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Original Article

A short review of Nanomaterials: Synthesis methods, properties, and applications

Ali ALNAZZA ALHAMAD[a], Soumeia ZEGHOUD[b,c], Ilham BEN AMOR[b,c]*, Abdelmalek ZAATER [d,e] , Asma BEN AMOR[b,c], Abdelatif AOUADI[f], Amira HEMMAMI[g], Emmanuel CHILE NLEONU[i]

[a]*Department of Chemistry, Faculty of Science, University of Aleppo, Syria*

[b]*Department of Process Engineering and Petrochemical, Faculty of Technology, University of El Oued, El Oued 39000, Algeria*

[c]*Renewable Energy Development unit in Arid Zones (UDERZA), University of El Oued, El Oued 39000, Algeria*

[d]*Department of Agronomy, Faculty of Nature and Life Sciences, University of El Oued, El Oued 39000, Algeria.*

[e]*Biodiversity laboratory and application of biotechnology in agriculture, University of El Oued, El Oued 39000, Algeria.*

[f]*Applied Sciences Faculty, Process Engineering Laboratory, KASDI Merbah-Ouargla University, Ouargla 30000, Algeria*

[g]*Department of Cellular and Molecular Biology, Faculty of Natural Science Sand Life, University of El Oued, El-Oued 39000, Algeria*

[i]*Department of Chemistry, Federal Polytechnic Nekede, P.M.B. 1036, Owerri, Imo State, Nigeria.*

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ABSTRACT

Due to their significant features, engineered nanomaterials have received much attention recently, sparking significant technical and monetary growth across various industrial sectors. Moreover, it is anticipated that nanomaterials will support a variety of industries, including microelectronics, materials, textiles, energy, healthcare, and cosmetics. Nanotechnology applications will lead to the development of lighter, stronger, and cleaner materials, intelligent medications, and diagnostics in the medical field. The relative hazards of various nanomaterials to humans and the environment are still up for debate, therefore, it's essential to be aware of the concerns related to possible toxicity and exposure route. Here, we go through several elements of creating, characterizing, and using nanoparticles.

1. Introduction

The usage of nanomaterials can assist in improving goods and industrial processes with enhanced features or new functions due to the future potential of nanotechnology. Nanotechnology-based goods are anticipated to significantly influence almost all industrial sectors in the future and will be widely available in the consumer market [1, 2]. A particle having lengths in two or three dimensions more than 1 nm and less than 100 nm and which may or may not display a size-related intensive feature is referred to as a nanoparticle in the field of nanotechnology. To distinguish them from one- and two-dimensional nanomaterials, which have dimensions that are one or two orders of magnitude bigger than nanoscale, respectively, NPs are also classified as zero-dimensional nanomaterials [3, 4]. Evolution in nanotechnology and nanoscience is the essential element, as recent technological growth proves. Nanotechnology is finding applications in practically all areas of science and technology [5].

An outstanding example of an emerging technology is nanotechnology, which provides designed nanomaterials with the huge potential to produce goods with much better performances[6]. Nanomaterials are used in various commercial products, including scratch-resistant paints, sporting goods, electronics, environmental cleanup, surface

* *Corresponding author.* Tel.: +213675821157
E-mail address: *ilhambenamor97@gmail.com*
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coatings, cosmetics, energy storage devices, and sensors [7]. By discussing relevant information and synthesis techniques, properties, and potential opportunities related to the vast and fascinating field of nanomaterials, this review aims to highlight the importance of technology and nanomaterials through production methods, the study of properties, and various applications.

2. Synthesis of nanomaterials

Three methods can be used to create nanoparticles (NPs); are listed below: Biological technique, Physical technique, and Chemical technique.

2.1. Biological technique

The biological technique is easy and simple, typically requiring only one step, and environmentally beneficial. In this regard, we can prepare the nanomaterials using microorganisms and different plant parts [8].

2.1.1.Using of microorganisms

From an aqueous solution of metal salts, various organisms like algae, fungi, and bacteria can be employed to generate many nanomaterials.

2.1.2.Using of bacteria

By employing a protein, living things will participate in biomineralization, which involves creating nanoparticles. For instance, magnetotactic bacteria use magnetosomes, which are protein-coated for the manufacture of nanosized magnetic iron oxide crystals, at the bottom of the sea in anaerobic circumstances to prepare the magnetic particles as a compass to the direction of their chosen home[9]. The production of homogenous particles with a core diameter of 20 to 45 nm has been shown to occur in vitro [10]. Despite this, magnetosomes have strong magnetic characteristics in medicinal applications like hyperthermia[11].

Using photosynthesis-producing microorganisms like Rhodopseudomonas capsulata, He et al. made 10–20 nm-sized gold nanoparticles extracellularly. The reduction of gold ions to gold nanoparticles is largely mediated by the bacterial enzyme Nicotinamide Adenine Dinucleotide Hydride -dependent reductase. They discovered that the growing media's pH regulates the nanoparticles' morphology and form [12]. Schluter et al. revealed that Pseudomonas cells from the alpine location were used to produce palladium nanoparticles extracellularly[13].

2.1.3.Using of fungus

Extracellular Ag NPs were created using the fungus Fusarium oxysporum. Due to NADH-enzymatic reductase's activity, these nanoparticles are long-term stable. In comparison to bacterial cells, more protein is secreted by fungal cells[14]. *T. reesei* is now widely used in the food, pharmaceutical, animal feed, textile industries, and paper.

2.1.4.Using of algae

Extracellular Au NPs made from Sargassum wightii algae were suggested by Singaravelu et al. 95% of the output was reached after just 12 hours of incubation [14]. There is a lack of further investigation into the Synthesis of NPs by algae. Some bacteria, fungi, and algae in this process are harmful. Thus, precautions should be taken to prevent them.

2.1.5.Using of biological templates

The production of nanomaterials inside the organism can be accomplished by leveraging the biological process. The main methods for doing this are biological templates. They create distinctive and sophisticated nanostructures by utilizing biological building blocks like DNA and proteins. Through the use of these nanoparticles, biosensors [15], bio NEMS, and bioelectronic systems [16] may be created. The majority of the components of nanocomposite materials are proteins. For instance, ferritin is the internal iron storage protein in prokaryotes and eukaryotes. It accumulates in the form of iron oxide and releases it gradually. When there is an iron deficit or an iron excess in people, it functions as a buffer and regulates. It has an iron oxide core that is encapsulated in a protein shell. The iron oxide core may be selectively degraded to produce apoferritin without harming the surrounding protein. Once more, iron oxide or any other desirable NPs can be inserted into the empty core of apoferritin. Now, an inorganic nanocomposite protein has been created. Fan et al. created the Au NPs in horse spleen ferritin[17]. Wu et al. produced a yttrium phosphate radionuclide NPs inside the apoferritin and coupled it with biotin [18]. The nanoparticles may be assembled using the DNA templates as well. The closed circular DNA molecules known as plasmids are present in many bacterial species. The combination of cadmium perchlorate and plasmid DNA may be spin coated to create 5–10 nm CdS DNA nanoparticle conjugates.

2.1.6. Using of plant components

The Synthesis of the NPs has also been carried out using plant extracts. The phytochemicals found in plants diminish the metal NPs. Phytochemicals such as organic acids, flavones, and quinones naturally function as effective reducing agents for creating NPs. From the biomass of the *Medicago sativa* and *Pelargonium graveolens* plants, variously shaped Au NPs are produced [19]. From the leaves of *Azadirachta indica*, bimetallic Ag, Au, and bimetallic Au core-Ag shell NPs are produced. This plant contains terpenoids and/or sugars that function as reducing agents[20]. Aloe vera leaf extract is used to create Au NPs[21]. Several plants, such as *Brassica juncea* and *Helianthus annuus*, are used to create Ag, Co, Ni, Zn, and Cu NPs.

2.2. Physical method

Different techniques, such as gas-phase deposition, electron beam lithography, pulsed laser ablation, laser-induced pyrolysis, powder ball milling, and aerosol, are included in the physical pathway or mechanism[22, 23]. In laser ablation synthesis, a powerful laser beam that strikes the target material produces nanomaterials[24]. Due to the high intensity of the laser irradiation used during the laser ablation process, the original material or precursor vaporizes, producing nanoparticles. Numerous other types of nanomaterials, such as oxide composites, metal nanoparticles, ceramics, and carbon nanomaterials, may be produced using this method [25, 26].

Lithography, which uses a focused beam of light or electrons, is useful for producing nano architectures. The two most popular types of lithography are mask- and maskless lithography. Masked nanolithography transmits nanopatterns across a large surface area using a predetermined mask or template. Examples of masked lithography methods include photolithography, soft lithography, and nanoimprint lithography[27]. A cost-effective method for converting bigger particles into nanoscale goods is mechanical milling. The creation of nanocomposites can benefit from mechanical milling, which blends different phases effectively [28].

Carbon nanoparticles that have undergone ball milling are a special nanomaterial that can be utilized for energy storage, energy conversion, and environmental remediation [29]. Electrospinning is one of the most fundamental procedures for producing nanostructured materials. Out of a variety of materials, polymers are most frequently utilized to create nanofibers. This method has created hollow polymer and core-shell, organic, inorganic, and hybrid materials[30]. Small atom clusters are physically ejected from the target surface during sputtering deposition due to intense gaseous ion bombardment [31]. Sputtering is appealing because it is less expensive than electron-beam lithography and has a similar composition to the target material with fewer imperfections[32].

2.3.Chemical

The chemical pathway uses a variety of techniques, including thermal breakdown, electrochemical deposition, coprecipitation, microemulsion, hydrothermal, and sonochemical deposition. Microemulsions, sonochemical reactions, sol-gel syntheses, hydrothermal reactions, hydrolysis, flow injection syntheses, thermolysis of precursors, and electrospray syntheses are only a few chemical processes employed to create magnetic nanoparticles for medical imaging applications[33, 34]. Chemical vapor deposition methods are essential for synthesizing nanomaterials made of carbon. Precursors are rated perfect for chemical vapor deposition if they have acceptable volatility, good evaporation stability, high chemical purity, low cost, and no hazards. Furthermore, no pollutants should be left over after its breakdown [35]. In the chemical vapor deposition process, multilayer graphene is created using Ni and Co catalysts, whereas a Cu catalyst creates monolayer graphene.

A well-known method for creating two-dimensional nanoparticles is chemical vapor deposition, which is also a successful strategy for creating high-quality nanomaterials in general [36]. Wet chemical techniques like the sol-gel process are frequently used to create new nanomaterials. This method may produce a wide range of premium metal-oxide-based nanomaterials. The cost-effective sol-gel method also offers several other benefits, such as the homogeneous material produced, the low processing temperature, and the ease with which complex nanostructures and composites may be created[37]. The utilization of the reverse micelle technique to create magnetic lipase-immobilized NPs [38] is highlighted by the production of NPs that are very small and monodispersed in nature. The length of the surfactant carbon chain may be changed, or additional pore-expanding agents can be added to change the pore sizes of nanoporous materials. Numerous nanostructured materials may be used, including mesoporous polymers, porous aluminas, carbonaceous nanospheres, single-crystal nanorods, and mesoporous N-doped graphene[39], created using the soft template method.

Engineering nanomaterials have recently been quite interested in the microwave-assisted hydrothermal technique, which combines the advantages of both hydrothermal and microwave processes [40]. Interesting and useful techniques for producing various nano-geometries of materials, such as nanorods, nanosheets, nanowires, and nanospheres, include hydrothermal and solvothermal processes [41].

3. Unique properties of nanomaterials

Compared to their bulk counterparts, the characteristics of matter at the nanoscale level are noticeably different. At the nanoscale, size-dependent effects are more pronounced. For instance, whereas the Au solution appears yellow in bulk, it appears purple or red at the nanoscale. By adjusting the nanomaterial size, the characteristics of nanomaterials may be modified[42]. The mechanical characteristics of nanoparticles are significantly better than their bulk equivalents due to improvements in crystal perfection or decreases in crystallographic flaws[43].

Quantum mechanical factors govern the electronic characteristics of semiconductors in the 1–10 nm region. Thus, quantum dots are nanospheres with sizes between 1 and 10 nm. The form and size of nanomaterials, such as quantum dots, have a significant impact on their optical characteristics[39].

The following important features may be obtained by adjusting the sizes and morphologies of nanomaterials, among various other special properties.

3.1.Surface area

All nanomaterials have the characteristic that their surface areas are significantly higher than their bulk counterparts [44].

3.2.Magnetism

At the nanoscale, the magnetic properties of elements can alter. At the nanoscale level [45], an element that is not magnetic can become magnetic.

3.3.Quantum effects

At the nanoscale, quantum effects are increasingly noticeable. However, the characteristics of the semiconductor material[45] significantly impact the scale at which these effects will manifest.

3.4.High electrical and thermal conductivity

Exceptional thermal and electrical conductivity can be seen at the nanoscale level compared to bulk analogues, depending on the nature of the nanomaterial. Graphene, produced from graphite [46], is one example.

3.5.Superior mechanical attributes

Excellent mechanical qualities that are lacking in their macroscopic counterparts are present in nanomaterial's[47].

3.6.Excellent catalyst support

The possibility for effective dispersion of active catalyst nanoparticles on 2D sheets of different nanomaterials has significantly improved catalytic performance[48]. Catalysts have recently been atomically disseminated to improve performance across 2D nanomaterial sheets.

3.7.Antimicrobial activity

Some nanomaterials have antiviral, antifungal, and antibacterial characteristics and are very effective at treating illnesses brought on by pathogens[49].

These characteristics have made nanoscale materials desirable for a variety of applications overall, significantly improving the performances of different technologies and materials in several disciplines.

4. Applications

Nanomaterials may be used in various applications, as shown in Figure 1, because they possess unique, beneficial physical, chemical, and mechanical characteristics.

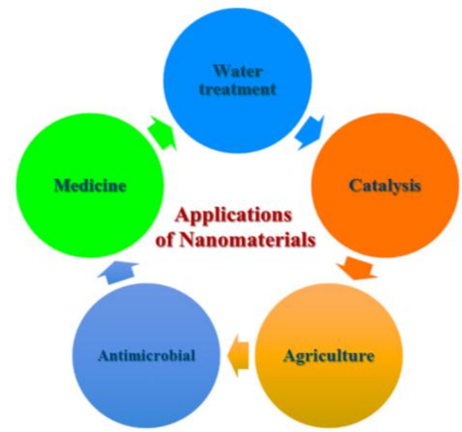

Figure 1. Different applications of nanomaterials.

4.1.Water treatment

Even in its ionic state, water may now be purified in almost infinite ways thanks to nanotechnology[50]. Many nanostructured materials have been developed, and they have qualities including high aspect ratio, reactivity, controlled pore volume, electrostatic, hydrophilic, and hydrophobic interactions that are helpful in adsorption catalysis, sensing, and optoelectronics[51]. Environmental mitigation has frequently employed nanoscale metals and their oxides, such as titanium, silver, iron, and gold [52]. Ag-NPs efficiently disinfect biological pollutants like viruses, bacteria, and fungus[53].

4.2.Applications in medicine.

4.2.1.Drug administration

As drug delivery methods, nanoparticles have the power to improve the efficiency of free medicines by improving their solubility, in vivo stability, pharmacokinetics, and biodistribution[54]. A wide range of nanostructures has been produced for the delivery of medications. Lipid or polymer particles, liposomes, micelles, Ag-NPs, quantum dots, silica NPs, Au-NPs, and drug nanocrystals are examples of nanostructures or nanocarriers for drug delivery [55].

4.3. Antimicrobial

The development of intelligent surfaces that lower infection rates is now possible because of advances in biological sciences and nanotechnology. The nanotechnology-based solutions described here may be helpful in creating materials that restrict or prevent the production of airborne virus droplets when used in biomedical devices and protective gear for medical workers[56]. Numerous investigations have shown that metal ions and metal-based compounds, such as Se, Au, Ag, CuO, MgO, TiO_2, and ZnO NPs, are efficient antimicrobial coatings[57].

4.4. Agriculture

Nanotechnology has a profound impact on agriculture and food production[58]. Current farming practices might be drastically changed[59] by nanotechnology. Due to a variety of causes, including leaching, photolysis, drifting, hydrolysis, and microbial degradation, the majority of agrochemicals sprayed into crops are lost and do not reach the target area[60]. A low-cost, site-specific method of distributing insecticides and fertilizers with the least amount of collateral harm is provided by nanoparticles and nanocapsules [61]. Due to its ability to precisely control and release fertilizers, insecticides, and herbicides, nanotechnology is becoming more and more popular in agriculture[62].

4.5.Catalysis

One of the first uses of NPs was in catalysis. Many substances and components, including aluminum, iron, titanium dioxide, clays, and silica, have been utilized as nanoscale catalysts for many years. Due to its high activity, selectivity, and productivity, nanocatalysis has recently become a burgeoning scientific subject. The high surface-to-volume ratio, geometric surface effect, electronic impact, and quantum size effect are a few crucial aspects contributing to nanocatalysts' high activity.

4.6.Sensors

The creation of a diverse range of nanomaterials has cleared the path for their use in the creation of high-performance electrochemical sensing devices for environmental and food safety monitoring as well as medical diagnostics. Biosensors have been significantly impacted by nanotechnology, in part because of their great sensitivity[63].

5. Conclusion

Various distinctive characteristics that distinguish nanomaterials from their bulk counterparts have been demonstrated. High surface area, magnetism, quantum effects, antibacterial activity, and high thermal and electrical conductivities are all characteristics of nanomaterials. To be used in many sectors, mixed-composition nanomaterials are also being created. Although a lot of research is being done in the disciplines of electronic storage devices, biomedicine, and sensors, these subjects still have room for further improvement. With the exception of a few specific cases, the majority of nanomaterials are being developed for lab-scale uses, and significant work is needed to get them to the commercial market. Finding alternatives to the usage of endangered and resource-limited materials in the manufacturing of nanomaterials is another significant difficulty linked with contemporary nanotechnology.

Conflict of Interest

The authors declare that they have no conflict of interest.

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