GSC Biological and Pharmaceutical Sciences

eISSN: 2581-3250 CODEN (USA): GBPSC2

Cross Ref DOI: 10.30574/gscbps

Journal homepage: https://gsconlinepress.com/journals/gscbps/

GSC ONLINE PRESS

(REVIEW ARTICLE)

Check for updates

A comprehensive review on Nanoparticle: Characterization, classification, synthesis method, silver nanoparticles and its applications

Priya B. Falke, Prashant G. Shelke, Pooja R. Hatwar *, Ravindrakumar L. Bakal and Nitin B. Kohale

Department of Pharmaceutics, Shri Swami Samarth Institute of Pharmacy, At Parsodi, Dhamangoan Rly, Dist -Amravati (444709) Maharashtra, India.

GSC Biological and Pharmaceutical Sciences, 2024, 28(01), 171–184

Publication history: Received on 11 June 2024; revised on 18 July 2024; accepted on 21 July 2024

Article DOI: https://doi.org/10.30574/gscbps.2024.28.1.0268

Abstract

Nanotechnology offers many advantages in various fields of science. Recent advances in nanotechnology have proven that nanoparticles acquire a great potential in medical applications. Recent advances in nanoscience and nanotechnology radically changed the way we diagnose, treat, and prevent various diseases in all aspects of human life. This present review provided a detailed overview of the synthesis, properties and applications of Nanoparticles (NPs) exist in different forms. NPs are tiny & small, ranges from 1 to 100 nm. They are classified into different classes based on their properties, shapes or sizes. The different groups include fullerenes, metal NPs, ceramic NPs, and polymeric NPs. NPs possess unique physical and chemical properties due to their high surface area and nanoscale size. Silver nanoparticles (AgNPs) are one of the most vital and fascinating nanomaterials among several metallic nanoparticles that are involved in biomedical applications. AgNPs play an important role in nanoscience and nanotechnology, particularly in nanomedicine. The major applications of silver nanoparticles in the medical field include diagnostic applications and therapeutic applications, apart from its antimicrobial activity.

Keywords: Nanotechnology; Nanoparticles; Characterization; Synthesis method; Application

1. Introduction

Nanoparticles are defined as particles having a single dimension of less than 100 nm and special qualities that are often absent from bulk samples of the same material are referred to as nanoparticles (NPs). Over the past ten years, the prefix "nano" has been increasingly prevalent in several disciplines of expertise [1]. Depending on their form, nanoparticles can be 0D, 1D, 2D, or 3D [2]. When scientists discovered that a substance's size may alter its physio-chemical characteristics, including its optical qualities, they began to understand the significance of these nanoparticles. One of the most important and basic characteristics of nanoparticles is their optical quality. i.e. 1) A silver NP is coloured grayish yellow. 2) A gold NP with a size of 20 nm has a characteristic red wine colour. 3)The nanoparticles of palladium (Pd) and platinum (Pt) are black in colour.

Nanoparticles are composed of three layers and are not simple molecules [3].

- Core.
- Surface layer.
- Shell layer.

* Corresponding author: Pooja R. Hatwar

AgNPs may take on several shapes depending on the diversity of items employed in their synthesis [2]. Examples of these shapes include "nanowires," cubes, octahedra, pyramids, and tabular prisms. To boost safety and effectiveness, NPs may enhance the stability and solubility of encapsulated cargos, encourage transport across membranes, and lengthen circulation times [4].

2. Nanotechnology

The scientific community at large has shown interest in the topic of nanotechnology. In a talk at the California Institute of Technology in December of 1959, Nobel Laureate Richard Feynman presented the idea of nanotechnology [5]. "Nanotechnology deals with the processing of separation, consolidation, and deformation of materials by one atom or by one molecule." [6].

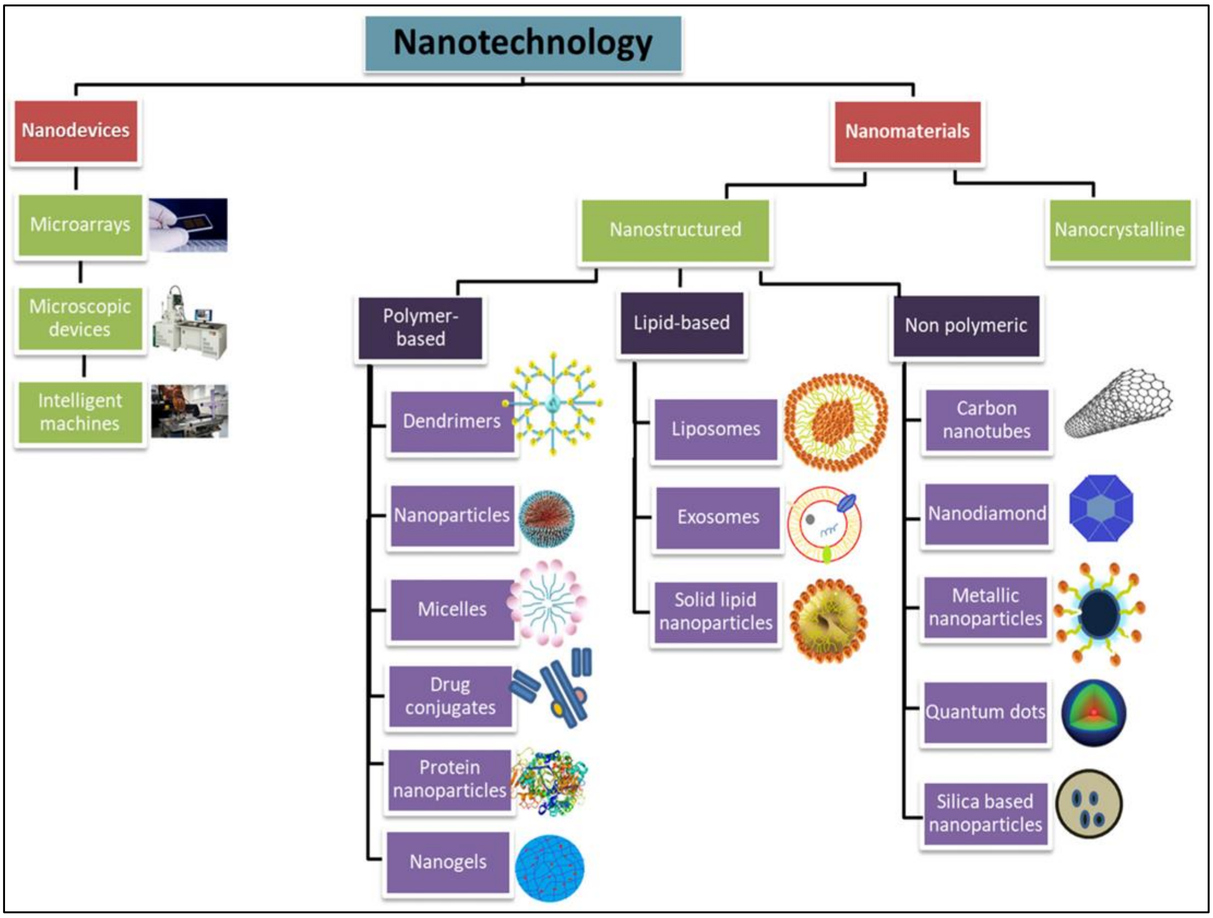

Figure 1 Elements of Nanotechnology, which are used in therapeutic application [7]

2.1. Silver Nanoparticles

Silver Nanoparticles (AgNPs) are described as nanomaterials having all their dimensions falling between 1 and 100 nm [8] Research on the "Holy water" solution, which has been used since the start of the first millennium as a defence against microbial infection, confirmed the existence of both silver ions and AgNPs [2]. It has long been known that silver exhibits wide spectral minimal tissue toxicity and antimicrobial activity [9]. Silver nanoparticles, or AgNPs, have been used in a variety of sectors, including medical products and daily Products because of advances in nanotechnology. Global AgNP production is now projected to be 500 tons annually, and over the coming years, this is expected to rise. AgNPs can be released into the environment in several ways, such as during synthesis, when they are incorporated into other products, and when these products and AgNPs are recycled or disposed of these goods and AgNPs [10]. Silver nanoparticles (AgNPs) stand out among most NPs because of their remarkable antimicrobial, electrical, optical, and thermal properties. The antimicrobial mechanisms of AgNPs are complex, resulting in their broad-spectrum activity making it difficult for microorganisms to develop resistance, thus there are AgNP-resistant strains. In addition, AgNPs' unique characteristic also enable wide application in various disciplines, including electronics, chemical/biological sensors, materials, and cosmetic and pharmaceutical products [11].

2.2. Advantages of Nanoparticles:

The following are some notable benefits of nanoparticles:

- Enhanced bioavailability.
- Proportionality of dose.
- Dosage forms smaller.
- Dissolves the active substance more quickly when there is a greater surface area. Increased absorption and bioavailability are typically correlated with faster dissolving rates.
- Lower dosages of drugs have less toxicity.
- Decreased variability between fed and fasting

Characterization of Nanoparticles:[3],[12]

- UV-visible spectroscopy.
- Fouries transform spectroscopy in the infrared.
- Analysis of X-ray diffraction.
- Electron microscope for transmission.
- Electron microscopy.
- Mass spectrometry.
- Electron microscopy using transmission.
- Microscopy using scanning electron.

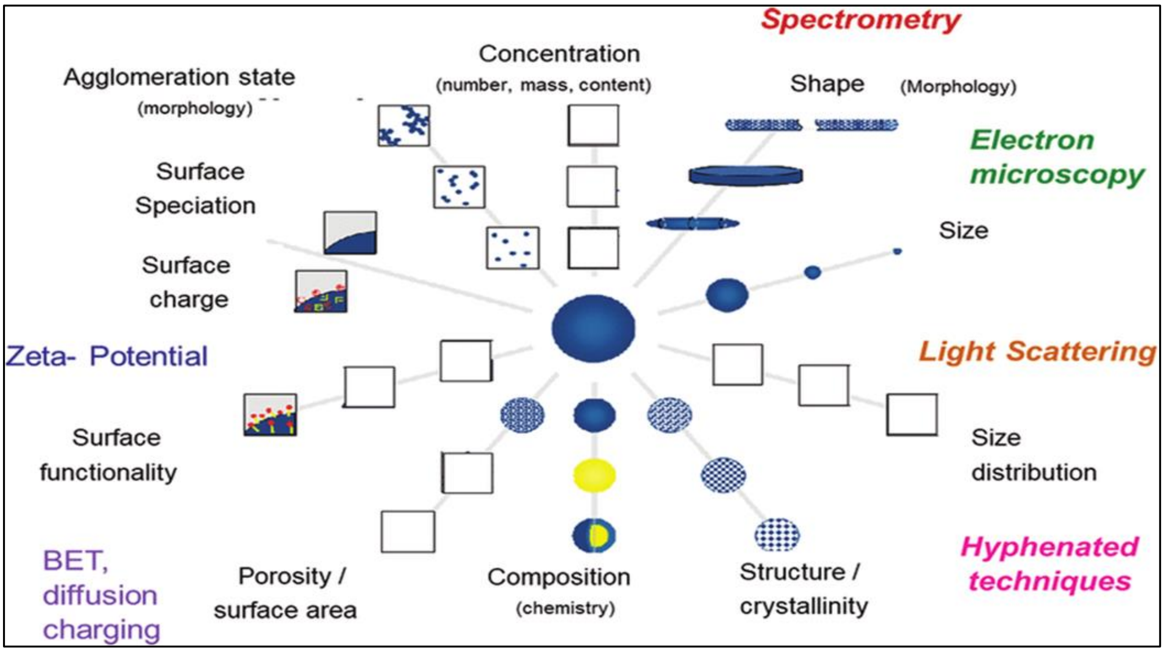

Figure 2 Nanoparticles characterization [13]

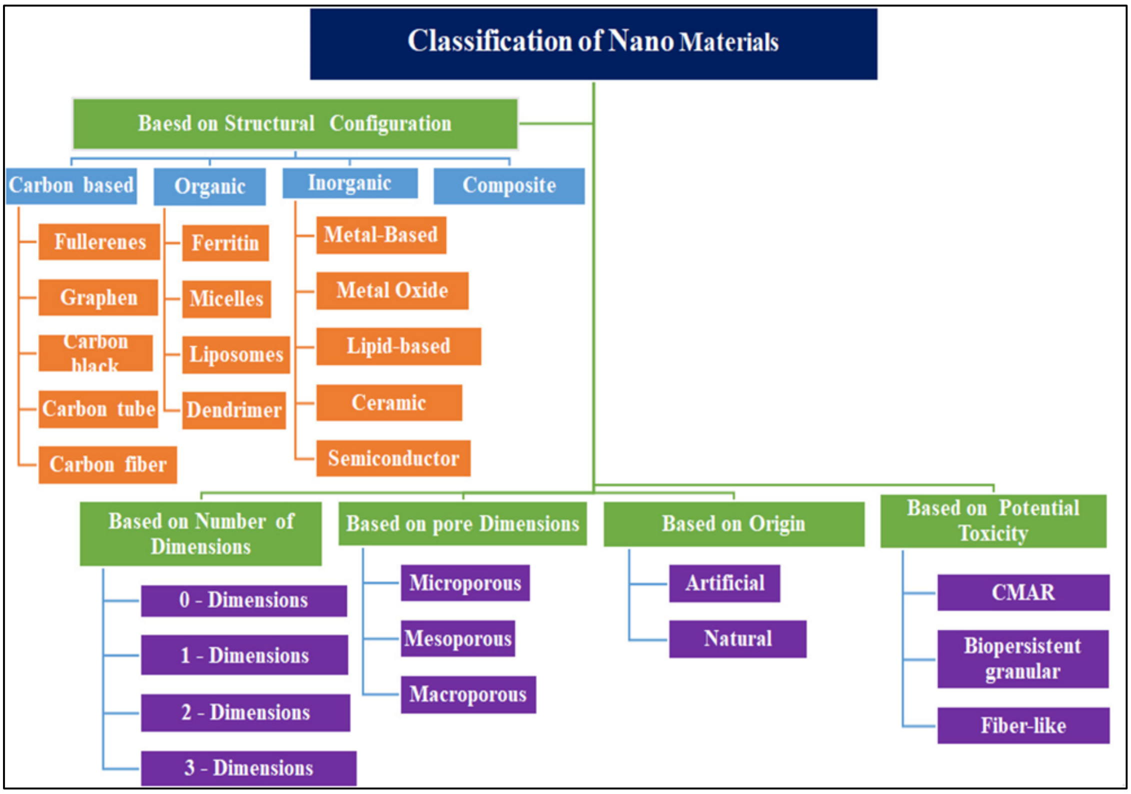

Figure 3 Classification of Nanoparticles [14]

3. Organic nanoparticles

Organic nanoparticles are solid particles with a diameter between 10 nm and 1 µm that are made of organic substances like lipids or polymers [15]. Ferritin, micelles, dendrimers, and liposomes are among the organic nanoparticles depicted in Figure 4. Certain organic nanoparticles, such as liposomes and micelles, contain a hollow sphere and are not harmful or biodegradable. It is also aware of the term for light- and heat-sensitive nano capsules [3]. For medication delivery, it is preferable for researchers to employ organic-based NPs due to their unique features. These substances are effective and potential mediators for the delivery of a drug's active components due to their stability, drug-carrying capacity, and capacity to adsorb or entrap certain drugs [16].

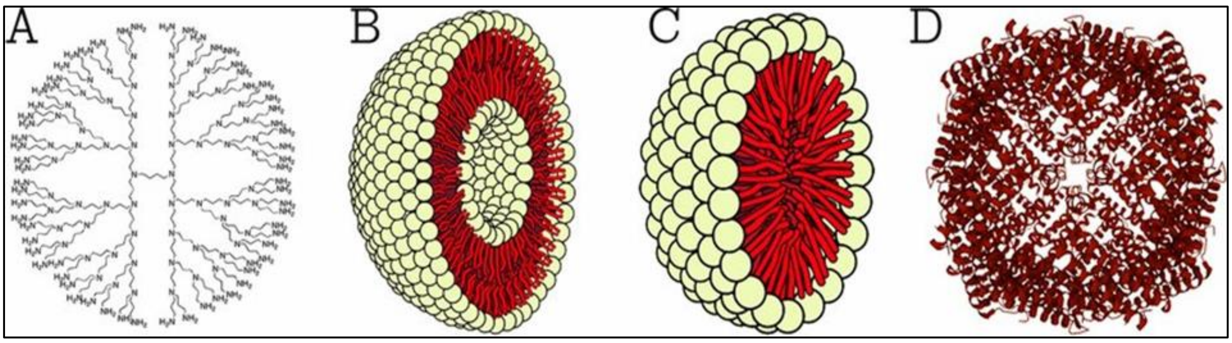

Figure 4 Types of Organic NPs. A) Dendrimers; B) Liposomes; C) Micelles; D) Ferritin [17]

3.1. Dendrimer

Dendrimers are derived from two Greek words: Dendron, which means tree and Meros, which means portion [18]. Dendrimers are highly branched, symmetrical, macromolecular, and hyper-branched structures radiating from a central core via connectors and branching units. Terminal groups are essential for targeting and interactions. Dendrimers are globular and contain three different regions central core, branches and terminal functional groups[19].

4. Inorganic nanoparticles

Non-carbon-based particles are known as inorganic nanoparticles. These are made of metal and metal oxide [20]. Additionally, because of the characteristics of the base material itself, inorganic nanoparticles have special physical, electrical, magnetic, and optical capabilities. For instance, AuNPs have photothermal features because of the free electrons that are constantly oscillating at a frequency that varies according to their size and shape at their surface [4]. Because of their special physical characteristics, inorganic nanoparticles have found applications, most notably in biotechnology [18].

- Metal Nanoparticles
- Metal-Oxide Based Nanoparticles
- Lipids based nanoparticles
- Ceramic based nanoparticles
- Semiconductor Nanoparticles

4.1. Metal Based Nanoparticles

Metals including aluminium (Al), gold (Au), silver (Ag), cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) can be used to create metal-based nanoparticles. Ag, Au, Cu, Fe, and Zn are the metals that are most frequently utilized [15]. Because of their size and composition, they have distinct qualities such as amorphous and crystalline structures, extended surface area, pore size, surface density of charge, colour, and cylindrical and spherical shapes. Air, heat, sunshine, and moisture are examples of environmental variables that also have an impact on NP characteristics [Table 1] [16].

Table 1 Classification of metal NPs and their physio-chemical properties

NP type	Reported Physio-Chemical Properties	References No.
Zinc NP	Antifungal, antibacterial, anticorrosive, UV filtering	21
Lead NP	Reactive, high toxicity, highly stable	22
Copper NP	Highly flammable solids, ductile, very high electrical, thermal conductivity	23
Cadmium NP	Insoluble, semiconductor of electricity	24
Gold NP	Reactive, interactive with visible light	25
Cobalt NP	Magnetic, toxic, absorb microwave unstable	26
Silver NP	Disinfectant, antibacterial, absorbs and scatters light, stable	27
Aluminum NP	Large surface area, highly reactive sensitive to the sunlight, heat, moisture.	28
Iron NP	Sensitive to water and air (O2), reactive, unstable.	29

4.2. Metal - Oxide Based Nanoparticles

Several types of metal oxides, including ZnO, Fe2O3, Al2O3, TiO2, and SiO2, have been produced by hydrothermal or sol-gel processes. In many applications, including catalysts, chemical sensors and semiconductors, a metal oxide has a substantial benefit because of the change in its surface characteristics, which affects the bandgap energy of materials [30].

Table 2 Classification of metal NPs and their physio-chemical properties

NP Type	Reported Physio-Chemical Properties	Reference
Aluminum oxide NP	Large surface area, increased reactivity, sensitivity to sunlight, moisture, heat	31
Zinc oxide NP	UV filtering, antibacterial, anti-corrosive, antifungal	32
Cerium oxide NP	Low reduction potential, antioxidant activity	33

Magnetite NP	Highly reactive, magnetic	34
Silicon dioxide NP	Less toxic, stable, having the ability to functionalize many molecules	35
Iron oxide NP	Unstable, reactive	36
Titanium oxide NP	Magnetic character inhibits bacterial growth, high surface area	37

4.3. Lipid Based Nanoparticles

Lipid-based nanoparticles typically have a diameter of 10–100 nm and are spherical in shape. It is composed of a matrix of soluble lipophilic molecules and a solid lipid core. Lipid-based nanoparticles are used as medication carriers and in RNA-release therapy for cancer treatment [38, 39]

4.4. Ceramic based nanoparticles

Ceramic nanoparticles are also known as nonmetallic solid. The ceramics nanoparticles are synthesized via heating or successive cooling. The ceramic nanoparticles may polycrystalline, amorphous, porous, dens or hollow form. The researcher focus on these nanoparticles due to their wide application such as photo degradation of dye, photocatalysis, catalysis and imaging applications[3].

4.5. Semiconductor based nanoparticles

Semiconductor materials have characteristics in between those of metals and nonmetals, they have been used in a variety of ways. Due to their large bandgaps, semiconductor nanoparticles (NPs) exhibit notable characteristics changes upon bandgap adjustment. For this reason, they are crucial components for electrical devices, photocatalysis, and photooptics (Sun, 2000). For instance, because of their ideal band gap and band edge locations, a range of semiconductor nanoparticles (NPs) are found to be incredibly effective in water splitting applications [40].

5. Carbon based nanoparticles

Two main kinds of carbon-based NPs are fullerenes and carbon nanotubes (CNTs) [40]. Fullerence is composed of nanomaterials, such as allotropic forms of carbon that are globular hollow cages. In addition, they have generated significant commercial interest in nanocomposites for a variety of uses, including fillers, effective gas adsorbents for environmental remediation, and support media for various inorganic and organic catalysts [38].

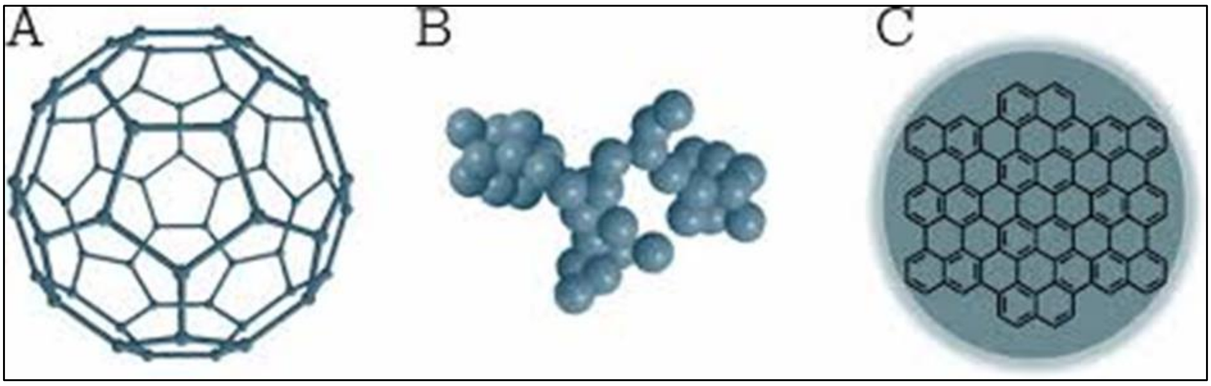

Figure 5 Different types of carbon-based NPs. A) C 60 Fullerence; B) Carbon black NPs; C) Carbon quantum dots[17]

5.1. Fullerence

One of the most well-known and often used fullerenes is Buckminster fullerene (C60). Its form is akin to a football due to the cage-like arrangement of its 60 carbon atoms, each of which has three bonds [41]. Twelve pentagons and twenty hexagons are utilised in the C60 structure. For this structure, resonance stabilisation and icosahedral symmetry are two well-established features. It is used in material research because of its unique combination of physicochemical properties. Recently, a wide range of applications in nanoscience and nanotechnology have made use of C60-based nanostructures, such as nanorods, nanotubes, and nanosheets. Because of its versatility, C60 may be used in a variety of ways to accelerate the reactions of a broad spectrum of chemicals [42].

5.1.1. Graphene and Graphene Oxide (GO)

The fabrication of polymer-based nanocomposites has found graphene to be a useful addition of polymers. [43]. This is because to the exceptional mechanical, electrical, and molecular barrier properties. Pure graphene does have several drawbacks, though, such as a difficult bottom-up production, restricted solubility, and agglomeration problems. This allows for the simple top-down synthesis of graphene oxide and other structurally similar molecules from carbon sources. They are good substitutes for graphene since they are easily synthesized. The effective surface modification and high solubility are facilitated by the diffusion of functionalized oxygen groups on their structural elements. Furthermore, GO performs well in nanocomposite polymers as a filler. This is a result of its superior qualities and good dispersion in polymer matrices. Sp2 carbon atoms obstruct the passage of gas molecules to form a tight structure. It is therefore widely used as a corrosion-resistant material, shield for sensitive electronics, and packaging material [44].

Synthesis methods

There are two types of methodologies used to synthesis the nanoparticles: top-down and bottom-up [13].

Several variables, including the synthesis technique, pH, temperature, pressure, duration, particle size, pore size, surrounding conditions, and proximity, have a significant impact on the amount and quality of the produced nanoparticles as well as their characterisation and uses [45]. The synthesis of nanoparticles has often been accomplished with three distinct methodologies: chemical, biological, and physical. Physical approaches involve the use of a tube furnace at atmospheric pressure for evaporation-condensation to create nanoparticles. The benefits of physical techniques include speed, the use of radiation as a reducing agent, and the absence of toxic chemicals. The drawbacks include high energy consumption and poor yield, contamination of the solvent, and non-uniform distribution [39]. The most used method is chemical reduction, often known as traditional chemical synthesis [46].

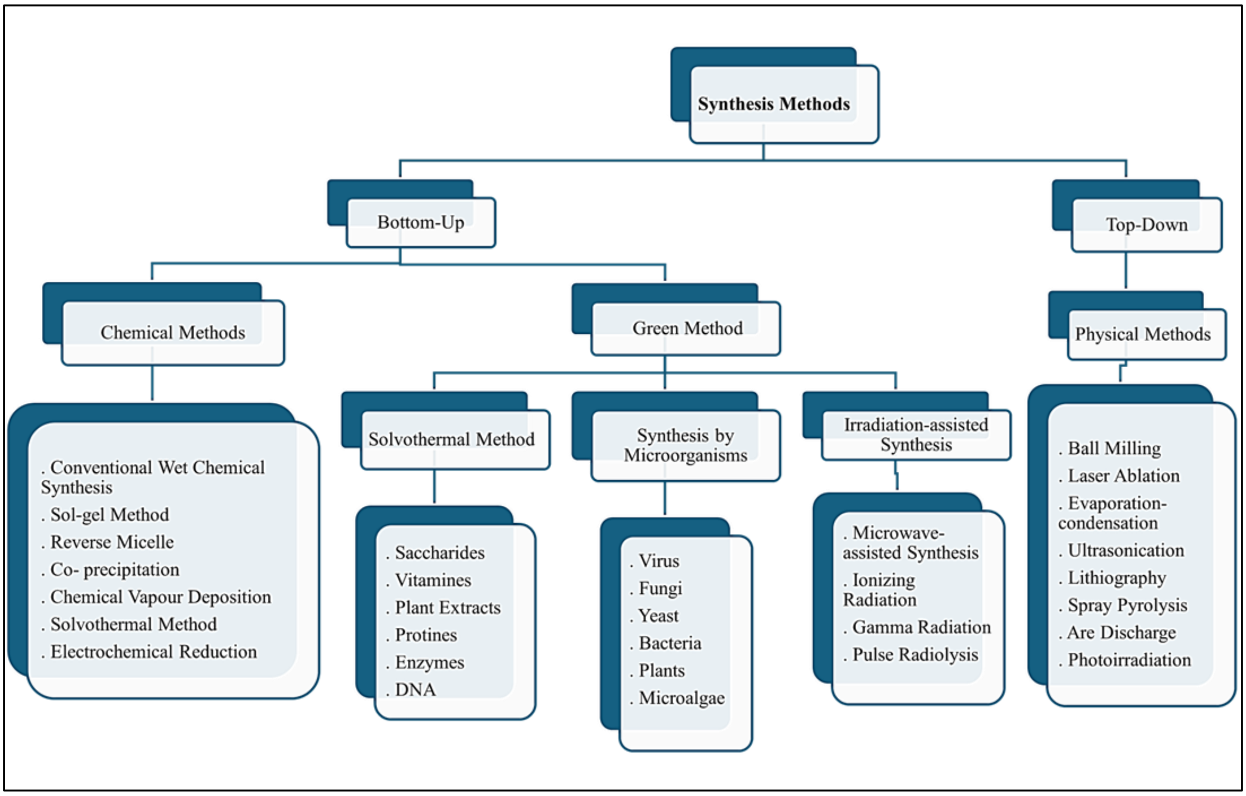

Figure 6 Classification of physical, chemical, and green synthesis methodologies of silver nanostructures with respect to reducing agent type, instruments, and processes [46]

- Top-down method

The destructive process, sometimes referred to as the top-down method, breaks down bulk materials into tiny components that eventually become nanomaterials. Examples of the top-down approach include lithography, thermal decomposition, arc discharge, laser ablation, sputtering, electron explosion, and mechanical or ball milling [14].

- Bottom-up method

The process of building material from atoms to clusters to nanoparticles is known as the bottom-up or constructive approach. The most popular bottom-up techniques for producing nanoparticles include sol-gel, spinning, chemical vapour deposition (CVD), pyrolysis, and biosynthesis [13]. Atom by atom or particle by particle, nanostructures are created during the bottom-up construction process. A high level of supersaturation followed by nuclei development can achieve this [47, 48]. Various scientists have reported a range of chemical and physical ways by taking these two approaches into consideration [49].

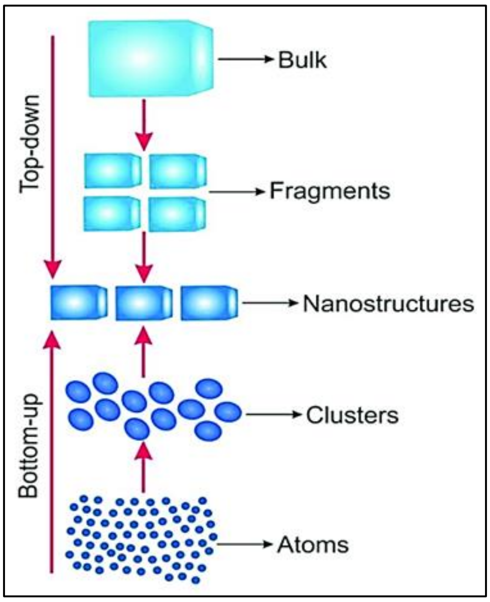

Figure 7 Schematic illustrating the top-down and bottom-up methods for nanoparticle preparation [49]

Table 3 Top-down and bottom-up synthetic techniques with merits, demerits and general remarks [38]

Top–down method	**Merits**	**Demerits**	**General remarks**
Optical lithography	a well-established, long-lasting micro/nano fabrication tool, particularly for chip manufacture, with a high throughput and adequate resolution	Trade-off between resist process sensitivity and resolution necessitates sophisticated, costly, cleanroom-based procedures.	The 193 nm lithography infrastructure has already attained a considerable degree of sophistication and maturity, and the method might be extended to sources of extreme ultraviolet (EUV) light to reduce the dimension. Future advancements must also address the rising expense of a mask set.
E-beam lithography	Well-liked in research settings, a very precise technique, and a useful tool for nanofabrication with a desired shape for nanostructure fabrication less than 20 nm	Expensive, slow (serial writing technique), low throughput, and challenging for less than five nanofabrication	E-beam lithography is able to create periodic nanostructure features by exceeding the light's diffraction limit. Multiple electron beam methods for lithography will be needed in the future to boost throughput and parallelism
Softand nanoimprint lithography	Transferable patterns Easy-to-use, efficient nanofabrication tool for creating features that are less than 10 nm in size.	Densely packed nanostructures are difficult to produce on a wide scale, require additional lithography	Self-assembled nanostructures may offer a practical answer to the issue of producing intricate and expensive templates, particularly for periodic patterns smaller than 10 nm.

		processes to heterogeneate the template, and are typically not cost-effective.	
Block copolymer lithography	A low-cost, high-throughput technique that can be used for large-scale, densely packed nanostructures with a variety of forms, such as spheres, cylinders, and lamella, and that can potentially build parallel assemblies	Complicated self-assembled nanopatterns that require varying periodicity for various functional purposes, typically with high defect concentrations patterns in block copolymer self-assembled	t appears that using triblock copolymers will produce more unusual nanopattern geometries. Additionally, a single-step nanofabrication procedure could produce a hierarchy of nanopatterning by functionalizing sections of the block copolymer
Scanning probe lithography	Ability to manage large molecules and individual atoms; precise control over nanopatterns in resists transfer to silicon; high resolution chemical, molecular, and mechanical nanopatterning capabilities.	Restricted for high-throughput applications and manufacturing, which is a costly operation, especially when it comes to fulltra-high-vacuum-based scanning probelithography.	For advanced bio nanofabrication, which entails the creation of extremely periodic biomolecular nanostructures, scanning probelithography can be utilized.
Bottom–up method	**Merits**	**Demerits**	**General remarks**
Atomic layer deposition	allows for precise atomic-level thickness control by depositing one atomic layer at a time. It also produces large-scale, pin-hole-free nanostructured films with good adhesion and repeatability because chemical bonds occur at the first atomic layer.	Due to the participation of vacuum components, difficult-to-deposit metals, multicomponent oxides, and some technologically significant semiconductors (Si, Ge, etc.) in an economical manner, the process is typically sluggish and costly.	It is a long process, but it does not hinder the production of ultra-thin integrated circuits in the future. Atomic layer deposition can satisfy the challenging specifications for the metal barriers (pure, dense, conductive, conformal, thin) used in contemporary Cu-based chips.
Sol gel nanofabrication	low-cost chemical synthesis procedure is used to fabricate a wide range of nanomaterials, including composite materials, glass, ceramic, film, and fiber	Notably scalable, typically challenging to manage synthesis and the ensuing drying processes	A versatile nanofabrication technique that can be scaled up with more advancements in the phases of synthesis
Molecular self-assembly	produces anatomically precise nanosystems by enabling the self-assembly of deep molecular nanopatterns with a width of less than 20 nm and enormous pattern expansions	Nanosystems are difficult to design and build, unlike mechanically directed assemblies.	Multimaterial molecular self-assembly could be a valuable strategy for creating multifunctional nanosystems and gadgets.

Physical and chemical vapor phase deposition	Tools for the versatile synthesis of nanomaterials, such as multicomponent, complex systems (such nanocomposites), and controlled, simultaneous deposition of multiple materials with high purity nanofilms, a scalable method, the ability to deposit porous nanofilms, and materials such as metal, ceramics, semiconductors, insulators, and polymers	Expensive vacuum components, a high temperature procedure, and hazardous and corrosive gases especially in the case of chemical vapor deposition make it less economical.	It offers a special chance to create extremely complex nanostructures using a variety of materials with unique features that are not able to achieve by utilizing the majority of alternative nanofabrication methods. "Initiated chemical vapor deposition" (i-CVD), one of the latest developments in chemical vapor deposition, offers previously unheard-of possibilities for forming polymers without lowering their molecular weights.
DNA scaffolding	provides for the highly accurate assembly of nanoscale parts into programmable configurations with far smaller dimensions (less than 10 nm in half-pitch)	Numerous topics need to be investigated, including throughput, cost, line edge roughness, compatibility with CMOS fabrication, and innovative unit and integration procedures	Quite early on, The semiconductor industry's propensity to invest in infrastructure, yield, and production costs will ultimately determine its level of success.

6. Application of Silver Nanoparticles

6.1. Antibacterial Applications

The fields of health and medicine have conducted the greatest research and development of technology that utilise nanoparticles' antibacterial properties. [50,51,52] Nano drug delivery systems can maintain drug release and avoid drug degradation resulting in great potential to improve drug therapy. [53] A concerning development in modern medicine is the prevalence of drug-resistant bacteria, which conventional monotherapy ineffective. One significant and common cause of mortality is bacterial infections and the consequences they might induce [54,55].

Using AgNPs in face masks to boost their protective capacity is one of their primary uses [56]. The efficiency of the amtimicrobial activity of AgNPs can be improved by combining them with other compounds, such as other nanoparticals and/or biological compounds [57].

6.2. Anti-fungal Application

Immunosuppressed individuals are more susceptible to fungal infections, and treating fungi-mediated illnesses might be difficult due to the scarcity of antifungals now. Different AgNPs were tested for their size-dependent antifungal properties against mature Candida albicans and Candida glabrata biofilms. At a dosage of 15 mg, biologically synthesised AgNPs showed antifungal action against several phytopathogenic fungi, such as Alternaria alternata, Sclerotinia sclerotiorum, Rhizoctonia solani, Botrytis cinerea, and Curvularia lunata [39].

6.3. 3] Anti-viral application

Viruses have been identified as one of the worst human disease pathogens in recorded human history. Notwithstanding their seeming structural simplicity, viruses pose a serious threat to humans when it comes to deadly illnesses like HIV, Ebola, Marburg, Spanish influenza, and, most recently, the COVID-19 pandemic of 2020. This shows us how little we know about combating viruses. Viruses are harmful when they adhere to and penetrate host cells. In this instance, the virus uses its own protein constituents to attach to ligands and proteins on the surface of the cell membrane. Keeping such binding from happening seems to be the strongest defence against cell infection. Although the exact mechanism underlying AgNPs' antiviral effect is yet unknown, the following information has been reported in the literature: (i) AgNPs connect to the virus's protective coat protein, inhibiting attachment; and (ii) AgNPs bind to the virus's DNA or RNA, preventing the virus from replicating or growing within host cells [58].

6.4. Anti-cancer application

A new era in cancer detection, therapy, and management has been ushered in by the application of nanotechnology. NPs increase the intracellular concentration of medications while preventing toxicity in healthy tissue by either active or passive targeting [59]. One of the leading causes of mortality in the modern world, cancer claims the lives of roughly 10 million people each year. The anti-tumor properties of silver nanoparticles, or AgNPs, are also the subject of much research. AgNPs have the power to increase the generation of reactive oxygen species (ROS), which destroys the cancer cells' mitochondrial respiratory chain. AgNPs have demonstrated encouraging anti-cancer properties [49 & 60]. It is commonly recognised that excessive ROS formation can cause toxicity by damaging the mitochondrial membrane, which can harm cells. [61] Cancer is characterised by genetic abnormalities that disrupt the cell cycle, which includes a complex network of signalling channels for cell growth, DNA replication, and division. This disruption results in unchecked cell proliferation. Therefore, the primary sites for the arrest include the most critical phases of the cell cycle, including DNA synthesis (S), Gap2/mitosis (G2/M), Gap1 (G0/G1), and subG1 [62].

7. Conclusion

Nanoparticles play a crucial role in various fields due to their unique properties and applications. The review covered the characterization and classification of nanoparticles, different synthesis methods, with a focus on silver nanoparticles. Silver nanoparticles, known for their antimicrobial properties, have a wide range of applications in pharmacy.

By understanding the synthesis methods and applications of silver nanoparticles, researchers can further explore their potential in developing innovative solutions for various challenges. The comprehensive review provides a solid foundation for future studies and applications of nanoparticles, contributing to advancements in science and technology.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Pal S. L., Jana U., Manna P. K., Mohanta G. P., & Manavalan, R. Nanoparticle: An overview of preparation and characterization. Journal of applied pharmaceutical science, 2011; (Issue): 228-234.

[2] Mikhailova E. O. Silver nanoparticles: Mechanism of action and probable bio-application. Journal of functional biomaterials, 2020; 11(4):84.

[3] Ijaz I., Gilani E., Nazir A., & Bukhari A. Detail review on chemical, physical and green synthesis, classification, characterizations and applications of nanoparticles. Green Chemistry Letters and Reviews, 2020;13(3): 223-245.

[4] Mitchell M. J., Billingsley M. M., Haley R. M, Wechsler M. E., Peppas N. A., & Langer R. Engineering precision nanoparticles for drug delivery. Nature reviews drug discovery, 2021; 20(2): 101-124.

[5] Malhotra N, Lee J. S., Liman R. A. D., Ruallo J. M. S., Villaflores O. B., Ger T. R., & Hsiao C. D. Potential toxicity of iron oxide magnetic nanoparticles: a review. Molecules, 2020; 25(14):3159.

[6] Jadoun S., Arif R., Jangid, N. K., & Meena, R. K. Green synthesis of nanoparticles using plant extracts: A review. Environmental Chemistry Letters, 2021; 19: 355-374.

[7] Mendake R. A., Hatwar P. R., Bakal R. L., Hiwe K.A. and Barewar S. S. Advance and opportunities in nanoparticle drug delivery for central nervous system disorders: A review of current advances. GSC Biological and Pharmaceutical Sciences. 2024; 27(03): 044-058.

[8] Bruna T., Maldonado-Bravo F., Jara P., & Caro N. Silver nanoparticles and their antibacterial applications. International Journal of Molecular Sciences, 2021; 22(13): 7202.

[9] Kim T., Braun G. B., She Z. G., Hussain S., Ruoslahti E., & Sailor M. J. Composite Porous silicon–silver nanoparticles as theranostic antibacterial agents. ACS Applied Materials & Interfaces, 2016; 8(44): 30449-30457.

[10] Thuesombat P., Hannongbua S., Akasit S., & Chadchawan S. Effect of silver nanoparticles on rice (Oryza sativa L. cv. KDML 105) seed germination and seedling growth. Ecotoxicology and environmental safety, 2014; 104: 302-309.

[11] Nguyen N.P.U.; Dang N.T.; Doan L.; Nguyen, T.T.H. Synthesis of Silver Nanoparticles: From Conventional to 'Modern' Methods-A Review. Processes 2023; 11: 2617.

[12] Gamboa S. M., Rojas E. R., Martínez V. V., & Vega-Baudrit, J. Synthesis and characterization of silver nanoparticles and their application as an antibacterial agent. Int. J. Biosen. Bioelectron, 2019; 5: 166-173.

[13] Ealia SAM., & Saravanakumar MP. A review on the classification, characterisation, synthesis of nanoparticles and their application. In IOP conference series: materials science and engineering 2017; 263(3):032019.

[14] Mekuye B., & Abera B. Nanomaterials: An overview of synthesis, classification, characterization, and applications. Nano select. 2023; 4:486-500.

[15] Kumari S., & Sarkar L. A review on nanoparticles: Structure, classification, synthesis & applications. J. Sci. Res. 2021; 65(8): 42-46.

[16] Zahoor M., Nazir N., Iftikhar M., Naz S., Zekker I., Burlakovs J. & Ali Khan F. A review on silver nanoparticles: Classification, various methods of synthesis, and their potential roles in biomedical applications and water treatment. Water, 2021; 13(16): 2216.

[17] Joudeh N., & Linke D. Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists. Journal of Nanobiotechnology, 2022; 20(1): 262.

[18] Heera P., & Shanmugam S. Nanoparticle characterization and application: an overview. Int. J. Curr. Microbiol. App. Sci, 2015; 4(8): 379-386.

[19] Gurunathan S., Qasim M., Choi Y., Do J. T., Park C., Hong K., & Song H. Antiviral potential of nanoparticles—Can nanoparticles fight against coronaviruses? Nanomaterials, 2020; 10(9): 1645.

[20] M. Mohan Varma, K. T. Sunil Kumar and I. Durga Srivalli*. A Review on nanoparticles: synthesis, characterization and applications. World journals of pharmaceutical and medical research, 2021; 7(8): 169 – 179.

[21] Ali, A., Phull, A. R., & Zia, M. (2018). Elemental zinc to zinc nanoparticles: Is ZnO NPs crucial for life? Synthesis, toxicological, and environmental concerns. Nanotechnology Reviews, 2018; 7(5): 413-441.

[22] Hasan, A., Nanakali, N. M. Q., Salihi, A., Rasti, B., Sharifi, M., Attar, F., & Falahati, M. Nanozyme-based sensing platforms for detection of toxic mercury ions: An alternative approach to conventional methods. Talanta, 2020; 215: 120939.

[23] Sarwar, N., Choi, S. H., Dastgeer, G., Humayoun, U. B., Kumar, M., Nawaz, A., & Yoon, D. H. Synthesis of citrate-capped copper nanoparticles: A low temperature sintering approach for the fabrication of oxidation stable flexible conductive film. Applied Surface Science, 2021; 542: 148609.

[24] Tiwary, K. P., Ali, F., Choubey, S. K., Mishra, R. K., & Sharma, K. Doping effect of Ni2+ ion on structural, morphological and optical properties of Zinc sulfide nanoparticles synthesized by microwave assisted method. Optik, 2021; 227: 166045.

[25] Jena, P., Bhattacharya, M., Bhattacharjee, G., Satpati, B., Mukherjee, P., Senapati, D., & Srinivasan, R. Bimetallic gold–silver nanoparticles mediate bacterial killing by disrupting the actin cytoskeleton MreB. Nanoscale, 2020; 12(6); 3731-3749.

[26] Xu, Z., Zhao, H., Liang, J., Wang, Y., Li, T., Luo, Y., & Sun, X. Noble-metal-free electrospun nanomaterials as electrocatalysts for oxygen reduction reaction. Materials Today Physics, (2020); 15: 100280.

[27] Tanaka, M., Saito, S., Kita, R., Jang, J., Choi, Y., Choi, J., & Okochi, M. Array-based screening of silver nanoparticle mineralization peptides. International Journal of Molecular Sciences, (2020); 21(7): 2377.

[28] Shi, X.; Qiao, Y.; An, X.; Tian, Y.; Zhou, H. Performance and mechanism. Int. J. Biol. Macromol. 2020, 159, 839–849.

[29] Harshiny, M., Iswarya, C. N., & Matheswaran, M. Biogenic synthesis of iron nanoparticles using Amaranthus dubius leaf extract as a reducing agent. Powder technology, 2015; 286: 744-749.

[30] Saleh T. A. Nanomaterials: Classification, properties, and environmental toxicities. Environmental Technology & Innovation, (2020); 20: 101067.

[31] Yu, H., Wang, M., Zhou, J., Yuan, B., Luo, J., Wu, W., & Yu, R. Microreactor-assisted synthesis of α-alumina nanoparticles. Ceramics International, (2020); 46(9): 13272-13281.

[32] Sharma S., Virk K., Sharma K., Bose S. K., Kumar, V., Sharma, V., & Kalia, S. Preparation of gum acacia-poly (acrylamide-IPN-acrylic acid) based nanocomposite hydrogels via polymerization methods for antimicrobial applications. Journal of Molecular Structure, (2020); 1215; 128298.

[33] Singh K. R., Nayak V., Sarkar T., & Singh R. P. (2020). Cerium oxide nanoparticles: properties, biosynthesis and biomedical application. RSC advances, (2020); 10(45): 27194-27214.

[34] Das C., Sen S., Singh T., Ghosh T., Paul S. S., Kim T. W., & Biswas G,. Green synthesis, characterization and application of natural product coated magnetite nanoparticles for wastewater treatment. Nanomaterials, (2020); 10(8):1615.

[35] Cheira M. F. Performance of poly sulfonamide/nano-silica composite for adsorption of thorium ions from sulfate solution. SN Applied Sciences, (2020); 2(3): 398.

[36] Giannakis S., Liu S., Carratalà A., Rtimi S., Amiri M. T., Bensimon, M., & Pulgarin, C. (2017). Iron oxide-mediated semiconductor photocatalysis vs. heterogeneous photo-Fenton treatment of viruses in wastewater. Impact of the oxide particle size. Journal of hazardous materials, (2017); 339: 223-231.

[37] Laad M., & Jatti V. K. S. Titanium oxide nanoparticles as additives in engine oil. Journal of King Saud University-Engineering Sciences, (2018); 30(2): 116-122.

[38] Khan I., Saeed K., & Khan I. Nanoparticles: Properties, applications and toxicities. Arabian journal of chemistry, (2019); 12(7): 908-931.

[39] Zhang X. F., Liu Z. G., Shen W., & Gurunathan, S. Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches. International journal of molecular sciences, (2016); 17(9):1534.

[40] Patil A A. Nanoparticles: Properties, Applications and Toxicities. International Journal of Innovative Science, Engineering & Technology, (2020); 8(5): 246-261.

[41] Khan Y., Sadia H., Ali Shah S. Z., Khan M. N., Shah A. A., Ullah N., & Khan M. I. Classification, synthetic, and characterization approaches to nanoparticles, and their applications in various fields of nanotechnology: A review. Catalysts, (2022); 12(11): 1386.

[42] Coro J., Suarez M., Silva L. S., Eguiluz K. I., & Salazar-Banda, G. R. Fullerene applications in fuel cells: A review. International Journal of Hydrogen Energy, (2016); 41(40): 17944-17959.

[43] