



General Introduction

1.1: Nanomaterials

Nanotechnology is a field that focuses on materials at a very small scale, dealing with structures at the atomic and bulk levels. The term 'nano' comes from the Greek word meaning 'dwarf,' emphasizing the extremely small scale involved.

In 1959, physicist Richard Feynman delivered a talk titled "There is plenty of room at the bottom," suggesting that arranging atoms in specific patterns could synthesize any chemical substance [1]. This sparked significant scientific creativity. In 1986, K. Eric Drexler envisioned nanoscaled robot assemblers in his book "Engines of Creation," predicting a transformative era for nanotechnology at that time [2].

One of the first and most important questions is "Why nanomaterials?" as their extremely small size makes handling and formation more complicated. The main answer is that such small materials impart a high surface area-to-volume ratio, making them highly reactive and allowing for more interactions with surrounding materials [3,4]. Scientists have proved that nanomaterials (particles that are smaller than 100 nm) exhibit unique properties such as high electrical conductivity, transparency, low thermal expansion, and mechanical strength. Due to their small size and large surface area compared to bulk materials, exhibit entirely new and improved properties which make nanomaterials valuable across various fields of chemistry, physics, material science, microelectronics, biology, and technology [5]. Smart nanomaterials with improved properties, finding applications in diverse areas, as shown in Figure 1.1.

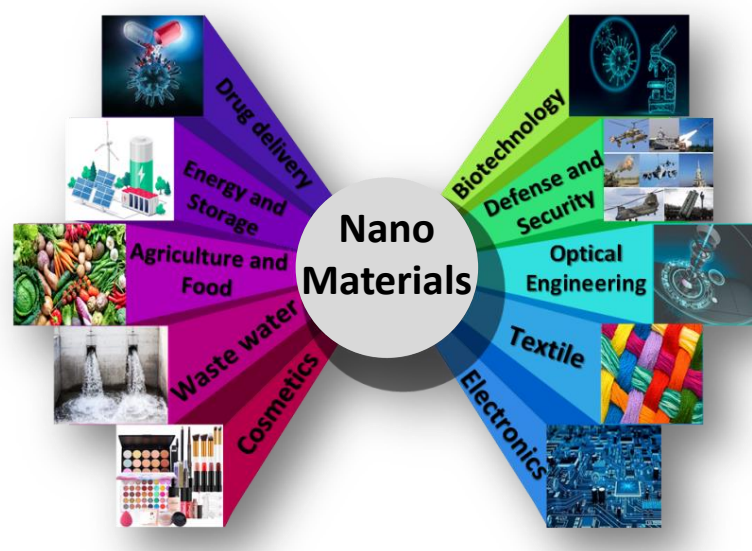


Figure 1.1: Applications of nanomaterials

Nanomaterials in which most important “nanoparticles (NPs)” can be broadly categorized as organic (like carbon NPs or fullerenes) and inorganic (such as semiconductor NPs like titanium oxide and zinc oxide, magnetic NPs, and noble metal NPs like gold and silver [6]). The properties of NPs, including shape, size, and morphology, play a very crucial role. NPs have their specific and controllable properties, which differ from larger particles on a macroscopic scale. The change in NPs properties is influenced by two main effects: the surface effect or size reduction effect and the quantum confinement modification in electronic structure [7]. Nowadays, researchers highly work on metal nanoparticles (MNPs) for the development of sustainable and economical processes.

1.2: Metal Nanoparticles (MNPs)

According to the American Society for Testing and Materials (ASTM) and the European Union (EU), a nanomaterial is defined as any natural or human-made material that has particle sizes mostly in between 1 and 100 nm [8]. Nowadays, with high demand and quick responses of newer nanomaterials for devices based on nanotechnology, the development of MNPs flourishes at a high pace.

The most noticeable and vital characteristic of MNPs is their particle size. As much as reduction in the size of materials leads to significant changes in their physical and chemical properties. At the nanoscale, the quantum confinement effects and surface effects are quite dominant, giving very unique properties. Size and shape control is a most important affair in the research of MNPs. Scientists can precisely design the structure of MNPs like spheres, rods, triangles, cubes, or more complex geometries [9]. MNPs exhibit high surface area relative to their volume. The high surface area of MNPs makes them extremely effective for catalysis and adsorption, as more active sites are available for chemical reactions and molecule adsorption [10], as well as sometimes it leads to increased reactivity and potential toxicity, which is difficult for their use in biomedical and environmental applications.

MNPs have significant roles in catalysis. Their small size, unique electronic structure, and the ability to facilitate reactions on their surfaces make them exceptional catalysts for a variety of chemical transformations. Their involvement is crucial in sustainability and enhancing efficiency. The inherent nature of MNPs sometime very useful in biomedical and catalytic development [11]. Figure 1.2 shows the various MNPs and their specified applications.

