change, leading to the development of new potential applications. The properties of nanoparticles play a key role in defining their functionality, effectiveness, and practical uses. For example, a nanoparticle's size and shape can affect how it can be modified, its optical characteristics, and its ability to penetrate cells—factors that are essential for applications such as cancer therapy and medical imaging.

Also, the surface charge of a nanoparticle plays an important role in how it behaves in different environments. It can affect how the particle interacts with cells and how toxic it might be, depending on the material it's made from. All these features influence how the nanoparticle can be used and make each one useful in its own special way. Nanoparticles are used in many specific fields, including industry, food products, drug delivery systems, fighting harmful microbes, medical imaging, and various treatments, among others. The way nanoparticles are made, along with their shape and size, can greatly affect how well they work and how active they are in different applications.[2]

II. CLASSIFICATION OF NANOPARTICLES [3]

A. Organic Nanoparticles

Organic nanoparticles such as micelles, dendrimers, ferritin, and liposomes are among the most widely studied nanoparticles. They are generally non-toxic, biodegradable, and biocompatible therefore they are suitable for biomedical applications. These carriers are responsive to external stimuli such as heat and light, which enhances controlled release. Due to their efficiency and ability to deliver therapeutic agents to specific sites, organic nanoparticles are widely used in targeted drug delivery systems.

B. Inorganic Nanoparticles:

Inorganic nanoparticles are mainly composed of metals, metal oxides and ceramics. These particles possess unique structural, optical, and catalytic properties which makes them valuable in drug delivery, imaging, catalysis, and environmental applications.

Following are the types of Inorganic nanoparticles:

Table I. Types of Inorganic nanoparticles

Type	Applications
Metal NPs (Au, Ag, Fe, Zn)	Biosensing, Bioimaging, SEM coating, drug delivery
Ceramic NPs (oxides, phosphates)	Catalysis, photocatalysis, drug delivery in tumour, glaucoma.
Semiconductor NPs (ZnO, CdS, Si, Ge)	Photocatalysis, electronics, water splitting.
Polymeric NPs	Controlled release, targeted therapy.
Lipi-based NPs	Drug delivery, RNA release in cancer therapy.

C. Carbon Based Nanoparticles:

Carbon-based nanomaterials mainly include carbon nanotubes (CNTs) and fullerenes. CNTs exist as single-walled (SWCNTs), double-walled (DWCNTs), or multi-walled (MWCNTs) structures. They are exceptionally strong, thermally conductive along their axis, and widely synthesized using techniques such as arc discharge, laser ablation, and chemical vapor deposition (CVD).

Fullerenes (e.g., C-60 Buckminsterfullerene) are hollow, cage-like carbon allotropes with pentagonal and hexagonal arrangements. Both CNTs and fullerenes exhibit remarkable electrical conductivity, mechanical strength, and electron affinity, making them valuable in nanocomposites, catalysis support, gas adsorption, and environmental remediation.

III. IMPORTANCE OF NANOPARTICLES

- 1) Increasing the duration that nanoparticles stay in the bloodstream
- 2) This includes enhancing the drugs' solubility in the blood serum.
- 3) Delivering drugs in a steady and controlled manner.
- 4) Targeting drugs specifically to the desired tissues and cells.
- 5) Simultaneously delivering multiple treatments to the same cells for combined therapy.[4]

- 6) Nanoparticles can be beneficial for treating liver conditions such as tumor metastasis or hepatitis.
- 7) Nanoparticle play important role in particle uptake, distribution and effects.[5]

IV. SYNTHESIS OF NANOPARTICLES [6]

Different techniques are utilized to synthesize nanoparticles (NPs) with precise control over their size, shape, structure, and dimensions.

Broadly, these synthesis strategies are classified into two categories:

- ✓ top-down
 - ✓ bottom-up approaches.
- A. *Top-down Approaches:*

The top-down approach refers to reducing bulk materials into nanoscale particles, making it essentially a destructive process. It typically involves removal, division, or miniaturization of bulk structures to achieve nanoparticles with desired properties. Common techniques include mechanical milling, nanolithography, laser ablation, sputtering, and thermal decomposition.

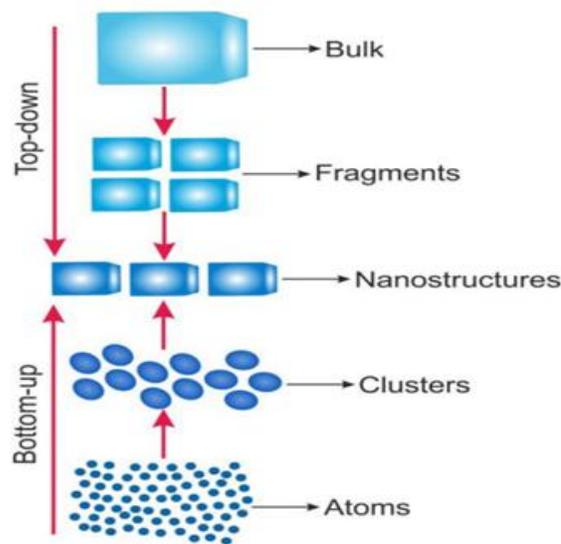


Fig I. Diagrammatic representation of Top-down Approach [7]

B. Bottom-Up Approaches:

The bottom-up approach, also called the constructive method, involves assembling nanoparticles from atoms or clusters. Techniques such as sedimentation and reduction are commonly used, making this method

more economical and environmentally friendly due to reduced waste generation. Widely adopted examples include sol-gel processing, spinning, green synthesis, chemical vapor deposition (CVD), pyrolysis, and biosynthesis. In addition, other synthesis techniques often discussed in the literature are mechanical milling, nanolithography, laser ablation, sputtering, thermal decomposition, and pulsed electrochemical etching.

V. PROPERTIES OF NANOPARTICLES

A. Nanoparticle Size:

To give a clearer idea of nanoparticle size, Table 1 shows a comparison with different objects. Since their size is similar to components found in human cells, nanoparticles are especially useful for drug delivery.

Table II. Typical Size of Various Objects

Object	Size (nm)
Carbon atom	0.1
DNA double helix (Diameter)	3
Ribosome	10
Virus	100
Bacterium	1000
Red Blood cells	5000
Human Hair (Diameter)	50,000
Resolution of unaided human eyes	100,000

B. Nanoparticle Surface:

As the size of a particle decreases, the number of molecules on its surface increases.

Table III. % Surface Molecules in Particles

Particle Size (nm)	Surface Molecule (%)
1	100.00
10	27.10
100	2.97
1000	0.30
10,000	0.03

VI. ADVANTAGES OF NANOPARTICLES: [8]

- 1) Nanoparticle surface characteristics and particle size can be easily tailored, enabling both passive and active targeting of drugs following parenteral administration.
- 2) Nanotechnology is an emerging field with diverse applications across industries, including aquaculture, particularly in areas such as nutrition.
- 3) Due to their very small size, nanoparticles can move through tiny capillaries and enter cells, which allows

drugs to collect effectively at specific target sites in the body.

- 4) Nanoparticles made from biodegradable materials can provide sustained drug release at the target site for several days or even weeks.
- 5) Nanotechnology has applications in reproduction, water purification, fishing, disease control, and in reducing toxicity and harmful effects.

VII. DISADVANTAGES

- 1) Nanoparticles are highly reactive in cellular environments due to their small size and large surface area.
- 2) In drug delivery, non-biodegradable nanoparticles can accumulate at the target site, potentially leading to chronic inflammation.
- 3) Nanoparticles have limited targeting ability, making it difficult to completely stop therapy once started.
- 4) Nanotechnology is costly, and its development requires even greater investment.
- 5) Nanotechnology also raises concerns, as it can contribute to the development of more powerful and destructive atomic weapons.

VIII. MAJOR TYPES AND APPLICATION OF NANOPARTICLES: [9]

Table IV. Types of Nanoparticles

Year	Types	Application
1991	Poly-alkyl-cyanoacrylate nanoparticles	Cancer chemotherapy and intracellular antibiotherapy
1992	Calcium hydroxyapatite ceramic(CHC)	The bactericidal activity is maintained, and the drug shows effective results.
1997	Nanoparticle	easily penetrate the arterial wall without causing injury, making them biocompatible and effective for treating restenosis.
2000	Liposome with hyperthermia as nanoparticle	Useful in treatment of Human Cancer.
2002	Transferrin mediated receptor endocytosis	Transferrin receptors help in iron uptake, and by regulating their expression, anticancer drugs can be delivered specifically to tumor cells.
2012	Silver nanoparticles	Used in treatment of Malaria, Dengue fever, Filariasis.
2022	1-Iridiumoxide NPs 2-Chitosan nanoparticles	Nanoprobes have shown effectiveness in healing studies by continuously suppressing tumor growth.

		Neuroprotective agents can also be incorporated into nerve guidance conduits (NGCs) and delivered to the brain through nanoparticles.
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IX. FUTURE PERSPECTIVE [10]

One of the major challenges in applying nanotechnology for cancer therapy is the development of next-generation nanocarriers capable of precise tumor targeting through ligand–receptor interactions. However, barriers such as limited expertise, difficulty in crossing cell membranes, narrow therapeutic windows, regulatory concerns, and high costs still exist. Despite these hurdles, nanocarriers have shown improved therapeutic outcomes in animal models, and several clinical trials are underway. To ensure safe and effective use, standardized nano formulations with validated efficacy and safety profiles are essential for successful clinical translation.

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