

# A Comprehensive Review of Nanomaterials: Types, Synthesis, Characterization, and Applications

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**Abstract:** Nanotechnology has infiltrated all sectors due to its unique and evident impacts, which give the scientific community numerous breakthroughs in the medical, agricultural, and other domains. Nanomaterials (NMs) have risen to prominence in technological breakthroughs due to their adjustable physical, chemical, and biological characteristics and superior performance over bulk equivalents. NMs are divided into many categories based on size, composition, capping agents, form, and origin. The capacity to forecast NMs' unique features raises the value of each categorization. As the manufacturing of NMs and industrial uses grow, so does their demand. The purpose of this review is to compare synthetic and naturally occurring nanoparticles and nanostructured materials to determine their nanoscale characteristics and to identify particular knowledge gaps related to the environmental application of nanoparticles and nanostructured materials. The paper review includes an overview of NMs' history and classifications and the many nanoparticles and nanostructured materials sources, both natural and manufactured. Furthermore, the many applications for nanoparticles and nanostructured materials.

**Keywords:** nanotechnology; nanomaterials types; synthesis; characterization; application.

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## 1. Introduction

Nanotechnology is the process of manipulating the shape and size of structures, electronics, and systems at the nanometer scale, i.e., 1 nm to 100 nm ( $10^{-9}$ m) [1,2]. The unit of nanometer takes its prefix nano from the Greek word "nano" which means "very little" [3]. Their small size gives them more significant surface areas than the corresponding bulk forms, higher reactivity, and a tuneable nature of several properties [4-6]. These special properties have stimulated the growth of nanoscience and the application of NPs in a wide range of fields like biomedicine, cosmetics, electronics, analysis food, environmental and remediation, or paints [7-11]. Nanoscale science and engineering allow us to gain a new level of understanding and control matter at the atomic and molecular dimensions [12]. Nanoscale particles have gotten a lot of attention because of their remarkable electrical, optical, and magnetic properties [13]. These NPs have the dimensions that make them suitable candidates for nanoengineering [14,15]. The desire for novel technology applications in data storage, biomedical sciences, and drug delivery has fueled nanoparticle research [16-19]. Core/shell (CS) NPs, polymer-coated NPs, Ag-NPs, Cu-NPs, Au-NPs, Ni-NPs, Pt-NPs, CuO-NPs, ZnO-NPs, Pd-NPs, Si-NPs, FeO-

NPs, ZrO<sub>2</sub>-NPs, and TiO<sub>2</sub>-NPs are among the metal, metal oxide, and dioxide NPs recently enumerated in various published publications. Each of these NPs has its own set of characteristics and uses [20-23].

## 2. Capping Agents and Their Types

Capping agents (polymers, organic-ligands, surfactants) are essential in producing metal nanoparticles with precise size and form [24,25]. Their impact on the performance of nanomaterials-based catalysts, on the other hand, is complex and contentious. Indeed, capping agent can operate as both a "poison," reducing active site accessibility, and a "promoter," resulting in higher yields and unexpected selectivity control [26]. These events can be attributed to the formation of metal-ligand interphase, whose specific features are responsible for the catalytic action. As a result, knowing the structure of this interphase is crucial for optimizing the design of customized nanocatalysts [24]. Typical capping agents used in nanoparticles synthesis involve heteroatom functionalized long-chain hydrocarbons. Depending on the nature of the donor atom, they may be categorized as; the broadly classified green capping agents are:

### 2.1. Biomolecules.

The use of biomolecules to make homogeneous NPs has lately sparked interest due to their non-toxic nature and lack of arduous synthetic techniques [27]. To produce NPs with a unique structure, amino acids serve as effective reducing and capping agents. Maruyama and colleagues used amino acids as capping agents to make Au-NPs with a 4–7 nm size range. They chose L-histidine from a list of 20 amino acids since it was discovered to reduce tetraauric acid (AuCl<sub>4</sub>) to Au-NPs. The size of NPs was discovered to be affected by the concentration of L-histidine; the higher the concentration, the smaller NPs [28].

### 2.2. Polysaccharides.

Dextran is a complex branched polysaccharide composed of many glucose molecules with chains of varying lengths [29]. It is hydrophilic, biocompatible, non-toxic, and used to coat many metal NPs [30]. Chitosan is a polysaccharide made up of glucosamine and N-acetylglucosamine units in a linear structure. Non-parenteral drug delivery using chitosan-based NPs can be used to treat cancer, lung diseases, gastrointestinal disorders, medication delivery to the brain, and eye infections [31]. Gelatin was used to coat gold NPs of various shapes and sizes [32].

### 2.3. Understanding the role of capping agents.

The growing kinetics of nuclei during the synthesis process dictate the final form of NPs [33]. As a result, NP growth can occur in either a thermodynamically or kinetically controlled manner. In general, isotropic nanocrystal growth results in spheres under thermodynamic control, whereas anisotropic nanocrystal growth results in NPs of diverse forms under kinetic control. NPs are generated in conditions far from thermodynamic equilibrium, in other words. NPs were synthesized in practice by significantly slowing down the rate of precursor decomposition or reduction [34]. When crystal development occurs outside of thermodynamic equilibrium, a slight change in reaction circumstances greatly amplifies variations in surface free energy at various facets, resulting in anisotropic growth at

various facets [35]. In such instances, the adsorption of capping molecules on specific facets might alter the difference in surface free energy, potentially hindering or enhancing development at these aspects. The interaction of biomolecules, particularly peptides, with metal surfaces has been expected to result in nanostructure stabilization, enhancing their usefulness as sensors, biomedical devices, and electronics[36]. Phage-display libraries have been created to generate peptides that can bind to the surface of semiconductor materials in a specific way based on crystallographic orientation and composition[37]. The phage display method identifies the physical relationship between peptide substrate interactions. Peptides could allow for the precise placement and assembly of molecules, expanding the scope of the 'bottom-up' approach to NPs synthesis [37].

### 3. Types of Nanoparticles

Depending on their morphology, size, and chemical characteristics, NPs are classified into several groups. Some of the most well-known classes of NPs are listed below, based on physical and chemical features [38].