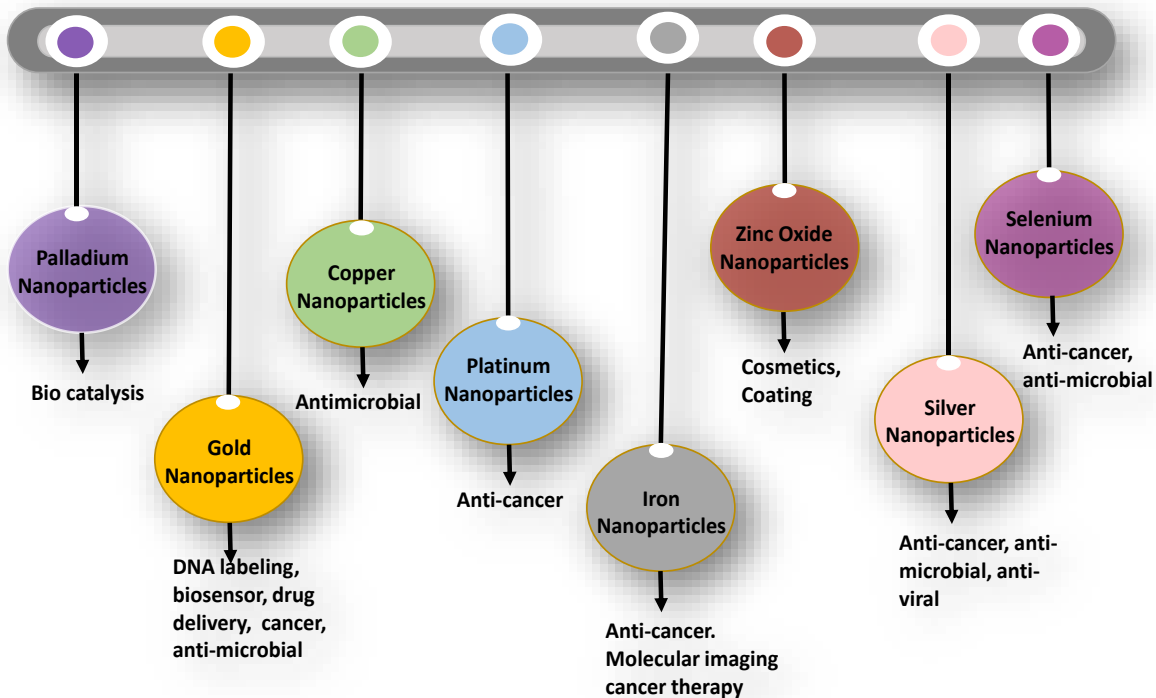


Figure 1.2: MNPs and their applications

In biomedical applications, gold nanoparticles (AuNPs) have been used particularly against many valuable formulations and devices [12]. The AuNPs are also utilized in genetic disease treatment and diagnosis, tumor detection, photothermal therapy, and photoimaging. Not only that, it was functionalized with biomolecules to establish targeted drug delivery systems as well as for visualization of biological structures and processes [13, 14]. Iron oxide nanoparticles (FeO/Fe₂O₃NPs) are used in the treatment of cancer, hyperthermia (heat treatment for diseases), immunoassays, tissue repair, magnetically responsive drug delivery, and magnetic resonance imaging (MRI) [15]. Silver nanoparticles (AgNPs) are known for their applications in wound treatment and other antimicrobial, anti-inflammatory, and anticancer activities [16].

The use of MNPs makes a revolution in electronic device development. The distinct electrical properties with nanosize make them good candidates for building next-generation electronic components and sensors that are more powerful and energy-efficient with advanced computing and communication to sensing and data storage [17]. MNPs are being explored for their potent role in energy applications, from catalysis in fuel cells to photocatalysis for solar energy conversion [18]. Many environmental problems are significantly addressed through MNPs, such

as the removal of contaminants from water and soil with adsorption and catalytic degradation processes, as well as hazardous compounds omitted from the effluent and surface water [19]. These MNPs, with their high sensitivity and selectivity, are essential components of a variety of sensors, including gas sensors for environmental monitoring, chemical sensors for industrial safety, and biosensors for medical diagnostics [20].

The MNPs can be fabricated through a variety of synthesis approaches, including radiation, thermal decomposition, microwave-assisted, electrochemical, photochemical, and chemical reactions methods. Utilizing biosources, such as plant extracts (leaf, stem, root, flower, bark, peels, twigs, seeds, etc.), fungi, enzymes, and bacteria, provides several advantages for the synthesis of MNPs [21]. The synthesis methods depend on the physical or chemical properties of precursor metals and MNPs.

1.3: Synthesis of MNPs

Potential uses of nanomaterials and nanostructures can only achieve when nanomaterials are synthesized with specific dimensions, shape, crystal microstructure, and chemical composition [22, 23]. In general, basic synthesis methods for MNPs have been understood for several decades.

MNPs are synthesized mainly by two ways: Top-down and bottom-up approaches. Figure 1.3 shows the various synthesis methods applied for the top-down and the bottom-up approach of MNPs fabrication [24]. The top-down approach involves the size reduction of bulk materials into smaller components to produce MNPs. This can be achieved by employing high-intensity ultrasonic generators, an electric arc within the liquid. Bottom-up approach involves the preparation of MNPs, either atom by atom or particle by particle. This can be achieved through the growth of nuclei after a high degree of supersaturation. Various chemical and physical synthesis methods have used by researchers for the synthesis of MNPs through top-down and bottom-up techniques. These include sol-gel [25], sono chemical [26, 27], pulsed electrochemical etching [28], the polyol method [29, 30], sputtering deposition [31], the microwave-assisted method [32, 33], laser ablation [34], lithography [35], and vapor deposition [36].

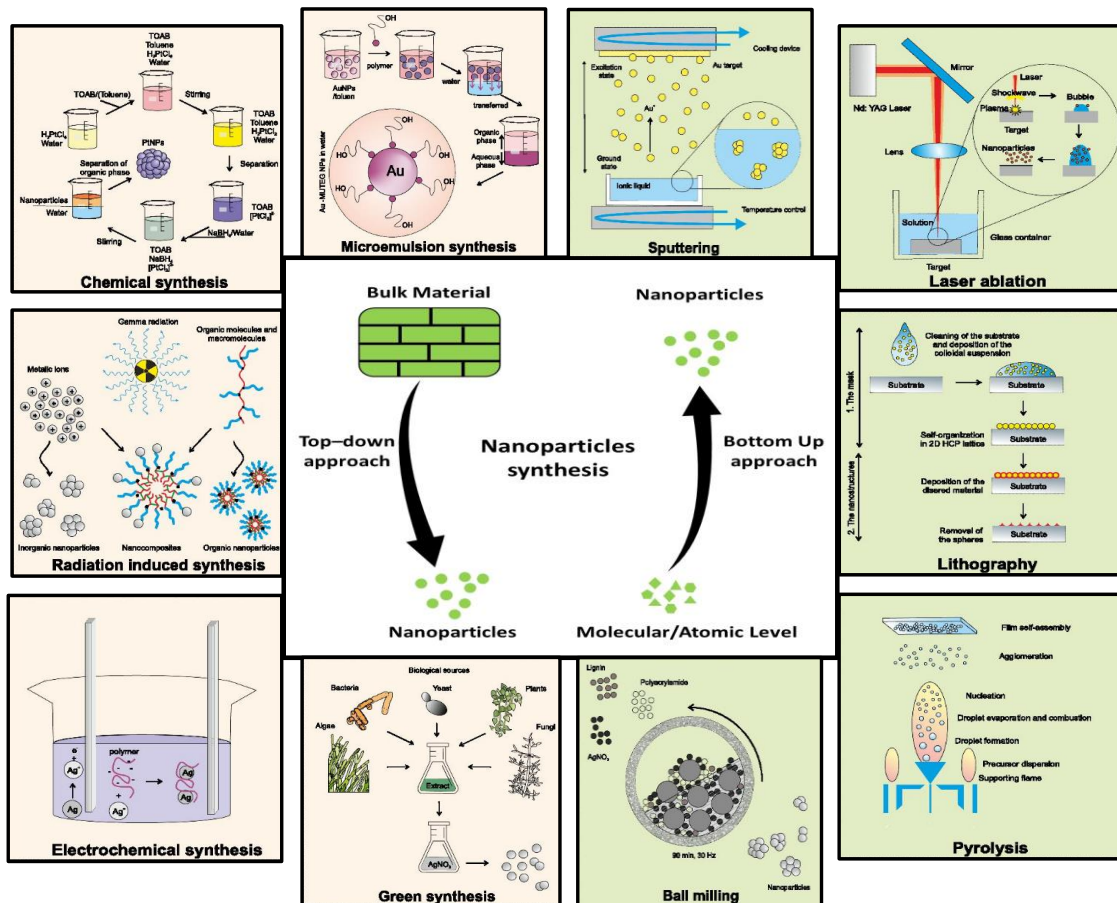


Figure 1.3: Top-down and bottom-up approaches of nanoparticle synthesis

To produce MNPs via chemical methods, sodium borohydride, dimethyl formamide, ascorbic acid, citric acid, and hydrazine are employed as reducing agents, along with polymers, surfactants, biomolecules, etc. as stabilizing agents. Furthermore, this approach requires various conditions, such as thermal, ultrasonication, microwave, and photo-emission effects [24]. Figure 1.4 shows one of the most exploited synthetic routes (bottom-up) of MNPs production from precursor metal salt solution. Here, it is clear that the reducing agent produces the nucleation, which grows to MNPs, and stabilizes through stabilizing agents like polymers, surfactants, etc.

