IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, October 2026
Impact Factor: 8.2

Nanotechnology in Pharmaceutical Sciences: Role of Nanoparticles in Drug Delivery

Pandit Harshal Sunil[1], Kedari Om Shivaji[2], Gaikwad Vaishnavi Dattatray[3], Ponde Punam Chandrakant[4], Deshmukh D. B[5], Unde R. S[6]
Mrs. Saraswati Wani College of D Pharmacy Ganegaon, Rahuri, Ahilyanagar[1,2,3,4]
Guide, Mrs. Saraswati Wani College of D Pharmacy Ganegaon, Rahuri, Ahilyanagar[5,6]

Abstract: *Nanoparticles are nanoscale materials whose physicochemical properties can be tailored for pharmaceutical and biomedical applications. Their high surface-area-to-volume ratio and modifiable surfaces make them promising carriers for protecting active ingredients, modifying drug release, and supporting delivery to selected tissues or cells. This narrative review summarizes commonly used nanoparticle synthesis methods, including chemical reduction, co-precipitation, sol–gel processing, hydrothermal synthesis, microemulsion, and green or biological synthesis. It also discusses interactions with extracellular environments and mechanisms of intracellular uptake, followed by an overview of polymeric nanoparticles, lipid nanoparticles, solid lipid nanoparticles (SLNs), gold nanoparticles, and magnetic nanoparticles. Purification, pharmaceutical applications, potential benefits, and safety limitations are considered. Nanoparticle systems may support drug delivery, imaging, antimicrobial research, and other biomedical applications; however, their performance depends on composition, size, surface properties, formulation, and route of administration. Toxicity, environmental fate, manufacturing cost, scale-up, and incomplete knowledge of long-term effects remain important challenges. Further progress requires reproducible synthesis, rigorous characterization, appropriate safety assessment, and evidence that a formulation offers a meaningful advantage over conventional approaches. [4,14]*

Keywords: Nanoparticles; nanotechnology; drug delivery; green synthesis; intracellular uptake; polymeric nanoparticles; lipid nanoparticles; nanomedicine

I. INTRODUCTION

Nanoparticles are particles with dimensions commonly described within the approximate range of 1–100 nm, although definitions can vary by material and application. At this scale, surface effects and size-dependent physicochemical properties can influence dispersion, optical behavior, biological interactions, and transport through tissues. Metallic and metal-oxide nanoparticles—including copper, silver, zinc, magnesium, titanium, gold, and iron oxide systems—have been investigated for a range of technological and biomedical uses. [1,4,14]

In pharmaceutical sciences, nanoparticles are studied as carriers for drugs and other therapeutic or diagnostic agents. Depending on their composition and surface properties, they may protect active ingredients from degradation, modify release, improve the apparent solubility of selected compounds, or influence interactions with biological barriers. These benefits are formulation-dependent and should not be assumed for every nanoparticle system [4,14].

It is a narrative review based on the topics and references provided in the source document, not a report of original experimental results.

II. SYNTHESIS OF NANOPARTICLES

Nanoparticles can be made using chemical, physical, or biological methods. [2,3,7,8,9,10,17]

The choice of method depends on the required composition, size and shape of the nanoparticles, surface properties, purity, cost, and the intended use. Chemical methods allow more control over the process but may require steps to

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, October 2026
Impact Factor: 8.2

remove leftover chemicals or solvents. Green and biological methods use plant extracts, microorganisms, or biomolecules and can reduce the need for some traditional chemicals; however, factors like consistency, purity, and safety still need to be checked. [2,3,8,9,10,14]

2.1 Common Methods

a) Chemical reduction: metal ions are converted into nanoparticles; silver and gold are common examples. [3,10]
b) Co-precipitation: compounds are formed as a solid from a solution under controlled conditions; this is often used to make iron oxide nanoparticles. [14]
c)Sol–gel method: a solution containing a precursor becomes a sol and then a gel, allowing the preparation of materials like silica and metal oxides. [17]
d)Hydrothermal synthesis: reactions happen at high temperature and pressure in a sealed container and are used to create various crystalline nanomaterials. [14,17]
e) Microemulsion method: nanoscale droplets create a confined environment where reactions occur, influencing how nanoparticles form and grow. [7]
f) Green synthesis: plant-based or microbial compounds help in reducing or stabilizing nanoparticles; examples include systems like silver, gold, and zinc oxide. [8,9,10]
g) Biological synthesis: microorganisms or biomolecules are involved in nanoparticle creation, such as silver and gold nanoparticles. [2,3,11,12,13]

III. GREEN SYNTHESIS OF NANOPARTICLES

Green synthesis is of interest in pharmaceutical and biomedical research because it can minimize the use of certain harmful chemicals. [8,9,10]
Plant extracts, fungi, bacteria, and isolated biomolecules may contain substances that act as reducing or stabilizing agents. The role of each component depends on the biological source and the reaction conditions. [8,9,10,11,12]
Phytochemicals such as phenolic compounds, flavonoids, terpenoids, proteins, and other substances may help in reducing or stabilizing the surface of nanoparticles. [8,9,10]
Important factors in this process include the concentration of the precursor, the ratio of extract to precursor, pH, temperature, reaction time, and mixing. These variables can affect the size, shape, aggregation, and stability of the nanoparticles. Green synthesis should not be assumed to be non-toxic; the final product still needs proper chemical and toxicological evaluation. [8,9,10,11,12]

IV. EXTRACELLULAR INTERACTIONS AND INTRACELLULAR UPTAKE

The behavior of nanoparticles in a biological system depends on factors like size, shape, surface charge, composition, coating, aggregation, and how they interact with proteins and other biomolecules. [4,13,14]
Extracellular interactions refer to events that happen outside cells, while intracellular uptake refers to how nanoparticles enter cells. [4,13,14]

4.1 Extracellular Interactions

Nanoparticles also release drugs outside a cell; these drugs can then enter the cell through their own transport or by spreading through the cell membrane. These events influence how nanoparticles are distributed, cleared from the body, and reach cells. [4,13]

4.2 Intracellular Uptake

Endocytosis is a primary way nanoparticles enter cells and can occur through various pathways such as Cathrin-mediated uptake, caveolae-mediated uptake, micropinocytosis, or phagocytosis in certain cell types. [4,13]

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, October 2026
Impact Factor: 8.2

Once inside the cell, nanoparticles may pass through endosomes and lysosomes, stay within cellular compartments, release their content, or reach other parts of the cell depending on how they are designed. Receptor-mediated uptake and direct interaction with the cell membrane may also play a role in specific situations. [4,13]

Cell-surface interaction → Entry into the cell via endocytosis → Movement within the cell → Release of content or localization of nanoparticles [4,13]

A delivery system should place a sufficient amount of active substance at the right location while minimizing unwanted exposure and toxicity. [4,14]

V. TYPES OF NANOPARTICLES IN PHARMACEUTICAL RESEARCH

5.1 Polymeric Nanoparticles

Polymeric nanoparticles are developed using biodegradable or biocompatible polymers. [4,14]

A drug can be dissolved, enclosed, or attached either inside or on the surface of these particles. Examples of such polymers are PLGA, PLA, PCL, chitosan, and alginate. These nanoparticles are useful in providing controlled drug release, protecting unstable drugs, and enabling targeted or transdermal delivery. Their effectiveness depends on factors like the chemical makeup of the polymer, the physical characteristics of the particles, and how they break down in the body. [4,14]

5.2 Lipid Nanoparticles

Lipid nanoparticles are small-sized structures primarily made up of lipids and are used to transport various substances including small molecules and nucleic acids. [4,14]

They can consist of ionizable lipids, phospholipids, cholesterol, and PEG-lipids. Their performance is influenced by the composition of the formulation, how well the drug stays inside the particles, their stability, how they distribute throughout the body, and how well they are tolerated. [4,14]

5.3 Solid Lipid Nanoparticles (SLNs)

Solid lipid nanoparticles use a solid lipid matrix that stays solid at room temperature and at body temperature. [4,14]

Commonly used lipids include glyceryl monostearate, stearic acid, and acetylpalmitate. These nanoparticles are being studied for protecting drugs and modifying their release through various routes such as oral, topical, ophthalmic, and more. However, they might have limitations in loading certain drugs and could lead to drug release during storage. [4,14]

5.4 Gold Nanoparticles

Gold nanoparticles (AuNPs) are made of gold at the nanoscale. [15]

Their unique optical properties and the ability to modify their surface have led to their use in imaging, biosensing, targeted drug delivery, and photothermal therapy. Their behavior in the body is affected by their size, shape, surface coating, and the dosage. However, findings from laboratory settings do not necessarily confirm their effectiveness in clinical settings.[15]

5.5 Magnetic Nanoparticles

Magnetic nanoparticles respond to an external magnetic field and are often made from iron oxide substances like magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3). [14,16]

These particles can be modified on their surface to help in attaching drugs or targeting molecules. They are being studied for applications such as magnetic resonance imaging, magnetic hyperthermia, biosensing, and magnetic assistance in drug delivery. Their performance is influenced by their characteristics, the strength of the magnetic field, how deep they reach in the body, and how they are cleared by the body. [14,16]

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, October 2026
Impact Factor: 8.2

Other important systems, such as nanostructured lipid carriers, dendrimers, and silver nanoparticles, are also used in pharmaceutical investigations. [4,14]

Nanostructured lipid carriers mix solid and liquid lipids; dendrimers are highly branched molecules with numerous functional groups on their surface; silver nanoparticles are primarily studied for their antimicrobial properties. For all these systems, their effectiveness and safety depend on the formulation and the conditions under which they are used. [4,14]

VI. PURIFICATION AND PREPARATION CONSIDERATIONS

Once the nanoparticles are synthesized, purification might be necessary to eliminate unreacted materials, free drugs, salts, solvents, extra polymers, and other impurities. [4,14]

The purification method depends on the size, density, surface chemistry, viscosity, and the nature of impurities. Gel filtration or size-exclusion techniques separate components based on their size. [4,14]

While this method is effective, it can be time-consuming and may not remove all large impurities. Ultracentrifugation separates particles based on how they settle. This method can be time-consuming and may cause particle aggregation or loss if the conditions are not properly controlled. [4,14]

After purification, appropriate characterization techniques should be used. [4,14]

These include UV–visible spectroscopy to study optical properties, FTIR to examine functional groups and surface interactions, X-ray diffraction to analyze crystalline structure, SEM/TEM to study the shape and size of particles, dynamic light scattering to measure size and distribution, zeta-potential measurement to determine surface charge, and elemental analysis when necessary. The selection of these techniques should be based on the specific material being studied. [4,14]

VII. APPLICATIONS AND POTENTIAL ADVANTAGES

a) Drug delivery: suitable carriers can help adjust the release of drugs and improve the dispersal of poorly water-soluble compounds. [4,14]

b)Protection of active ingredients: encapsulation can reduce the exposure of sensitive compounds to environmental factors that might degrade them. [4,14]

c)Targeted delivery: surface features or physical properties can enhance interaction with certain tissues, although complete targeting is rare. [4,14]

d)Cancer research: nanoparticles are being studied for use in delivering anticancer drugs, for imaging, photothermal therapy, and magnetic hyperthermia. [4,15,16]

e) Antimicrobial research: silver nanoparticles and other nanomaterials are being explored for use in antimicrobial coatings and related applications. [10,11,12]

f) Nucleic acid delivery: certain lipid and polymer-based systems are being developed to transport RNA, DNA, or other genetic materials. [4,14]

g) Non-pharmaceutical uses: nanomaterials are also being examined for environmental cleanup, water treatment, agricultural applications, energy storage, and advanced materials. These are potential or under investigation uses rather than confirmed clinical benefits. [22,23,24,25]

VIII. DISADVANTAGES, SAFETY, AND TRANSLATION CHALLENGES

Nanoparticles can pose different risks compared to the same materials in bulk form or in free form. [14,26,27]

Toxicity may vary based on the composition, size, shape, surface charge, coatings, impurities, dosage, route of administration, and the length of exposure. Potential issues include oxidative stress, inflammation, unexpected interactions with cells, accumulation in organs, and environmental persistence. Long-term effects of certain materials are still unclear. [14,26,27]

The use of specialized equipment and strict process controls can raise the cost of development. [4,14]

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, October 2026
Impact Factor: 8.2

When scaling up production, changes in size distribution, drug loading, or stability may occur. For pharmaceutical products, ensuring batch consistency, proper sterilization, storage conditions, packaging, and regulatory approval are essential. Managing environmental impact and worker exposure also requires careful risk assessment. Ethical and privacy issues must be addressed when nanotechnology is used in monitoring or surveillance contexts. [4,14,26,27]

IX. FUTURE PERSPECTIVES

Future studies should focus on achieving consistent synthesis methods, clearly defined surface chemistry, scalable manufacturing processes, and reliable analytical techniques. [4,14,26,27]

More research is needed to better understand how protein coronas form, how nanoparticles move inside cells, the relationship between material properties and biological effects, methods for predicting toxicity, and the long-term impact on the environment. In drug development, progress should be judged by clear improvements compared to existing treatments, along with acceptable levels of safety and ease of production. [14,26,27]

X. CONCLUSION

Nanoparticles are valuable materials in pharmaceutical research because their composition and surface characteristics can affect drug delivery, release, interactions with the body, and imaging capabilities. [4,14]

Different synthesis methods—chemical, green, and biological—each have their own benefits and drawbacks. Various types of nanoparticles, such as polymeric, lipid-based, metallic, and magnetic, have unique properties rather than a single best option. Developing these into dependable medicines requires thorough characterization, effective purification, safety testing, consistent results, and proof of clinical benefits. [4,8,9,10,14,15,16]

REFERENCES

1. Dubchak S, Ogar A, Mietelski JW, Turnau K. Influence of silver and titanium nanoparticles on arbuscular mycorrhiza colonization and accumulation of radiocerium in Helianthus annuus. Spanish Journal of Agricultural Research. 2010;8(1):103–108.

2. Konishi Y, Uruga T. Bio reductive deposition of platinum nanoparticles on the bacterium Shewanella algae. Journal of Biotechnology. 2007; 128:648–653.

3. Ahmad N, Sharma S, Singh VN, Shamsi SF, Fatma A, Mehta BR. Biosynthesis of silver nanoparticles from Disodiumtrifolium: a novel approach towards weed utilization. Biotechnology Research International. 2011; 2011:454090.

4. Kim BYS, Rutka JT, Chan WCW. Nanomedicine. New England Journal of Medicine. 2010;363(25):2434–2443.

5. Namaka et al. The source document lists a 2023 review titled “A review on nanoparticles: characteristics, synthesis, applications, and challenges”; full bibliographic details require verification.

6. Srinivasan and Rana. The source document lists “Nanoparticles: synthesis and applications” (2024); full bibliographic details require verification.

7. López-Quintela MP, Rivas J. Foundational work on controlling nanoparticle growth using microemulsions (1993); full title and publication details require verification.

8. A review on green synthesis of nanoparticles and their diverse biomedical and environmental applications. Catalysts. 2022;12(5):459. Verify author list and DOI.

9. Biosynthesis of gold nanoparticles: a green approach. Journal of Photochemistry and Photobiology B: Biology. 2016; 161:141–153. Verify author list and DOI.

10. Rafique M, Sadaf I, Rafique MS, Tahir MB. A review on green synthesis of silver nanoparticles and their applications. Artificial Cells, Nanomedicine, and Biotechnology. 2017; 45:1272–1291.

11. Kalimuthu K, Babu RS, Venkataraman D, Bilal M, Gurunathan S. Biosynthesis of silver nanocrystals by Bacillus licheniformis. Colloids and Surfaces B: Bio interfaces. 2008; 65:150–153.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, October 2026
Impact Factor: 8.2

12. Nanda A, Saravanan M. Biosynthesis of silver nanoparticles from Staphylococcus aureus and its antimicrobial activity against MRSA and MRSE. Nanomedicine: Nanotechnology, Biology and Medicine. 2009; 5:452–456.
13. Narayanan KB, Sakthivel N. Biological synthesis of metal nanoparticles by microbes. Advances in Colloid and Interface Science. 2010; 156:1–13.
14. Khan I, Saeed K, Khan I. Nanoparticles: properties, applications and toxicities. Arabian Journal of Chemistry. 2019; 12:908–931. Verify pagination and DOI.
15. Rad AG, Abbasi H, Afzali MH. Gold nanoparticles: synthesizing, characterizing and reviewing novel application in recent years. Physics Procedia. 2011;22:203–208.
16. Zhuang J, Gentry RW. Environmental application and risks of nanotechnology: a balanced view. In: Biotechnology and Nanotechnology Risk Assessment: Minding and Managing the Potential Threats around Us. ACS Publications; 2011. Verify chapter details.
17. Bokova D, et al. Nanomaterial by sol-gel method: synthesis and application. 2021. Full journal and publication details require verification.
18. Ugemuge N, et al. Synthesis and luminescence study of silicate-based phosphors for energy-saving light-emitting diodes. In: Energy Materials. 2021. Full publication details require verification.
19. Cao Y, et al. Laser micro/nano-fabrication techniques and their applications in electronics. In: Advances in Laser Materials Processing. 2010. Full publication details require verification.
20. Khan I, Saeed K, Khan I. A review on nanoparticles: characteristics, synthesis, applications, and challenges. The source document lists Frontiers in Microbiology (2023); verify journal, year, and DOI.
21. Jha S, Kori A, Patil SM. A review on nanoparticles. International Journal of Pharmaceutical Sciences. 2024. Verify journal title, volume, issue, pages, and DOI.
22. Pomerantseva E, Bonaccorso F, Feng X, Cui Y, Gogotsi Y. Energy storage: the future enabled by nanomaterials. Science. 2019;366(6468): eaaw8285.
23. Santhosh C, Velmurugan V, Jacob G, Jeong SK, Grace AN, Bhatnagar A. Role of nanomaterials in water treatment applications: a review. Chemical Engineering Journal. 2016; 306:1116–1137.
24. Kah M, Kookana RS, Gogos A, Bucheli TD. A critical evaluation of Nano pesticides and Nano fertilizers against their conventional counterparts. Nature Nanotechnology. 2018;13(9):677–684.
25. Odegard GM, Griffith DN, King JA, Schulz MJ. Carbon nanotube materials for aerospace applications. NASA Technical Reports. 2020. Verify report number and URL.
26. Xuan L, Ju Z, Skonieczna M, Zhou PK, Huang R. Nanoparticles-induced potential toxicity on human health: applications, toxicity mechanisms, and evaluation models. MedComm. 2023;4(4): e327.
27. Human and environmental impacts of nanoparticles: a scoping review of the current literature. BMC Public Health. 2023;23:1059. Verify authors and DOI.