#### 3.1. Carbon-based NPs.

Carbon nanotubes (CNTs) and fullerenes are two main groups of carbon-based NPs.

##### 3.1.1. Fullerenes.

Fullerenes (C<sub>60</sub>) are spherical carbon molecules made up of carbon atoms that are bound together by sp<sup>2</sup> hybridization. The spherical structure is made up of around 28 to 1500 carbon atoms, with diameters ranging from 8.2 nm for single layers to 4 - 36 nm for multi-layered fullerenes [39]. Nanomaterials composed of globular hollow cages, such as allotropic forms of carbon, are found in fullerenes. Because of their electrical conductivity, high strength, structure, electron affinity, and adaptability have attracted commercial interest [40].

##### 3.1.2. Graphene.

Graphene is a carbon allotrope. Graphene is a two-dimensional planar hexagonal network of honeycomb lattices composed of carbon atoms. The thickness of a graphene sheet is usually approximately 1 nm [41].

##### 3.1.3. Carbon nanotubes (CNT).

Carbon nanotubes (CNT) are produced from a graphene nano foil with a honeycomb structure of atoms sore into hollow coils to form nanotubes with sizes as tiny as 0.7 nm for single-layered CNT and 100 nm for multi-layered CNT, and lengths tend to range from a few micrometers to several millimeters. The ends can be hollow, or half fullerene molecules can close them[42]. These have a similar structure to a graphite sheet rolling on itself [43]. Because the rolled sheets can have one, two, or multiple walls, they are referred to as single-walled (SWNTs), double-walled (DWNTs), or multi-walled carbon nanotubes (MWNTs). Deposition of carbon precursors, particularly the atomic, is common to synthesize them. Carbons are vaporized from graphite and deposited on metal particles using a laser or an electric arc. Recently, they have been produced using the chemical vapor deposition (CVD) method [44].

### 3.1.4. Carbon nanofiber.

Carbon nanofiber is produced in the same way as graphene nano foil and CNT. The difference is that it wound into a cone shape as a substitute for regular cylindrical tubes [45].

### 3.1.5. Carbon black.

An amorphous carbon material usually has a spherical shape with diameters ranging from 20 to 70 nm. They aggregate because the particles interact rapidly, and nearly 500 nm agglomerates are formed [46].

## 3.2. Metal NPs.

Metal-based nanoparticles are synthesized from metals to nanometric sizes using destructive or constructive processes. Almost all metals have nanoparticles that can be synthesized [47,48]. Aluminum, cadmium, cobalt, copper, gold, iron, lead, silver, and zinc are commonly used for nanoparticle synthesis [47,49,50]. Nanoparticles have distinct properties such as sizes ranging from 10 to 100nm, surface characteristics such as pore size, high surface to volume ratio, surface charge with density, crystalline structures, spherical shapes, color, reactivity, and sensitivity [51,52]. The metals precursors are used for the synthesis of metal NPs. Because of confined surface plasmon resonance (SPR), these NPs have unique optoelectrical characteristics [53,54]. Noble metal and alkali NPs, such as Cu, Au, and Ag, exhibit a noticeable absorption band in the solar electromagnetic spectrum. In today's cutting-edge materials, the synthesis of size and shape-controlled metal NPs is critical [38,55,56].

## 3.3. Metal oxide nanoparticles synthesis.

Metals like Cu and Ag, for example, can be exceedingly poisonous to bacteria in very low quantities [57]. Due to their biocidal impact, metals have been widely employed as antimicrobial agents in various applications in industry, healthcare, and agriculture in general. Unlike other antibacterial agents, metals are stable under current manufacturing conditions, allowing them to be used as additives [58,59]. These metal-based additives can now be found in various forms, including particles, ions absorbed/exchanged in various carriers, salts, hybrid structures, and so on [60-62]. Many metal oxide nanoparticles, such as ZnO, NiO, MnO<sub>2</sub>, TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, and Co<sub>3</sub>O<sub>4</sub>, have been explored for the electrochemical detection of biomolecules [63]. Furthermore, mixed metal oxides have attracted enough attention in this area. CuO-NPs have unique characteristics that have made them useful in various applications, including super-strong materials, sensors, antibacterial, and catalysts [64]. Due to the high surface area to volume ratio can also contact and interact with other nanoparticles [65]. CuO-NPs have recently been found to have better antibacterial action than Ag-NPs against *E coli* and *B subtilis* [66]. CuO-NPs are commonly utilized in paints and textiles as antibacterial agents since they are polymer-coated [67]. Due to their photolytic capabilities, TiO<sub>2</sub> and ZnO are commonly used. Other interesting metal-oxide NPs are based on CeO<sub>2</sub>, CrO<sub>2</sub>, MoO<sub>3</sub>, Bi<sub>2</sub>O<sub>3</sub>, and LiCoO<sub>2</sub>. CeO<sub>2</sub> is increasingly being used in diesel fuels as a combustion catalyst to enhance emission quality [68]. Iron oxide NPs (IO-NPs) must be highly crystalline, monodisperse, and water-soluble, providing high magnetization values, reproducible quality, and good biocompatibility under biological conditions [69,70]. Nanoparticles of superparamagnetic iron-oxide (SPIO) with a mean crystal size of 50–100 nm and ultra-small superparamagnetic iron-oxide (USPIO) nanoparticles with a size below 50 nm are the two types of superparamagnetic IONP-based