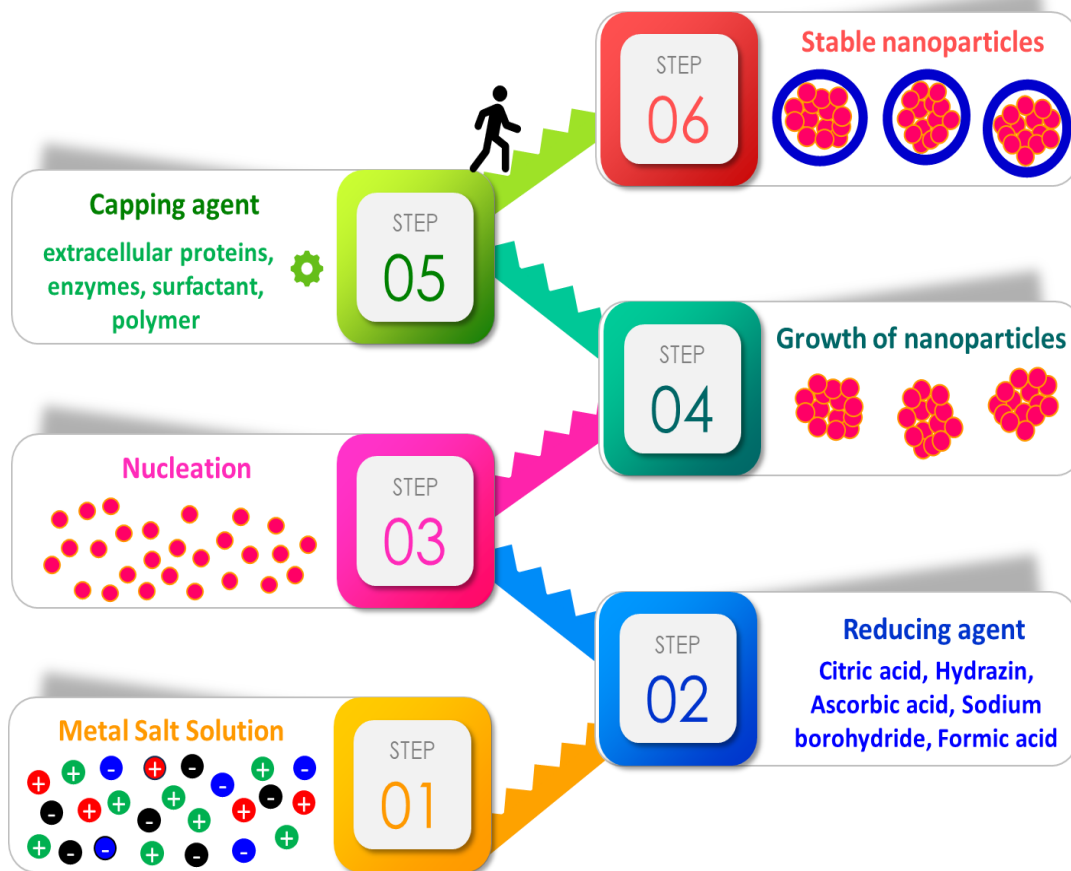


Figure 1.4: Synthetic route of MNPs production from metal salt solution.

Nowadays, polymers are also employed for the synthesis of MNPs, as such macromolecules with distinct properties favor the desired reactions, such as reduction and stabilization. The unique properties of polymers help to not only control the size of MNPs but also prevent against their aggregation.

1.4: Polymer mediated MNPs

The synthesis of MNPs requires precise control over their size, shape, and dispersability. Polymers with their long-chain molecular structure, functionality, and compact properties offer a better structured environment for the growth of MNPs. By modifying the properties of polymers, such as chain length or functional groups, one can tailor the MNPs to desired specifications as per the applications. To understand the importance and high efficiency of polymers in comparison to small molecules, researchers work on polymer mediated MNPs, which benefit

size control, shape management, and compatibility with other surrounding compounds in various fields of applications [37, 38].

Figure 1.5 depicts the number of research articles published on the topic "*Polymer mediated metal nanoparticles*" in the search engine of *Science Direct* for the last decade. It clearly proved the potent use of polymers (increasing trend) in the MNPs development for a variety of applications in chemistry, physics, biology, and material sciences.

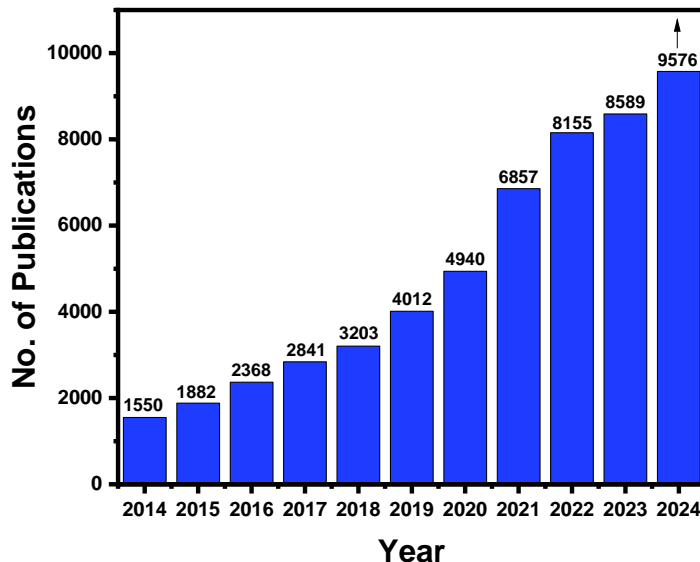


Figure 1.5: Research articles published in the browsing the topic "*Polymer mediated metal nanoparticles*" in the *ScienceDirect*[®]

As far as the crucial role of polymers in MNPs development is concerned, stabilizing MNPs is mostly proven with impactful results. MNPs are prone to aggregation due to their high surface energy, and when polymers are used as capping agents or stabilizers, they surround and shield the MNPs, which control the high surface energy of metal through coating and preventing MNPs to agglomerate. Such stabilizing effect through polymers is vital for maintaining the dispersibility and long-term stability of MNPs.

Polymers can be modified to have specific interactions with MNPs, which influencing their behavior. For instance, functional groups on the polymer chains can promote or inhibit the growth of nanoparticles, leading to controlled nucleation and growth processes. These interactions can be finely tuned to achieve desired characteristics in the developing MNPs based nanomaterial. Polymers can also modify the surface chemistry of MNPs to introduce specific chemical groups or ligands that enhance the reactivity or compatibility of the nanomaterials in

various applications [39, 40]. The interplay between polymers and MNPs creates a host of intriguing phenomena.

Polymer mediated MNPs often exhibit enhanced properties compared to MNPs alone. Figure 1.6 displays the distinguishing nature of polymer mediated MNPs when synthesized with polymer and MNP characteristics as individuals. In polymer mediated MNPs, the polymer matrix can introduce additional functionalities, such as improved mechanical strength, increased biocompatibility, or enhanced electrical conductivity [41, 42]. This combination of polymer and MNP properties opens up new possibilities for a wide range of applications.

