Review Article

Metal Nanoparticles: Synthesis Approach, Types and Applications – A Mini Review

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Abstract

The study of nanoparticles has grown in significance during the last several years. Nanoparticles are a kind of material that is composed of very tiny particles. Nanoparticle characteristics vary greatly depending on their size and form. The surface of a nanoparticle significantly affects its optical, mechanical, magnetic, and other characteristics. Nanoparticles are categorised according to their size, origin and chemical composition. We created nanoparticles using both top-down and bottom-up techniques. In this article, we discuss various different methods for creating nanomaterials, such as sol-gel processes, gas condensation, vacuum deposition and vaporisation, chemical vapour deposition and condensate, mechanical attrition, chemical precipitation, electrodeposition,

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and chemical vapour condensation. When it comes to creating nanoparticles, green synthesis is one of the most effective approaches. In this article, we explore eco-friendly techniques for manufacturing alloy nanoparticles, silver, gold, silver oxide and silver sulphide. We also explore the process by which microorganisms in this setting produce nanoparticles. Size and form must be maintained under certain conditions. We consider ways in which to enhance the production of nanoparticles in the future. The risks posed by nanoparticles and the ways in which to mitigate them were also taken into account.

Keywords: nanoparticles; structural morphology; applications; green synthesis

Introduction

In recent years, the branch of research and development known as the study of nanostructures has become increasingly popular all around the world. The term “nanomaterials” refers to substances with a size smaller than 100 nanometres. Numerous disciplines are now investigating the ways in which green chemistry may be used to improve and protect the environment on a global scale. Metal nanoparticles are often used in catalytic reactions because of the low-cost, environmentally friendly nanomaterials that are used in fields such as health, electronics, physics, materials science and environmental restoration. Improving synthetic methodologies is still a challenge for science. It is commonly accepted that structural characteristics including composition, shape, size, and surface chemistry have an impact on the toxicity of nanomaterials. It is crucial to employ safe, non-toxic stabilisers and simple procedures to increase the lifetime of metal nanoparticles [1].

Nanotechnology is an area of study that examines the design, manufacturing and characterisation of materials smaller than 100 nanometres. It is now being studied in the developing fields of electronics, chemistry, biology, physics, medicine, food and aerospace. It includes every step of the development process. Nanobiotechnology, on the other hand, is the outcome of combining the sciences of nanotechnology and biotechnology with related purposes [2].

Owing to their physicochemical characteristics, such as morphology, size and distribution, magnetic properties, antibacterial properties, and catalytic activity, advanced precious metal nanomaterials, such as copper, silver and gold, have attracted the attention of scientists in recent decades [3]–[11]. There are several means to create nanoparticles, including physical, chemical and biological means [12], [13]. However, physical and chemical approaches have drawbacks, including the creation of poisonous and hazardous by-products.

Stable metal nanoparticles with regulated size and form could be created using low-cost, secure and environmentally friendly methods. Numerous plant extracts, including Ocimum Sanctum [14], Petroselinum Crispum [15], Murraya koenigii [16] and

Coriandrum Sativum [17], have lately shown cutting-edge green/biosynthetic methods for the manufacture of metal nanoparticles.

Inorganic micro- and nanoparticles have been produced by a variety of synthetic processes. The field of nanomaterial biosynthesis, which is still developing, was intended to be promoted, with green chemistry being the most well-known method. Nanoparticles made using biological or eco-friendly methods have various qualities, such as improved stability and acceptable sizes, because they are generated in a single step. Plants are an ideal starting point for the production of diverse nanoparticle materials since they are free of hazardous substances and have natural capping agents [18], [19].

When microorganisms biosynthesize nanoparticles, they first take up target ions from the environment and then consume enzymes obtained by cellular processes to change the metal ions into metallic elements. Depending on where it occurs, the creation of nanoparticles can be classified as extracellular or intracellular [20], [21]. In order to generate nanoparticles, intracellular procedures require introducing ions into microbial cells [22]. Extracellular nanoparticle production entails extracting metal ions from cell surfaces and depleting them in the presence of enzymes. Applications for biosynthesised nanoparticles include targeted drug delivery systems, gene therapy, cancer treatment (Figure 1(a)), antibiotics, biosensors, DNA analysis, separation science, response rate enhancement, and magnetic resonance imaging (MRI) to serve a function.