materials now used in medical applications [71]. These two groups of IO-NPs have received much attention in the medical community, especially as the next (possible) generation of MRI contrast agents. They are also being considered as possible medication and gene delivery vectors [72,73]. The use of an external magnetic field can change the biodistribution of these nanoparticles. *In vivo* applications for SPIO-NPs with the proper surface chemistry includes MRI contrast enhancement, tissue healing, immunoassay, biological fluid detoxification, hyperthermia, drug delivery, and cell separation. Nanoparticles with high magnetization values, a size smaller than 100 nm, and a narrow particle diameter distribution are required for all of these biomedical applications [74-76]. SPIONs typically have two structural configurations: (i) a core of magnetic particles (usually magnetite,  $\text{Fe}_3\text{O}_4$ , or maghemite,  $\gamma\text{-Fe}_2\text{O}_3$ ) coated with a biocompatible polymer or (ii) SPIO-NPs are deposited inside the pores of a porous biocompatible polymer [77]. CuO-NPs are frequently utilized for their antimicrobial and biocidal properties [78]. Strong magnetic dipole-dipole attractions between particles cause magnetic nanoparticles to sediment to lower their enormous surface energy ( $>100\text{dyn/cm}$ ). As a result, stabilizers such as surfactants have been used to modify these particles in order to prevent aggregation[79]. Highly stable aqueous dispersions of IO-NPs have been obtained using polymers as the stabilizer [80]. For practical biomedical applications of SPIO-NPs, the surface of NPs must be modified with nontoxic and biocomposable materials. Multidentate ligands (polymers having several groups capable of attaching to particle surfaces) might improve the colloidal stability of inorganic NPs, such as SIO-NPs, as well as their optical, magnetic, and electrical characteristics [81]. In the visible region of the electromagnetic spectrum, most synthetic and bio-based polymers are transparent, meaning they don't interfere with biological processes. Compared to gadolinium-based contrast agents, SPIO-NPs have a slower renal clearance and higher relaxation values, making them more appealing for imaging [82]. Feridex, Endorem, Combidex, and Sinerem are SPIO-NPs with core sizes of 3–6 nm, and dextran coatings (with 20–150 nm hydrodynamic sizes) have been approved for MRI in the patient. Similarly, drug-loaded SPIO-NPs may be directed to the right target location using an external magnetic field while the particle's bio dispersion is tracked. They are actually theragnostic as a result of this method (therapeutic and diagnostic) [83].

#### 3.4. Ceramics NPs.

Ceramic NPs are nonmetallic inorganic solids that are made by heating and cooling. They come in various shapes and sizes, including amorphous, polycrystalline, dense, porous, and hollow. As a result of their usage in applications such as catalysis, photo-degradation of dyes, photo-catalysis, and imaging applications, these NPs are attracting much attention from researchers [84,85].

#### 3.5. Semiconductor NPs.

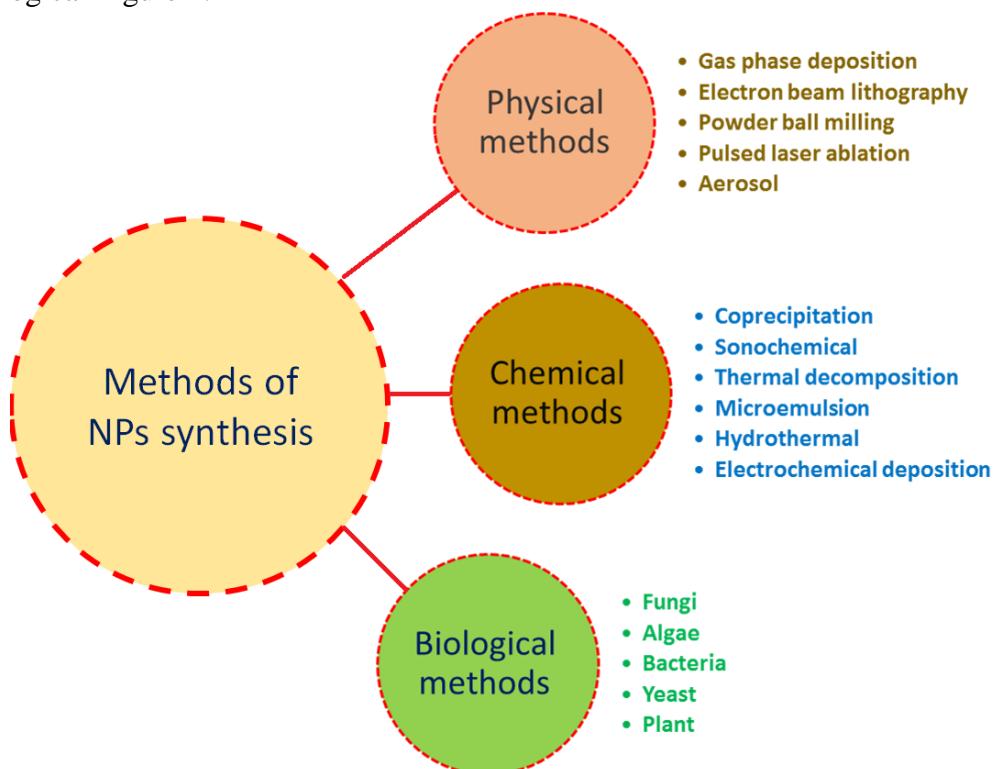
Semiconductor materials have properties halfway between metals and nonmetals, giving them a wide range of uses in the literature [86]. Due to the huge bandgaps of semiconductor NPs, bandgap tuning resulted in significant changes in their properties. As a result, they're crucial in photocatalysis, photo optics, and electronic devices. Due to their optimal bandgap and band edge positions, several semiconductor NPs are particularly efficient in water splitting applications [87,88].

### 3.6. Polymeric NPs.

These are usually organic-based NPs, and they're referred to as polymer nanoparticles (PNPs) in the literature [89,90]. Typically, they are nano-spherical or nano capsular in form. The former are matrix particles with a solid overall mass, whereas the other molecules are adsorbed at the outside edge of the spherical surface. In the latter case, the solid mass is completely encapsulated within the particle [91]. PNPs are simple to functionalize, and as a result, they have a wide range of uses in the literature[45]. Lipid nanotechnology is a specialized topic concerned with the design and manufacturing of lipid nanoparticles for a number of applications, such as medication delivery and RNA release in cancer [92,93].

## 4. Synthesis of Nanomaterials

There are three different methods for synthesizing nanomaterials: physical, chemical, and biological Figure 1.