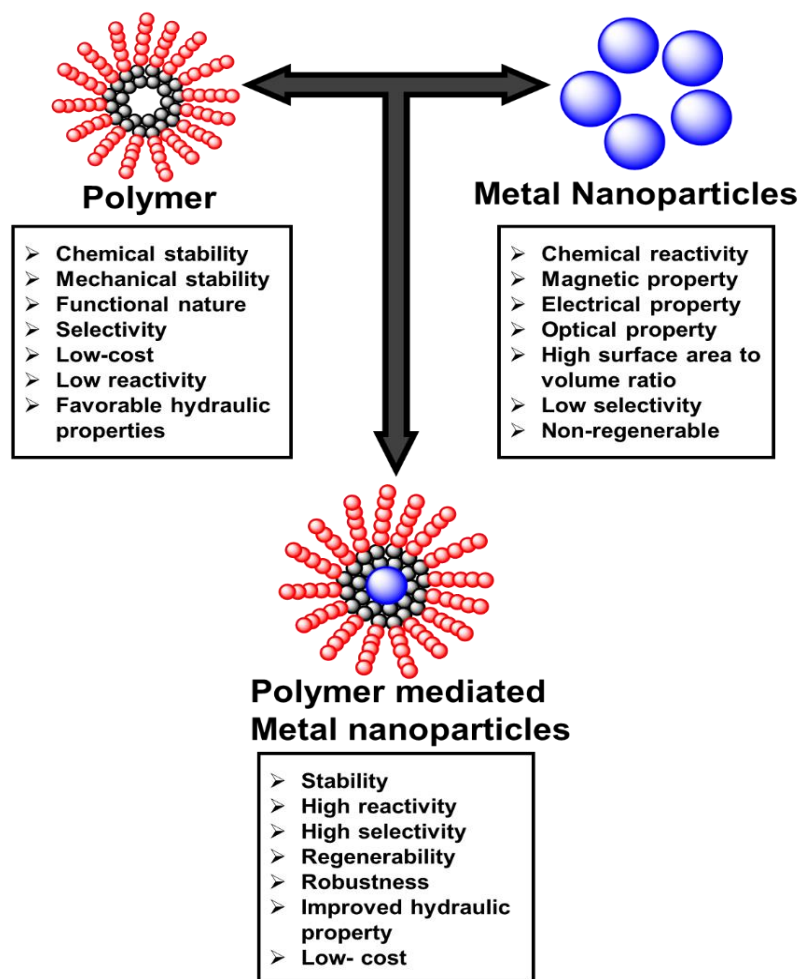


Figure 1.6: Polymer mediated MNPs with enhancement of their properties

In recent advancements in the analysis techniques, the quality characterization of nanomaterials confirmed the desirability of material for appropriate applications. The characterization of nanomaterials, specifically polymer mediated MNPs, is made comprehensive information about their behaviour [43]. In characterization methods, UV-Vis spectroscopy and fluorescence

spectroscopy are quite employed for the plasmonic and luminescent behavior of the MNPs. Optical techniques, TEM and SEM, along with scattering DLS techniques, are often employed to determine the size, shape, and morphology of the MNPs, providing insights into the structural integrity and uniformity of the polymer mediated MNPs. Spectroscopic methods like, FTIR and XPS, play a vital role in elucidating the chemical composition, surface chemistry, and electronic properties of polymer mediated MNPs. These techniques enable the identification of surface functional groups, chemical bonding interactions, and the electronic state of the metal atoms, which collectively influence the reactivity and stability of MNPs. Furthermore, the crystalline structure and molecular arrangement of MNPs are well characterized by XRD. Not only that, the TGA and DSC are utilized to investigate the thermal stability, degradation behavior, and melting characteristics of the polymer mediated MNPs. Understanding the thermal properties of nanomaterials is crucial for assessing their performance and durability under different environmental conditions. Moreover, rheological measurements, such as viscosity and elasticity analysis, comprehend the dispersion and flow properties of polymer mediated MNP suspensions, which are crucial for their processability and applications in various fields. Figure 1.7 shows the applications of polymer mediated MNPs.

Applications of polymer mediated MNPs

Biomedical applications: Chitosan, polycaprolactone, alginate and block copolymers (Pluronic) mediation developed the potent MNPs which have revolutionized various aspects biomedical sciences. Polymer mediated MNPs are extensively used in drug delivery systems, imaging, diagnostics, and therapeutics. AuNPs coated with biocompatible polymers have shown promise in targeted drug delivery, cancer therapy, and bioimaging due to their high surface area-to-volume ratio and tunable surface chemistry. Salem, S.S. et al. [44] synthesized chitosan mediated AuNPs and used for the antimicrobial and wound healing activity. Dos Santos, E.A. et al. [45] prepared Pluronic assisted AgNPs and applied for the potent antimicrobial applications.

Catalysis: MNPs supported on polymer matrices serve as highly efficient catalysts due to their large surface areas and unique surface properties. They find applications in various catalytic processes, such as hydrogenation, oxidation, and organic synthesis. These MNPs offer increased catalytic activity, selectivity, and stability, making them valuable in industrial processes [46]. Zhang, Y. et al. developed Cu-Ag bimetallic nano-catalyst using polyvinyl alcohol (PVA) polymer and successfully used for catalytic reduction of 4-nitrophenol to 4-amino phenol [47].

Sensors and electronics: Polymer mediated MNPs are integral components in the development of sensors for detecting various analytes, including gases, biomolecules, and pollutants. Their exceptional sensitivity and selectivity make them suitable for creating advanced sensing platforms. Additionally, these nanomaterials are utilized due to their enhanced electrical and mechanical properties in flexible electronics, conductive coatings, and printed electronics. Pitchumani, K. et al. developed alginate stabilized Agnanocube–Rh6G nanomaterials for the sensing applications for hazardous Hg metals in water [48].

Environmental remediation: MNPs embedded in polymer matrices are successfully employed in environmental remediation processes and utilized for the removal of pollutants (metals, dyes, and organic compounds) from water and air owing to their high surface reactivity and adsorption capabilities [49]. Jothivenkatachalam, K. et. al synthesised chitosan-TiO₂ nanocomposite materials and used as a photocatalyst for waste water treatment [50].

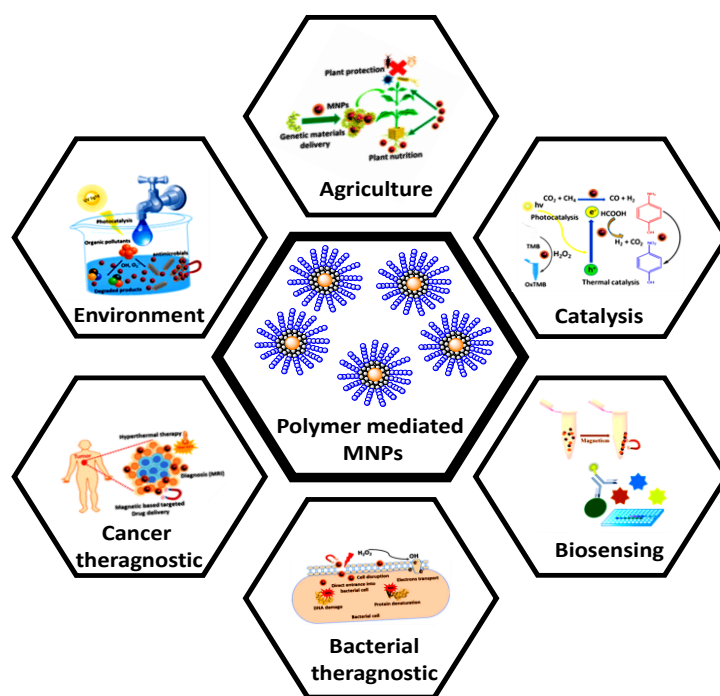


Figure 1.7: Polymer mediated MNPs and their application in various field.

Amongst polymers applied in MNPs development, triblock copolymer of polyethylene oxide and polypropylene oxide, Pluronic polymers (commonly poloxamers) is recently well utilized due to their amphiphilic nature.

1.5: Pluronic mediated MNPs

Pluronic is an amphiphilic copolymers that has significantly studied in the realms of materials science, nanotechnology, and biomedical applications. Their structure consists of hydrophilic PEO blocks connected to a hydrophobic PPO block and arranged in a $PEO_xPPO_yPEO_x$ pattern, where x and y represent the number of PEO and PPO blocks, respectively (Figure 1.8). The code naming for Pluronic[®], involves the use of the letters F, P, or L, which correspond to the physical state of these polymers, specifically solid, paste, and liquid. This is followed by a two or three-digit numeric code, denoting a specific identifier [51, 52]. The numeric codes are associated with the structural parameters, with the last digit representing PEO content in weight percent (e.g. 80% wt. if the digit is 8). Meanwhile, the initial one or two digits represent the molecular mass of the PPO, which requires multiplying the given number by 300. For example, the PO block of L65 has a molecular weight of 300 multiplied by 6, resulting in 1800 Da.

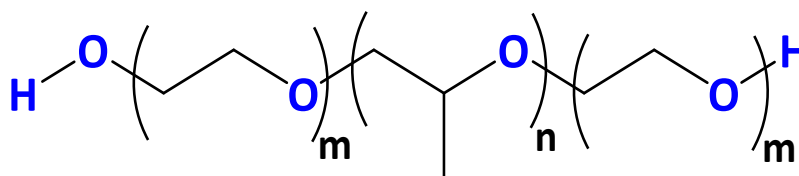


Figure 1.8: The molecular structures of Pluronic polymer

The Pluronic surfactants, with its water-attracting part (PEO) and water-repelling components (PPO), contributes to its versatility in various applications. The presence in the same molecule of both PEO and PPO blocks leads to the self-assembly in solutions (microscopic phase separation occurs because of the tendency to minimize the contact between the hydrophobic PPO parts and the aqueous polar medium) and their adsorption at surfaces and interfaces. Many Pluronic surfactants are approved by the Food and Drug Administration (FDA) and Environmental Protection Agency (EPA) for several applications, such as food additives, drug delivery carriers in cosmetics, pharmaceutical ingredients, and tissue engineering [52, 53]. Pluronic offers several advantages that have expanded its applications, particularly its high biocompatibility, making it well-suited for use in biomedical and pharmaceutical contexts.

One of the notable uses of Pluronic is in the reduction of metal salts into MNPs and stabilization of MNPs through capping.

MNPs are commonly synthesized in aqueous solutions through the chemical reduction of metal ions using reducing agents like NaBH_4 , citric acid, or ascorbic acid. This reduction occurs through the utilization of externally provided energy sources, such as photoirradiation, heating, or ultrasound irradiation in the presence of one or more water-soluble polymers, surfactants, or capping agents [54-56]. Precise control of the size and concentration of the dispersed particles can be attained, while the surface-modifying or capping agents restrict the aggregation of nanoparticles [57, 58]. The most frequently used approach to achieve colloidal stability involves chemically binding ligands to the surface of nanoparticles. However, a covalent bond between the ligand and the nanoparticle can change the properties of the nanoparticles by modifying their electronic density and the dielectric constant of the surrounding medium [59]. A strategy utilizing the physical adsorption of ligands, such as block copolymers, onto the surface of nanoparticles can effectively maintain the desired properties of the nanomaterial [60].

PEO-PPO-PEO block copolymers serve as effective stabilizers and reductants in the synthesis of MNPs from metal ions in water solutions. This method is environmentally friendly and economical, utilizing only water and non-toxic commercially available Pluronics. Depending on the concentration, molecular mass, and composition of the polymer, MNPs of various shapes can be produced, such as spheres, plates, prisms, and icosahedra [61, 62]. Compared to other synthesis methods, this polymer-based approach offers advantages such as speed, minimal reactants, cost-effectiveness, and immediate usability of the product, which is beneficial for diverse applications.

The formation of MNPs in the polymer solutions can be divided into three main stages: (1) the initial reduction of metal ions within crown-ether-like domains created by the PEO-containing block copolymer in a solution, (2) the absorption of the block copolymer onto the initially formed metal clusters, leading to localized reduction of metal ions on the surface of these clusters, leading to an increase in their size. (3) The growth of metal particles is then controlled by block copolymers and stabilized them, which determine their final size and shape. Although Pluronic with both PEO and PPO blocks play a role in reducing the metal ion (step 1), it seems that the contribution of PEO is more significant. During step 2, the block copolymers attach to the metal clusters' surface due to the amphiphilic nature of the copolymer, which arises from the hydrophobic properties of PPO. Their growth is restricted by the adsorption of the block copolymers due to their amphiphilic nature. According to the reaction mechanism, a longer

length of the PEO chain promotes the reduction of metal ion and the resulting formation of MNPs. PEO is capable of creating pseudo crown ether cavities that bind metal ions [63]. The reduction process of bound metal ions occurs when the metal center oxidizes the oxyethylene and oxypropylene segments [64, 65]. The PEO-PPO block copolymers, which are responsible for synthesizing the MNPs, also play a crucial role as colloidal stabilizers for the nanoparticle dispersions. The colloidal stability of the nanoparticle was found to increase with higher concentrations of polymer, longer PEO and PPO block lengths, or overall polymer length [66, 67].

Teixeira, Z. et al. [68] synthesized AuNPs were using a Pluronic F127 as both the reducing and stabilizing agent. The nanoparticle size (ranging from 2 to 70 nm) and stability were influenced by factors such as F127 concentration, temperature, and UV light exposure, monitored via UV-Vis spectroscopy and TEM. These Pluronic-capped AuNPs exhibited superior catalytic activity in the reduction of 4-nitrophenol to 4-aminophenol. Pellosi, D.S. et al. [69] developed multifunctional nanostructured systems by synthesizing Pluronic-based AgNP/MB nanohybrids using supramolecular chemistry principles. The nanohybrids enhanced MB's fluorescence and singlet oxygen production through resonant coupling between AgNPs and MB. Due to controlling the size/shape of the AgNPs and modulating the AgNP-MB distance within the Pluronic matrix, further improved MB's photophysical properties (shown in Figure 1.9). These findings highlight the potential of Pluronic AgNP/MB hybrids in advancing photodynamic therapy. Astilean, S. et al. [70] synthesized Ag nanoprisms coated by Pluronic with edge lengths of 30–50 nm and thicknesses of 4–6 nm. In vitro tests showed that Pluronic-coated Ag nanoprisms exhibited strong antibacterial effects against two methicillin-resistant *S. aureus* strains, with higher activity against the UCLA 8076 strain. These promising results suggest potential for further development of therapeutics based on Pluronic-coated AgNPs.

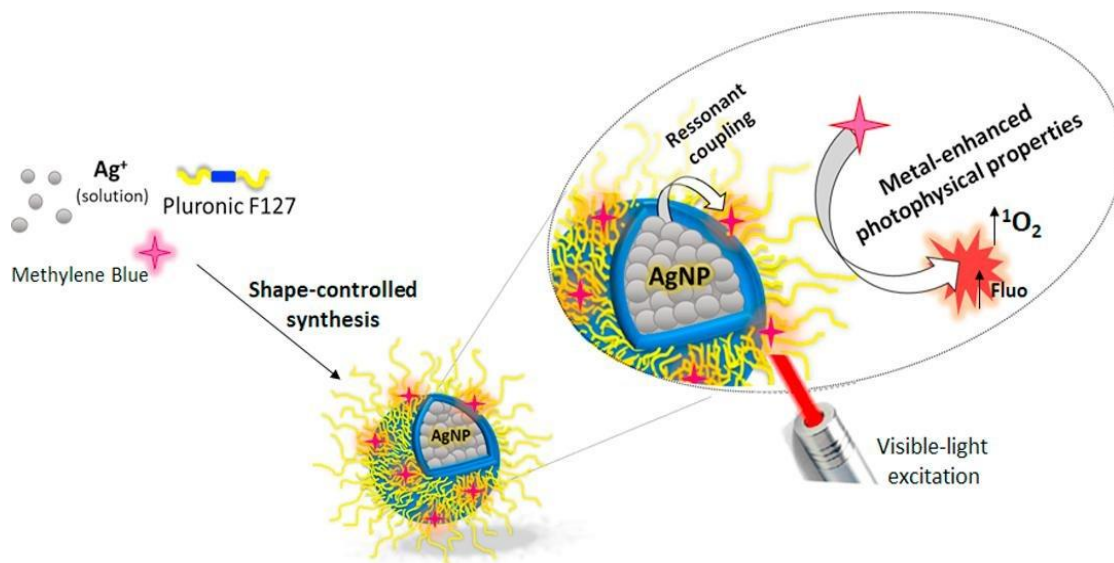


Figure 1.9: Synthesis of AgNPs using Pluronic as a size and shape controller. (The figure is authorized ©2020 Elsevier B.V. and article is cited as Ref.no.69)

The synthesis of CuNPs has attracted significant attention, particularly in comparison to the synthesis of other nanoparticles, due to their advantageous properties that can be achieved at a lower cost than silver and gold [71, 72]. Copper, along with other noble metals, demonstrates both thermal and electrical conductivity, making it suitable for utilization in electronic systems and conductive inks. Moreover, it possesses antimicrobial characteristics and is easily accessible [73, 74]. Various techniques can be employed for the synthesis of CuNPs, such as thermal reduction, metal-vapor synthesis, chemical reduction, vacuum vapor deposition, radiation methods, microemulsion techniques, polyol processes, and laser ablation [75, 76]. A significant restriction in the synthesis process is the tendency of the materials to oxidation, resulting in the formation of CuO or Cu_2O . This oxidation tendency poses a challenge in achieving the synthesis of CuNPs without the provision of an inert environment such as argon or nitrogen gas.

One of the pivotal results involves the development of methods for the synthesis of CuNPs through polymer-mediated approaches. These methods include chemical reduction, thermal decomposition, green synthesis, and other techniques [77, 78]. The choice of polymers as stabilizing agents or templates has enabled precise control over the size, shape, and dispersity of CuNPs. For example, polymers like Pluronic, PVP, PVA, PEG, and PVP-N have been instrumental in tailoring the size of CuNPs, from a few nanometers to larger dimensions, with

defined morphologies such as nanospheres, nanowires, or nanorods [79, 80]. Research efforts have focused on developing eco-friendly and scalable synthesis routes for polymer mediated CuNPs. Liu, J. et al. [81] presented a simple method for in-situ fabrication of highly luminescent and stable Cu-nano assemblies with uniform morphology by using Pluronic F127. The number of encapsulated CuNPs is controlled by adjusting the hydrophobic core size of the F127, while cross-linking with a multidentate thiol ligand enhances emission and stability. These properties make the Cu-nano assemblies suitable for potential biomedical applications. Amalraj, J. et al. [82] synthesized hydrogels with spherical CuNPs (around 8 ± 2 nm in size) were incorporated into a 1:1 chitosan-Pluronic F127. This hydrogel was used for the antimicrobial tests against *E. coli* and *S. aureus*. This hydrogel holds promise for antimicrobial and wound dressing applications.

Polymer mediated SiO₂NPs have also emerged as a significant area of research, offering a wide array of important results and applications across various scientific fields. These nanoparticles, with silica as the core material and polymers as stabilizers or surface modifiers, have demonstrated numerous impactful findings that contribute to diverse technological advancements.

The synthesis of SiO₂NPs through polymer mediated approaches allows precise control over their size, shape, and surface properties. Various polymers like Pluronic, PVP, PEG, polystyrene, and others serve as templates or stabilizing agents, influencing the nucleation and growth of SiO₂NPs. This control over size and morphology is crucial for applications in drug delivery, catalysis, coatings, and biomedical imaging [83, 84].

SiO₂NPs functionalized or coated with polymers have shown remarkable potential in catalysis and sensing applications. These nanoparticles with tailored surface properties exhibit enhanced catalytic activity and selectivity in various reactions [85, 86]. Additionally, their use in sensors benefits from the high surface area and ability to attach specific recognition molecules for detecting analytes in environmental or biological samples. Polymer-mediated SiO₂NPs offer a versatile platform for encapsulating and delivering various active compounds. The combination of silica's inertness with polymer coatings allows for the encapsulation of drugs, dyes, or functional molecules, offering protection and controlled release kinetics. This feature is essential for sustained drug delivery systems and other controlled release applications. Polymer mediated SiO₂NPs have also been explored for environmental applications, such as adsorption and

removal of contaminants from water and air. Their large surface area, tunable surface chemistry, and high adsorption capacity make them promising candidates for pollutant removal and remediation purposes [87, 88]. Wang, S. et al. [89] developed a novel drug delivery system by coating Pluronic P123 on mesoporous SiO₂NPs (MSNs) via hydrophobic interaction with octadecyl-modified MSNs. This nanoassembly with a disulfide bond (PSMSNs) exhibited redox-responsive drug release, enhancing therapeutic effects and reducing toxicity. This study confirmed improved drug release at both in vitro and cellular levels, while the P123 coating provided anti-metastatic properties. Lin, Y.S. et al. [90] synthesized and characterized magnetic silica nanocomposites (MSNCs) coated with Pluronic F127 and loaded with doxorubicin (DOX) for hepatocellular carcinoma (HCC) treatment. In this study, in-vitro tests showed MSNCs-F127 were biocompatible with HEK293T and HepG2 cells, while MSNCs-F127-DOX had a strong therapeutic effect on HepG2 cells, and in-vivo studies demonstrated significant tumor inhibition and increased cell apoptosis, highlighting the potential of MSNCs-F127-DOX as an innovative drug delivery system for cancer therapy.

With the understanding of the importance of the MNPs and role of Pluronic in MNP synthesis for their wider and newer applications in material chemistry, the present thesis research work includes the synthesis, characterization, and evaluation of newer Pluronic mediated MNPs and applied for enhanced antimicrobial as well as catalytic applications. Pluronic mediated MNPs (here, CuNPs) were investigated for common textile dye degradation. Pluronic mediated SiO₂NPs and use of them to synthesize chitosan-based SiO₂NPs biosorbents were studied for their potent applications in gas adsorption and common dye removal applications.

Our work comprises in chapters 2 to 6 materials, methods, characterization techniques, development of CuNPs, SiO₂NPs, and biosorbents and their successful applications in the above-mentioned applications.

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