History

In the 4th century, nanoparticles were first used in Rome to make the diachronic glass cup of Lycurgus. In the 9th century, it was used in Mesopotamia (Iraq) to give vessels a glossy appearance. Medieval and Renaissance pottery today generally retains its characteristic gold or copper metallic lustre. Mixing copper and silver salts and oxidising them with vinegar produces nanoparticles in ceramics [23]–[25]. In the Islamic world, this technique was developed. Renaissance Muslims were not allowed to use pure gold, so instead of using pure gold they had to create a gold-like appearance. [26]. The properties of nanoparticles are described in Faraday's classic work and the relationship experimental between gold and other metals with light published in 1857 [27]–[29].

Properties

Because of the small size of nanoparticles, they show many properties. Some of them are described as follows:

- Nanoparticles are optically active compounds [30].

- Nanoparticles are tiny in sizes to enclose their electrons and create a quantum effect [31].
- Nanoparticles have higher absorption of solar radiation [32].
- The core-shell of nanoparticles shows improved forward scattering when solar plasmon (a type of solar cell that converts light into electricity with the help of a plasmon) is located ahead of the solar cell [33].
- Nanoparticles show both electric and magnetic resonance [31].
- Nanoparticles show suspension in solution due to the strong interaction between the particle surface and solvent.
- At higher temperatures, nanoparticles show diffusion because of high surface-to-volume ratio [34].
- Those nanoparticles which are made up of semiconductor material have quantisation electronic energy levels. Such types of nanoparticle are used in biomedical applications [35].
- Nanoparticles that contain both the hydrophobic property on one part and hydrophilic on the other are called Janus particles [36]. Metallic nanoparticles produced by the green method are of great importance and use for various purposes [37], [38] (Figure 1(b)).

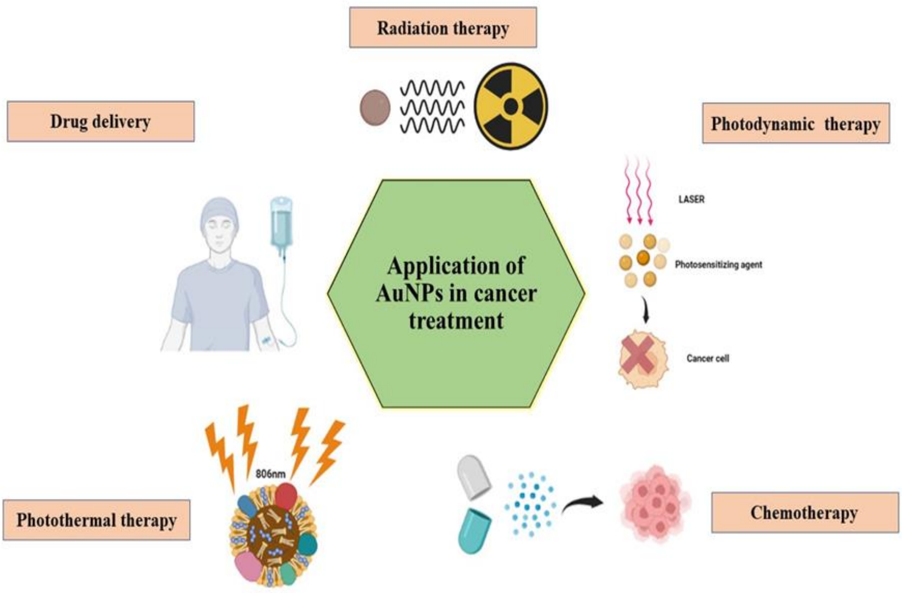

Figure 1(a): The various ways gold nanoparticles (AuNPs) are used to treat cancer