**Figure 1.** Schematic illustration of the production of nanoparticles via several processes.

### 4.1. Physical.

Physical route or mechanism includes different methods, e.g., gas-phase deposition, electron beam lithography, pulsed laser ablation, laser-induced pyrolysis, powder ball milling, and aerosol [47,94]. Nanomaterials are generated utilizing a strong laser beam that impacts the target material in laser ablation synthesis [95]. The original material or precursor vaporizes during the laser ablation operation due to the high intensity of the laser irradiation, leading to nanoparticle production. This process can manufacture a wide spectrum of nanomaterials, including carbon nanomaterials, metal nanoparticles, ceramics, and oxide composites [96,97]. Using a focussed beam of light or electrons, lithography is a valuable technology for creating nanoarchitectures. Masked and maskless lithography are the two most common forms of lithography. Using a specified mask or template, masked nanolithography transfers nanopatterns over a vast surface area. Photolithography, soft lithography, nanoimprint

lithography are examples of masked lithography techniques [98,99]. Mechanical milling is a price approach for creating nanoscale products from larger particles. Mechanical milling is an efficient method for blending distinct phases and is useful in creating nanocomposites [100]. Carbon nanoparticles that have been ball-milled are a unique form of nanomaterial that can be used for environmental cleanup, energy storage, and energy conversion [101]. One of the most basic processes for creating nanostructured materials is electrospinning. It is commonly used to make nanofibers out of many materials, most commonly polymers. Hollow polymer and core-shell, organic, inorganic, and hybrid materials have been developed using this technology [102]. Sputtering deposition causes the physical ejection of tiny atom clusters by bombarding the target surface with powerful gaseous ions [103]. Sputtering is appealing because the composition of sputtered nanomaterials is similar to that of the target material, with fewer contaminants, and it is less expensive than electron-beam lithography [104].

#### *4.2. Chemical.*

The chemical route includes different methods, e.g., coprecipitation, microemulsion, hydrothermal, electrochemical deposition, sonochemical, and thermal decomposition [47]. Numerous chemical methods are used to synthesize magnetic nanoparticles for medical imaging applications: e.g. microemulsions, sol-gel syntheses, sonochemical reactions, hydrothermal reactions, hydrolysis and thermolysis of precursors, flow injection syntheses, and electrospray syntheses [105-107]. In the production of carbon-based nanomaterials, chemical vapor deposition technologies are crucial. If a precursor has acceptable volatility, high chemical purity, good evaporation stability, cheap cost, non-hazardous, and long shelf life, it is deemed ideal for chemical vapor deposition. Furthermore, its breakdown should not leave any contaminants behind [108]. Ni and Co catalysts produce multilayer graphene in the chemical vapor deposition method, whereas a Cu catalyst produces monolayer graphene. Chemical vapor deposition is a well-known process for manufacturing two-dimensional nanomaterials, and it is an effective approach for producing high-quality nanomaterials in general [109]. The sol-gel method is a wet chemical approach that is widely utilized in nanomaterial development. This technique is used to create a variety of high-quality metal-oxide-based nanomaterials. The sol-gel technique is cost-effective and has a number of additional advantages, including the fact that the material generated is homogenous, the processing temperature is low, and the procedure provides a simple approach to make composites and complicated nanostructures [110]. The reverse micelle approach produces NPs that are very tiny and monodispersed in nature highlights the use of the reverse micelle approach to make magnetic lipase-immobilized NPs [111]. The pore diameters of nanoporous materials can be adjusted by changing the surfactant carbon chain length or adding supplementary pore-expanding agents. The soft template approach may be used to make various nanostructured materials, including mesoporous polymeric, carbonaceous nanospheres, porous aluminas, single-crystal nanorods, and mesoporous N-doped graphene [112]. The microwave-assisted hydrothermal approach, which combines the benefits of both hydrothermal and microwave processes, has lately attracted much interest in engineering nanomaterials [113]. Hydrothermal and solvothermal methods for creating different nano-geometries of materials, such as nanorods, nanowires, nanosheets, and nanospheres, are interesting and practical [114].

#### 4.3. Biological.

The biological route includes different methods, e.g., fungi mediated, algae, bacteria mediated, yeast mediated, etc. [115-117]. Nanoparticles made by a biogenic enzymatic process are significantly superior to those made by chemical methods in various aspects [118]. Even though the latter methods can produce large quantities of NPs with a defined size and shape in a short amount of time, they are complicated, outdated, expensive, and inefficient, and they generate hazardous toxic wastes that are harmful not only to the environment but also to human health [119,120].

#### 4.4. Biosynthesis of NPs using microorganisms.

##### 4.4.1. Synthesis of nanoparticles using Fungi.

Fungi are the largest group among microbes, where are used in multiple applications in different sciences such as bioremediation, enzyme production, nanotechnology, etc. [121-124]. Fungi have sparked a lot of interest in manufacturing metallic nanoparticles since they have several benefits over bacteria in nanoparticle synthesis [125,126]. The simplicity of scaling up and downstream processing, the economic feasibility, and the existence of mycelia, which provides a larger surface area, are all significant benefits [127,128]. A biominerization mechanism is used in fungal-based NP production, which involves internal and extracellular enzymes and biomolecules reducing various metal ions. Silver has been the metal of choice for the manufacture and research of NPs. In addition, Au, Se, Ti, Cu, and Zn have been identified as the next most important metal ions employed by fungus in the production of NPs. More research on NP biosynthesis has been done on *Fusarium*, *Aspergillus*, *Trichoderma*, *Verticillium*, *Rhizopus*, and *Penicillium* species [126]. The size and form of NPs generated by fungus can be relatively limited or quite diversified, such as Au-NPs produced by *Aspergillus* sp. and Ag-NPs produced by *Fusarium* strain [125,129]. Magnetite NPs have been found to be formed by the pathogenic fungus *F. oxysporum* and fungus *Verticillium* sp. Magnetite ( $\text{Fe}_3\text{O}_4$ ) is a common iron oxide with magnetic characteristics [130]. Fungi-produced nanoparticles have been employed in various applications, including medicine, anticancer drugs, antimicrobials, antibiotics, antivirals, diagnostics, antifungals, engineering, biosensors, agriculture, bioimaging, and industry. Agricultural and medicinal applications have been identified as the most common uses of NPs [131]. When compared to bacteria, fungi produce a huge number of nanoparticles. Fungi secrete more proteins, resulting in increased nanoparticle output [132].

##### 4.4.2. Synthesis of nanoparticles using yeast.

Extracellular synthesis of nanoparticles by yeast cell mass might be beneficial in large-scale production and simple downstream processing. This group isolated silver tolerant yeast strain MKY3 by inoculating with aqueous silver nitrate [133]. The formation of Ag-NPs takes place in forced ecological conditions [134]. Different processes used by yeast strains of different genera for nanoparticle formation result in significant differences in size, particle position, mono dispersity, and characteristics [135,136]. These molecules determine the mechanism for the formation of nanoparticles and stabilize the complexes in most of the yeast species studied. Resistance is defined as the ability of a yeast cell to convert absorbed metal ions into complex polymer compounds that are not toxic to the cell [137]. In the mass

production of metal nanoparticles, yeast production is easy to manage in laboratory settings. The rapid growth of yeast strains and the use of basic nutrients have various advantages. *Candida glabrata* and *Saccharomyces pombe* yeast strains have been described to produce intracellular synthetized silver, cadmium sulfide, titanium, selenium, and gold nanoparticles for this purpose [138].

#### 4.4.3. Synthesis of nanoparticles using bacteria.

Research has concentrated primarily on prokaryotes to synthesize metallic nanoparticles [139]. Due to their ubiquity in the environment and their capacity to adapt to harsh situations, bacteria are suitable for study. They are also quick-growing, affordable to cultivate, and easy to manage. Growth parameters such as temperature, oxygenation, and incubation time can be easily regulated. Bacteria are known to synthesize inorganic materials either intracellularly or extracellularly. For example, Ag-NPs are synthesized using microorganisms by the bioreduction process [140]. Metal ions are reduced to nanoscale ranges by extra-reductase enzymes produced by microorganisms [141]. According to a protein assay of microorganisms, the NADH-dependent reductase enzyme is involved in the bioreduction of silver ions to silver nanoparticles. The electrons for the reductase enzyme come from NADH which is then oxidized to NAD+. The enzyme is also oxidized by the reduction of Ag+ to Ag-NPs at the same time [142,143]. *Pseudomonas stutzeri* was used to produce Ag-NPs outside the cells [144]. In addition, several bacterial strains (Gram-negative and Gram-positive), namely *A. calcoaceticus*, *B. amyloliquefaciens*, *B. flexus*, *B. megaterium*, and *S. aureus* have been used for both extra and intracellular biosynthesis of Ag-NPs. These Ag-NPs are spherical, disk, cuboidal, hexagonal, and triangular. They have been fabricated using culture supernatant, aqueous cell-free extract, or cells [2]. *Rhodopseudomonas capsulata* was shown to produce Au-NPs of various sizes, with the form of the Au-NPs being regulated by pH [145]. Bacteria are thought to be a possible biofactory for producing NPs such as selenium, silver, palladium, gold, platinum, titanium, magnetite, titanium dioxide, cadmium sulfide, and other metal NPs [146-148].

#### 4.4.4. Synthesis of nanoparticles using actinomycetes.

These actinomycetes have a good ability to make antibiotics as secondary metabolites [149]. Actinomycetes have been found to have a significant role in creating metal nanoparticles [150,151]. Biogenic synthesis of metal nanoparticles has been demonstrated using bacteria, fungus, algae, actinomycetes, plants, and other organisms. Actinomycetes are one of the less well-known microorganisms employed in producing metal nanoparticles [152]. However, reports suggest that actinomycetes are effective candidates for the intracellular and extracellular synthesis of metal nanoparticles [153]. Actinomycetes produce nanoparticles with good polydispersity and stability and high biocidal activity against a variety of diseases [154]. *Thermoactinomycete* sp., *Rhodococcus* sp., *Streptomyces viridogens*, *Nocardia farcinica*, *Streptomyces hygroscopicus*, and *Thermomonospora* sp. have all effectively manufactured Au-NPs. *Streptomyces* spp., on the other hand, were used to successfully produce Cu-NPs, Ag-NPs, Mn-NPs, and Zn-NPs [2,155].

#### 4.4.5. Synthesis of nanoparticles using the plant.

Plant parts such as leaves, stems, roots, shoots, flowers, barks, seeds, and their metabolites have been used to synthesize nanoparticles successfully [156-158]. Plants with minimal costs and a high eco-friendliness are highly sophisticated and advantageous to human uses. Using plant extracts such as *Pinus resinosa*, *Cinnamom zeylanicum*, *Ocimum sanctum*, *Anogeissus latifolia*, *Curcuma longa*, *Musa paradisica*, *Pulicaria glutinosa*, *Glycine max*, *Doipyros kaki*, *Cinnamomum camphora*, and *Gardenia jasminoides*, green production of Pd-NPs and Pt-NPs has been described [159]. Silver from silver nitrate, zinc oxide from zinc nitrate and zinc acetate, gold from gold chloride, cadmium sulfide, and zinc sulfide from cadmium sulfate and zinc sulfate, and other nanoparticles were manufactured with the assistance of various types of plants and their various components [157]. Recently reported green production of Ag-NPs from *Pongamiapinnata* seed extract [160]. An absorption maximum of 439 nm confirmed the production of nanoparticles. The zeta potential of the well-dispersed nanoparticles with an average size of 16.4 nm was 23.7 mV, which indicates dispersion and stability [160]. The interaction of Au-NPs with human serum albumin was examined, and helices were shown to be unaffected [161].

## 5. Controlling the Size and Stabilizing Synthesized Nanoparticles (Optimization)

### 5.1. Coating or stabilizing of NPs with polymers.

Individual colloidal nanoparticles encapsulated in porous inorganic shells have recently gained a lot of interest [162].

**Table 1.** A summary of common coating processes and materials used to protect iron oxide cores against corrosion [171].

Coating material	Synthesizing procedure	Experimental conditions	Application/purpose	Core-shell form of FeO NPs	Advantages
Silver and Gold	In the presence of iron oxide NPs, Au or Ag precursors are reduced	Differentiate according to the solubility, surface chemistry, and size of iron oxide NP cores.	Protect iron oxide NPs from low pH corrosion	Fe <sub>3</sub> O <sub>4</sub> /Au and/or Fe <sub>3</sub> O <sub>4</sub> /Au/Ag	Additional optical qualities should be included. Gold–silver chemistry can help with organic conjugation.
SiO <sub>2</sub>	TEOS is alkaline hydrolyzed in the presence of core NPs	Changing reaction conditions to either porous or dense	Colloid surface modification	Fe <sub>3</sub> O <sub>4</sub> /SiO <sub>2</sub>	For bioconjugations, it's compatible with a wide range of chemicals and compounds. Small compounds, such as dyes and drugs, as well as quantum dots, can all be used. Antibody–antigen recognition covalently binds to numerous ligands and biomolecules in target organs .Even without surfactants, it's stable and easy to disperse in an aqueous or organic solution.
TaOx	By thermal decomposition of iron oleate precursor and fast hydrolysis of TaOx	In a mixture of Igepal CO-520, NaOH, and other organic solvents	applied in Clinical studies.CT is used to image newly formed blood vessels in tumours, whereas MRI is used to detect the tumor microenvironment.	Fe <sub>3</sub> O <sub>4</sub> /TaOx	CT contrast agent with a low price tag.CT and MRI bifunctional agent Possibility of accurate cancer diagnosis

Coating material	Synthesizing procedure	Experimental conditions	Application/purpose	Core-shell form of FeO NPs	Advantages
<b>Polymer (both natural and synthetic)</b>	By use of polymerization in the presence of precursors and iron oxide NPs	Similar to the hydrolysis synthesis of silica-coated Fe <sub>3</sub> O <sub>4</sub> NPs	To enhance dispersibility in an aqueous medium	Fe <sub>3</sub> O <sub>4</sub> and CdSe/ZnS NPs incorporated into the PLGA matrix	It has a protecting and increasing biocompatible functionalization of organic surface
<b>Small molecules</b>	surfactants were produced by thermal decomposition of Fe(CO) <sub>5</sub> . 4-MC could be directly conjugated with a peptide, c(RGDyK), using the Mannich process.	Oxidation under air	To avoid a large hydrodynamic size	c(RGDyK)–MC–Fe <sub>3</sub> O <sub>4</sub>	Stable. Target tumor cells with high levels of integrin avb3. For tumor cell detection, the MRI contrast was increased. Fe <sub>3</sub> O <sub>4</sub> NPs coated with RGD were shown to be stable in an aqueous solution for months.
<b>Carbon</b>	Hydrocarbon precursors are carbonized. Using a CVD technique at 800°C with nitrogen gas as a shield	annealing at a high temperature that needs to be decreased to enhance the process	Gives cytotoxicity results	Carbon-coated FeCo and/or Fe <sub>3</sub> O <sub>4</sub>	Both single NPs and tiny NP clusters can be absorbed by cells. both of which have an impact in the measurement of cytotoxicity

Bottom-up techniques at the single-nanoparticle level, while conceptually elegant, have obstacles in large-scale manufacture and use. Solid catalysts are made up of metal nanoparticles distributed on a porous medium. Technical catalysts frequently have irregular spatial distributions and ultra-short interparticle distances [163]. Yang *et al.* used zwitterionic polymers to make Au-NPs. Unfortunately, during the coating process, their particles clumped together. These aggregates were stable in human serum after being coated [164]. Qi *et al.* were able to produce stable NPs with a BSA/chitosan/doxorubicin core under physiological circumstances by adding an extra chitosan coating [165]. Hauser *et al.* [166] used three ways to encapsulate iron oxide nanoparticles with dextran: (1) Two-step approach for making dextran-coated iron oxide nanoparticles. (2) A semi-two-step process for making dextran-coated iron oxide nanoparticles. (3) Simultaneous semi-two-step production of dextran-coated IO-NPs. There are two ways to attach polymers to the IO-NP surface: grafting 'onto' and grafting 'from.' Grafting 'from' involves attaching an initiator to the IO-NPs' surface and growing the polymer from there, whereas grafting 'onto' involves grafting a functional, pre-formed polymer onto IO-NPs *in situ*. Furthermore, grafting 'from' can make keeping the hybrid nanoparticles' integrity in organic solvents [167]. Utilizing live radical polymerization in conjunction with a carefully developed protocol, it is possible to modify IO-NPs using the grafting "from" method [168,169]. Sommertune *et al.* [170] prepared multi-core magnetic hybrid particles based on the ESE method. Other reports show that controlling the size and shape of other nanoparticles by polymer and using them for different applications is possible Table 1. Table 2 showed different polymers for magnetic NP stabilization [171].

**Table 2.** Different polymers for magnetic NPs to stabilization.

Polymers	Benefits
PEG	PEG improves biocompatibility by immobilizing PEG on the surface noncovalently, increasing NP internalization efficiency and decreasing blood circulation time.
Dextran	colloidal solution stabilization and blood circulation time increasing

Polymers	Benefits
PVP	blood circulation time enhancing and colloidal solution Stabilization
Fatty acids	stability of colloidal and terminal functional carboxyl groups
PVA	particles monodispersing and particles coagulation prevention
Polyacrylic acid	particles biocompatibility improvement, bioadhesion, and stability increasing
Polypeptides	targeting to the cell that is worthy for cytology
Phosphorylcholine	stabilization of colloidal solution and activating coagulation
Poly(d, l-lactide)	high biocompatibility and lowering cytotoxicity
PolyNIPAAm	Delivery of drug and improving cell separation
Chitosan	Biocompatible, utilized in medicine and food, employed in water treatment, polymers, textiles, biotechnology, hydrophilic, and used in agriculture, this natural cationic linear polymer is widely used as a nonviral gene delivery mechanism.
Gelatin	Biocompatible, gelling agent, hydrophilic emulsifier, and used as a natural polymer

## 6. Characterization of Nanoparticles

### 6.1. UV-visible spectrometry.

The determination of NP synthesis of various nanoparticles from different methods was analyzed by UV-visible spectroscopy. The production of nanoparticles is clearly indicated by a steady increase in the characteristic peak with increasing reaction time and concentration of biological extracts with salt ions. The UV-vis absorption spectrum of nanosized particles reveals peaks characteristic of the surface plasmon resonance [126].

### 6.2. Transmission Electron Microscopy (TEM).

The morphology of the nanoparticles was recorded by using a TEM. TEM is based on the electron transmittance principle so that it can provide information of the bulk material from very low to higher magnification. TEM also provides essential information about two or more layer materials, such as the quadrupolar hollow shell structure of NPs observed through TEM [128].

### 6.3. Particle size and zeta potential.

The zeta potential analyzer was used to detect surface charge. The zeta potential (ZP) is a useful parameter for assessing the behavior of suspended particles in aqueous media, whether for predicting colloidal stability or investigating particle deposition in water cooling process equipment; colloidal stability is influenced by the surface charge and biodistribution of NPs. The nature and behavior of surface groups in solution at a specific pH in the presence of an electrolyte can be qualitatively defined. It can be measured quantitatively as an electrical potential in the interfacial double layer on the surface of suspended NPs. Because of the electrostatic interaction, a high zeta potential value indicates that NPs are dispersion stable. It is an important technique used to determine the size distributions of nanoparticles and use DLS to determine the size distributions of nanoparticles [126].

### 6.4. Fourier transformation infrared spectroscopy (FTIR).

FTIR is a commonly used method for detecting functional groups in pure substances and mixtures and comparing compounds. The vibrational motion of atoms and molecules is linked to infrared analysis [172].

### 6.5. X-ray diffraction (XRD).

X-ray fluorescence is a non-destructive analytical method used to fine the elemental composition of materials. X-ray diffraction patterns have long been used to identify important aspects in a compound, such as the types and nature of the crystalline phases present. The position (angle) and intensities of the X-ray beam diffraction induced by the sample in XRD can provide information about the sample [49].

### 6.6. Scanning Electron Microscopy (SEM).

Magnetic nanoparticles' size and shape are examined using SEM. SEM can produce images of three-dimensional objects because, in its regular mode of operation, it records secondary electrons emitted from the sample by the electron beam impinging on it, rather than the electrons flowing through it [63].

## 7. Applications of Synthesis NPs

### 7.1. Water treatment.

Nanotechnology has opened up limitless possibilities for purifying water, even in its ionic condition [173]. The numerous nanostructured materials have been created with properties including high aspect ratio, reactivity, controllable pore volume, and electrostatic, hydrophilic, and hydrophobic interactions that are useful in adsorption catalysis, sensing, and optoelectronics [174,175]. Nanoscale metals and their oxides (silver, titanium, gold, and iron) have been widely used in environmental mitigation [176]. Biological contaminants such as bacteria, viruses, and fungi are effectively disinfected by Ag-NPs [177].

#### 7.1.1. Carbon nanotube.

Generally, carbon is one of the most multilateral elements present in the periodic table due to its strength and ability to bond with other elements. Carbon nanotube (CNTs) discovered in 1991 by Iijima has been extensively adapted by many researchers to study show capability into water treatment [178]. Rizzuto, *et al.* [179] use carbon nanotube membranes for water purification. CNT membranes were utilized to direct water desalination or remove salts from water molecules without changing their flow rate [180].

#### 7.1.2. Metal oxides.

Metal oxides such as iron oxide, titanium dioxide, and alumina are effective, low-cost adsorbents for heavy metals and radionuclides [181,182]. The sorption is mainly controlled by the complexation between dissolved metals and the oxygen in metal oxides [183,184]. The great sorption capability, operational simplicity, and resourcefulness of nanosized iron oxides have sparked increased interest in their usage for wastewater treatment [185]. Non-magnetic goethite (-FeOOH) and hematite (-Fe<sub>2</sub>O<sub>3</sub>), magnetic magnetite (Fe<sub>3</sub>O<sub>4</sub>) and maghemite (-Fe<sub>2</sub>O<sub>3</sub>), and hydrous ferric oxides are the phases of iron oxides. In their complex matrixes, goethite and hematite include a variety of geochemically and ecologically significant oxyanions and cations [186]. They have been touted as effective and low-cost adsorbents for the removal of a variety of pollutants [187,188]. ZnO was primarily used as an adsorbent to remove H<sub>2</sub>S. Nanosized ZnO has recently been discovered to be capable of eliminating a

variety of pollutants with great performance and selectivity [189]. Rambabu *et al.* created nanosized porous ZnO plates with low pore diameters and a high specific surface area. It exhibited significant and selective adsorption to cationic pollutants, such as various hazardous metals [190]. A significant number of polar sites on the walls of pores within the nanoplates resulted in such strong, structurally increased adsorption [191]. The adsorbed hydrated Cu(II) could partially hydrolyze, forming Cu-O-Cu on the pore walls, thereby multiplying its adsorption capacity, exhibiting Freundlich-type adsorptive activity [192]. At 303 K, the highest capacity of nanosized ZnO for Cd(II) and Hg(II) ions was 387 and 714 mg/g, respectively [193]. The initial adsorption rate was thought to be controlled by film diffusion, followed by pore diffusion. As previously stated, the surface hydroxyl groups of nanosized ZnO have been shown to play a significant role in the adsorption of certain heavy metals [194].

#### 7.1.3. Polymers.

Polymers are exceptional nanomaterial supports because they often have customizable porosity structures, great mechanical qualities, and chemically attached functional groups [195]. Polymer-based nanocomposites (PNCs) are being investigated as potential water and wastewater treatment materials. The inherent advantages of both nanoparticles and the polymeric matrix are frequently combined in PNCs [196]. The use of nanoparticles in the manufacturing process of polymeric membranes has received much attention during the last years, particularly as a new step in flux enhancement and fouling reduction [197,198]. Hybrid membranes comprising inorganic fillers in a polymer matrix are well-known [199]. Common fillers are oxides such as SiO<sub>2</sub> and zeolites [200, 201].

### 7.2. Medical application.

#### 7.2.1. Drug delivery.

As drug delivery systems, Nanoparticles are capable of uplifting the several crucial properties of free drugs, such as solubility, *in vivo* stability, pharmacokinetics, biodistribution, and enhancing their efficiency [202,203]. Because of their beneficial properties, nanoparticles might be exploited as prospective medication delivery devices in this area. *In vitro* delivery of a hydrophobic fluorophore was achieved using mixed monolayer protected metal clusters as an example of cellular delivery [204,205]. For medication delivery, a variety of nanostructures have been developed. Lipid or polymer particles, liposomes, micelles, Ag-NPs, quantum dots, Au-NPs, silica NPs, and drug nanocrystals are examples of nanostructures or nanocarriers for drug delivery [206]. Peptides, DNA molecules, chemotherapeutic, radioactive, and hyperthermic pharmaceuticals have been delivered using SPIO-NPs assisted drug delivery systems [207]. IO-NPs have been used as nanocarriers for medication and gene delivery in a number of studies [208,209].

Furthermore, by introducing platinum into the IO-NPs cores, the iron-oxide core can be designed to unleash harmful organic molecules [210]. The polymer covering can now be used as a scaffold (reservoir) for the drug or gene cargo, in addition to stabilizing IO-NPs in a biological medium. The loading and release of bioactive compounds from the polymer coating consequently become a key determinant of IO-NPs' nano-carrier efficiency [211]. Covalent coupling, charge complexation, hydrogen bonding, and hydrophobic/hydrophilic interactions are some ways therapeutics can be attached to polymer strands [212]. The nanoparticles' magnetic characteristics were used to boost cell absorption [213]. Nanoparticles in drug

delivery have benefited the medical field thanks to nanotechnology [172]. Nanoparticles can be used to deliver the medicine to targeted cells by placing the drug in the required area and the required dosage. The total drug consumption and side effects are significantly reduced [214]. This method is less expensive and has fewer side effects [2]. Nanotechnology can help with tissue engineering, which involves replicating and repairing damaged tissue. Tissue engineering can be used to replace traditional treatments like artificial implants and organ transplant s[215]. The formation of carbon nanotube scaffolds in bones is one such example [216].

#### 7.2.2. Antimicrobial.

Pathogenic bacteria's resistance to antimicrobial drugs has arisen in recent years, posing a huge challenge to the healthcare business[217,218]. Nanotechnology and biological sciences advancements have made it feasible to develop smart surfaces that reduce infection. Once applied to biomedical devices and medical personnel protective equipment, the nanotechnology-based solutions outlined here may be useful in developing materials that limit or prevent the development of airborne virus droplets [219]. Metal ions and metal-based materials, such as Au-NPs, Se-NPs, Ag-NPs, MgO-NPs, CuO-NPs, TiO<sub>2</sub>-NPs, and ZnO-NPs, have been demonstrated in several studies to be effective antimicrobial coatings [219-226]. Metal-oxide nanoparticles' potential antibacterial processes have yet to be fully identified. Ion concentrations, oxidative stress, ROS, and membrane damage have all been discovered to be plausible modes of action against bacteria [227-230].

#### 7.3. Waste management.

Many things are essential for the life and growth of living organisms, but none are more crucial than water. Around 1.2 billion people lack access to clean drinking water, 2.6 billion people struggle to meet basic sanitation needs, and millions of people, particularly children, have died as a result of illnesses spread by unsafe and dirty water [231]. Polymeric-NPs, metal oxide-NPs, metal-NPs, zeolite, carbon nano, self-assembled monolayer on mesoporous-substrates, biopolymers, and others have all been described as nanomaterials that might be employed in wastewater treatment. Adsorption and biosorption, nanofiltration, photocatalysis, disinfection, pathological control, sensing and monitoring, and other nanotechnology-based wastewater remediation pathways are used [232]. Yang *et al.* used algal-bacterial aerobic biological sludge to evaluate chromium Cr(VI) biosorption from synthetic wastewater. They discovered that Cr(VI) biosorption was strongly influenced by pH, with the greatest Cr(VI) biosorption efficiency of algal-bacterial aerobic-granular sludge being 51.0 mg g<sup>-1</sup> at pH 2, Cr(VI) [233]. Researchers are now interested in metal-based nanoparticles as adsorbents [234]. Heavy metals, dyes, and ions are commonly removed from wastewater using nanometals and related oxides, such as MgO, Fe<sub>3</sub>O<sub>4</sub>, MnO<sub>2</sub>, TiO<sub>2</sub>, ZnO, and CdO [232].

#### 7.4. Agriculture.

Agriculture and food production are being drastically altered by nanotechnology [235,236]. Nanotechnology has the potential to alter current farming techniques [237] significantly. The majority of agrochemicals applied to crops are lost and do not reach the target location due to several factors such as leaching, photolysis, drifting, hydrolysis, and microbial degradation [238]. Nanoparticles and nanocapsules offer a low-cost, site-specific technique to

distribute pesticides and fertilizers while minimizing collateral damage [239]. Nanotechnology is gaining popularity in agriculture because of its capacity to precisely manage and release insecticides, herbicides, and fertilizers [240-243]. Goswami *et al.* found that various manufactured NPs, such as TiO<sub>2</sub>-NPs, Al<sub>2</sub>O<sub>3</sub>-NPs, SiO<sub>2</sub>-NPs, and ZnO-NPs, can suppress infections caused by *Sitophilus oryzae* and baculovirus *B. mori* virus in silkworms [244]. Nanosensors for pesticide residue detection have high sensitivity, low detection limits, great selectivity, quick reactions, and small dimensions. They can also determine the soil's quantity of moisture and nutrients [245].

## 8. Conclusions

Nanoparticles having different characteristics are a prominent type of nanomaterials that have aided in the advancement of nanotechnology. Scientists interested in such approaches have recently developed their nanocomposites due to recent improvements in the characteristics of novel nanomaterials and their applications. This article defined nanotechnology and described the processes for making nanomaterials out of metals, metal oxides, graphene oxides, and polymers. Green approaches, such as plant extracts and microorganism biomolecules, are intriguing strategies that lead to nanoparticle synthesis with reduced or no toxicity compared to other methods. This review opens up new possibilities for producing and utilizing various nanomaterials.

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## Conflicts of Interest

The authors declare no conflict of interest.

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