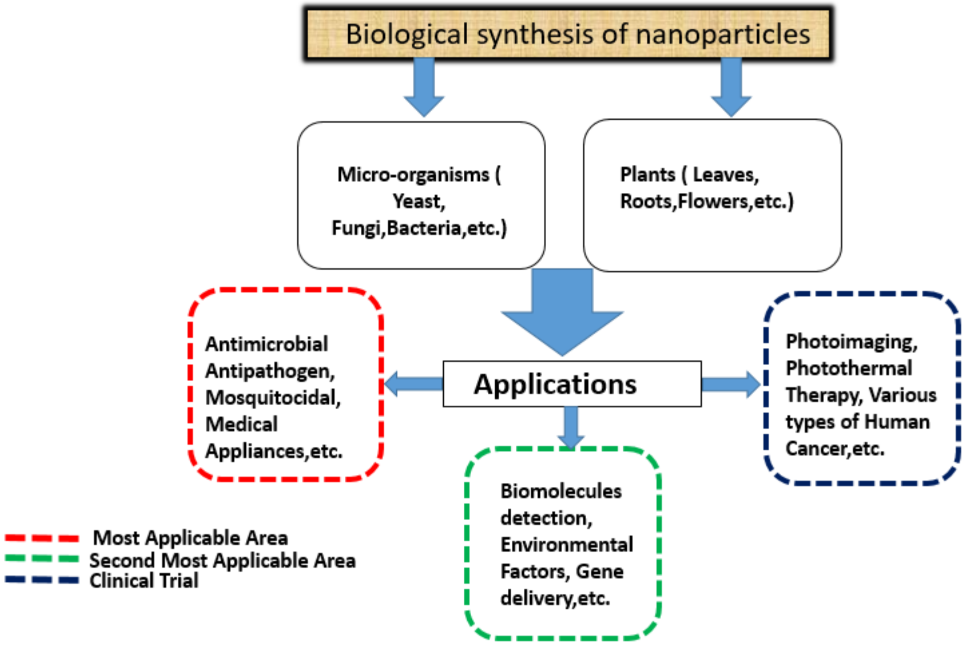

Figure 1(b): Application of metallic nanoparticles for various purposes [37], [38]

Types

Nanoparticles are classified according to their origin, the number of dimensions and the structural basis [39]–[41] (Figure 2). Nanoparticles are classified into the following two categories based on their origin:

- natural nanoparticles; and
- artificial nanoparticles.

Natural Nanoparticles

Natural nanoparticles are naturally available. Examples of natural nanoparticles are proteins, enzymes and minerals.

Artificial Nanoparticles

Artificial nanoparticles do not occur naturally and can be obtained artificially by chemical, physical and biological synthesis techniques. When based on the number of dimensions, nanoparticles are classified into the following four types:

- zero-dimensional nanoparticles (which include semiconductor and metallic nanoparticles);

- one-dimensional nanoparticles (which include nanowires, nanotubes and nanodots);
- two-dimensional nanoparticles (which include nanoplates and nanocomposites); and
- three-dimensional nanoparticles (which include bulkers).

When based on the structural configuration, nanoparticles are classified into the following four groups:

- ❖ metallic nanoparticles;
- ❖ carbon-based nanoparticles;
- ❖ composites nanoparticles; and
- ❖ dendrimers nanoparticles.

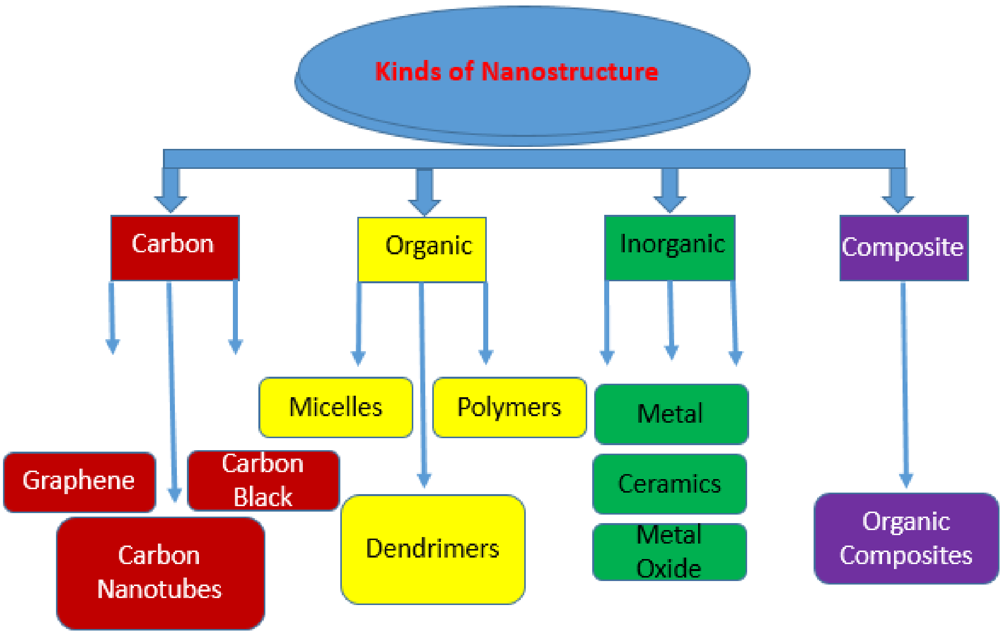

Figure 2: Different types of nanoparticle

Synthesis

Nanoparticles occur naturally and can be synthesised in the laboratory. For the synthesis of nanoparticles, there are two approaches and both have advantages and disadvantages with respect to each other [42]–[44] (Figure 3). The two approaches are the following:

- top-down approach; and
- bottom-up approach.

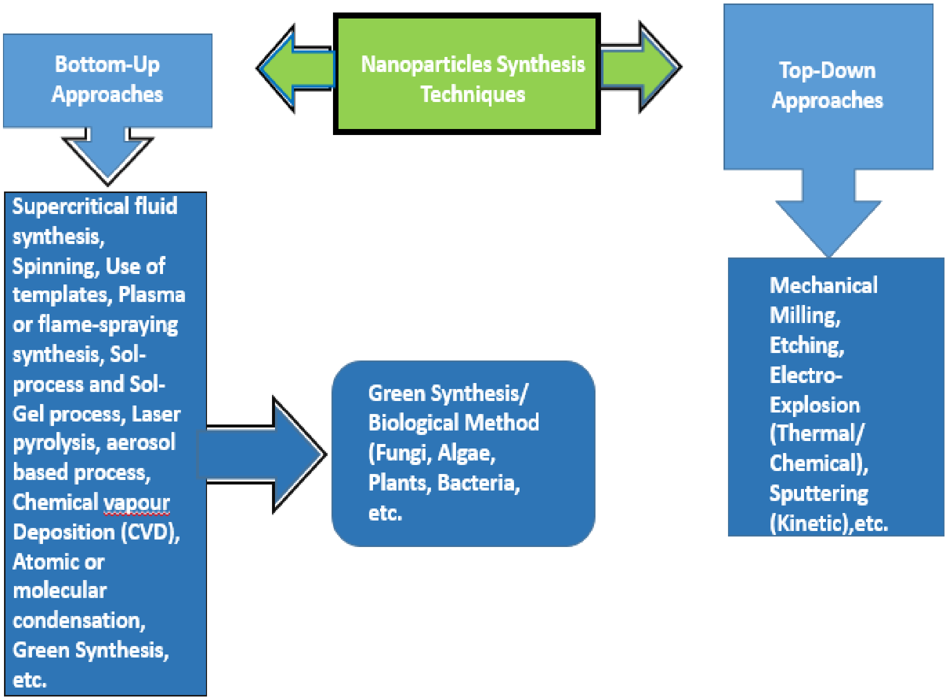

Figure 3: Synthesis techniques of nanoparticles

Top-Down Approach

In this approach, numerous thermal, chemical and physical techniques are used for breaking down the solid bulk materials into tiny particles by applying external force [45]–[47].

Bottom-Up Approach

In this approach, the gathering and combining of gas and liquid ions, atoms and molecules occur.

The bottom-up approach is based on the following methods:

- gas condensation;
- vacuum deposition and vaporisation;
- chemical vapour deposition (CVD) and chemical vapour condensation (CVC);
- mechanical attrition;
- chemical precipitation;
- sol-gel techniques; and
- electro-deposition.

Gas Condensation

Gas condensation is employed to obtain nano-crystalline metals and alloys. In this technique, the thermal evaporation method is used to obtain vapours of inorganic and metallic materials [48], [49].

Vacuum Deposition and Vaporisation

In this method, compounds, alloys and elements are vapourised and deposited in a vacuum by thermal process [50].

Chemical Vapour Deposition and Chemical Vapour Condensation

CVD and CVD refer as chemical deposition of solid deposited on a heated surface from vapour and gas phase. The reaction is activated at a high temperature. In 1994, CVC was initiated in Germany. It is based on the pyrolysis of vapours of metal-organic precursors in a reduced atmospheric pressure. This reaction is induced by ultraviolet radiation and the reaction is activated and deposited at room temperature [51]–[53].

Mechanical Attrition

In this method, nanoparticles are obtained by a structural breakdown of rough-grained structure which is obtained by plastic malformation. This method can be conceded at room temperature in the following mills [54], [55]:

- high-energy mills;
- attrition-ball mills;
- centrifugal-type mills;
- vibrating-ball mills;
- planetary-ball mills; and
- low-energy tumbling mills.

Chemical Precipitation

In this method, the size of nanoparticles can be adjusted accordingly. The separation between particles formed can maintain by using a surfactant [56]–[58].

Sol-Gel Techniques

This is the most commonly used method. It comprises the evaluation of the network by the formation of gelatin (gel) and colloidal suspension (sol) to form a continuous liquid phase network [59]. The gel and sol are organic metallic precursors for various compounds. To control the pH and initiate a reaction, a catalyst is used. The formation of sol-gel can take place in the following four steps [60]:

- hydrolysis;
- condensation;
- growth of particles; and
- agglomeration of particles.

Electrodeposition

Electrodeposition plates are mechanically uniform and strong. The hypersonic plasma particle deposition (HPPP) method can also be used to synthesise and deposit nanoparticles [61], [62].

Green Synthesis

There are three methods for the synthesis of nanoparticles, namely, physical, chemical and green synthesis.

Green synthesis is the most commonly known method. It is environmentally friendly and does not produce any toxic chemicals. Instead, it helps to remove toxic substances from the environment to make the atmosphere pollution free. The green synthesis method is low-cost and less time-consuming. In recent years, various kinds of nanoparticle of different sizes, shapes, contents, and physiochemical properties were synthesised [63], [64].

In the green synthesis method, microorganisms such as bacteria, yeast, algae and fungi are used. This is a one-step process. The synthesis of nanoparticles which is done by bacteria is performed ex situ and in situ [65].

Applications

There are many applications of nanoparticles owing to their small size (Figure 4). A few of them are described as follows:

- Nanoparticles play an important role in the diagnosis and treatment of human diseases [66].
- Nanoparticles are used as drugs, fluorescent biological labels, bio-detection of pathogens, gene delivery agents, tissue engineering, phaco-kinetics studies, and tumour destruction (hypothermia) [67].
- Nanoparticles can help to deliver the drug safely to the target site at the right time [68].
- Nanoparticles are used for target cancer treatment, stem cell sorting, manipulation, guided drug delivery, gene therapy, DNA analysis and MRIs [69].
- Doxorubicin can form a covalent attachment with bacterial magneto and evaluate the capability of these particles to resist tumour growth [70].
- Magnetotactic bacteria are used in drug delivery to help in blood clotting [71].
- Silver nanoparticles are used as antibacterial, antifungal, antiviral and anti-inflammatory agents [72].
- Silver nanoparticles that are biosynthesised using the fungus Trichoderma viride as antibacterial agent also help in developing new antimicrobial agents. Nanoparticles are used in agriculture, cosmetics, the environment, food, home appliances, medicine, sport and fitness, and many other textile industrial sectors [73].
- Nanoparticles help in the magnetic separation and detection of attractive material for building assay systems. They are developed for sensitive and small molecules such as atmosphere pollutants, hormones and toxic detergents [74].
- Nanoparticles have wide applications in medicine, physics, optics and electronics [75].
- Nanoparticles can also be used as dietary supplements for delivering biologically active substances [76].

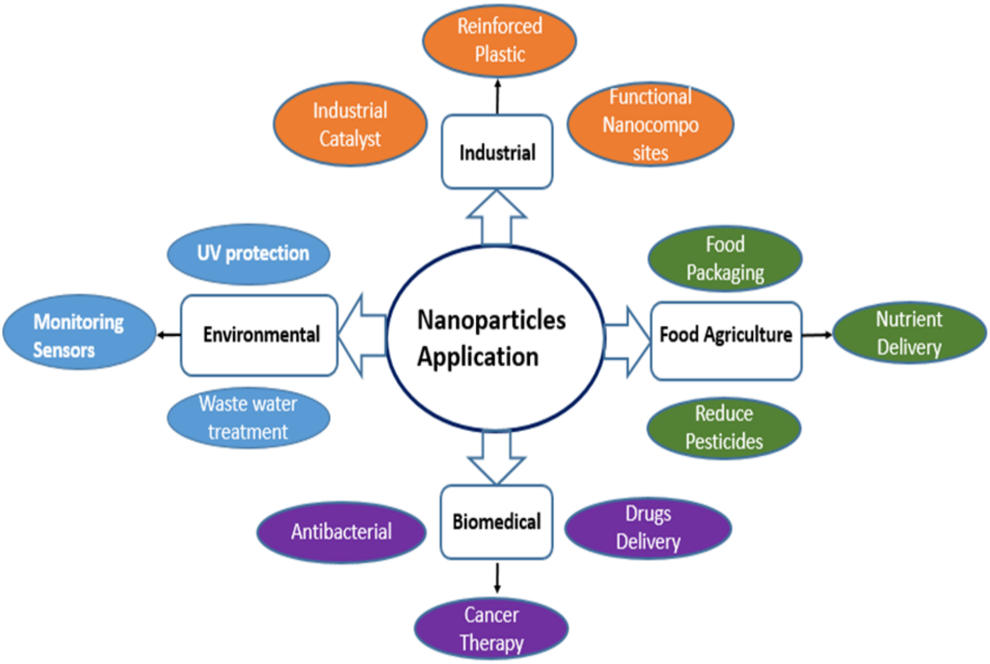

Figure 4: Schematic diagram of different applications of nanoparticles

Future Perspective and Recommendations

- Over the last 10 years, there have been significant developments in the field of microorganisms manufacturing nanoparticles and their use.
- Work must be done on the synthesis and the adoption of particle size and morphology continuously.
- In comparison to chemical and physical processes, nanoparticle production is an extremely sluggish activity within the realm of knowledge [77].
- The biosynthesis corridor will be considerably more attractive if the synthesis time is reduced.
- In the evaluation of nanoparticles, there are two major issues, namely, the mono disparity and particle size.
- Remarkable particle size control and mono disparity must be further investigated.
- Several investigations have indicated that the nanoparticles produced by microbes can disintegrate over time [78].
- Additional research into the establishment of nanoparticles formed by biological processes is needed, and the quality of these particles should be improved.

- The physical and chemical production of nanoparticles for particle shape control is still a work in progress, and the capacity to regulate particle morphology in biological processes would provide significant benefits.
- Different parameters such as growth average, microorganism type, synthesis conditions, microbial cell growth stage, substrate concentrations, pH, reaction time, temperature, collection of nano-target ions, and source compound of target nanoparticle may all influence particle size and mono disparity in a significant way.
- Biosynthesis techniques are advantageous because nanoparticles are covered with a lipid layer that provides physiological solubility and stability, which is important in biomedical applications and a bottleneck in other synthetic processes.
- Currently, research is being conducted on cells at the proteomic and genomic levels.
- Molecular and cellular levels, including the identification and isolation of chemicals, are responsible for nanoparticle reduction.
- It is estimated that high synthesis and short reaction time can be obtained [79].

Health and Safety

Nanoparticles may pose a threat both medically and ecologically. The majority of these threats are attributable to the high surface-to-volume ratio of the particles, which makes them highly reactive and catalytic [80]. They may also travel through the cell membrane of living creatures, and their interactions with biological systems are generally unnoticed. Owing to the size and intracellular assembly of the nanoparticles, it is doubtful that they would pass through the Golgi complex, nucleus, endoplasmic reticulum, and other internal cellular components [81]. A recent study explored the impact of ZnO nanoparticles on human immune cells and discovered various degrees of cytotoxicity resistance. There are concerns that pharmaceutical firms, in their strive for acknowledging nano-reformulation of existing medications, may use safety data generated during previous clinical trials and pre-formulation translation of medicine. This might lead to regulatory agencies such as the US Food and Drug Administration overlooking new adverse effects related to nano-reformulation [82]. On the other hand, a reasonable study has revealed that zinc nanoparticles are not strongly involved in the bloodstream in vivo. Concerns about the health consequences of repairable nanoparticles produced by particular combustion methods have also been expressed [83]. Some nanoparticles were investigated by the US Environmental Protection Agency in 2013 [84]–[86].

Conclusion

A combination of plant extracts and microorganisms has recently been used successfully to manufacture metal nanoparticles for green synthesis. The most practical, straightforward and environmentally acceptable method for creating nanoparticles is therefore through green synthesis. Green synthesis minimises the adverse impacts of physical and chemical processes by avoiding the use of dangerous chemicals and producing damaging by-products. Owing to their outstanding qualities, nanoparticles are frequently used and have been the area of research attention in recent years. Antioxidant, antibacterial and non-toxic nanoparticles made through green synthesis are having a noticeable physical and therapeutic impact. Most likely, research in future will deliberate on creating nanoparticles with little toxicity and maximum antimicrobial efficacy.

Creating metallic nanoparticles is therefore crucial nowadays, especially when utilising a non-toxic green synthesis method, which is employed in a number of applications such as drug delivery, cancer treatment, and the development of biosensors. The science of nanomedicine is expanding quickly and has much potential to help better diagnoses and cure human diseases. The manufacture of nanoparticles by microbes is thought to be a secure, non-toxic and environmentally responsible "green chemistry" process. Depending on where the nanoparticles are created, the employment of microorganisms such as bacteria, yeast, fungus and actinomycetes can be divided into intracellular and extracellular production.

The pace of intracellular particle creation and the size of the nanoparticles are, to some extent, influenced by the governing parameters such as temperature, pH, substrate concentration, and exposure time to a substrate. At the genomic and proteomic levels, microorganisms are currently being modified for scientific purposes. It is hoped that large-scale research and commercial usage of these approaches in medicine and health care will emerge in the next years as a result of recent advancements and ongoing work to increase particle synthesis efficacy and to investigate biomedical applications. The nanomaterials were the area of research attention over the past 10 years owing to the wide range of applications. Producing nanomaterials seems to be a very busy field. In order to create nanomaterial, a variety of techniques are used, including gas condensation, mechanical attrition, chemical vapour synthesis, the sol-gel method, chemical precipitation, electrodeposition, molecular beam epitaxial, consolidation, ionised cluster beam, sputtering, liquid metal ion source, and gas aggregation of monomers. It is common practise to combine chemical precipitation with capping agents, auto-combustion, and reaction in microemulsions to create nanophosphors. These techniques can be used to produce a wide variety of nanomaterials.

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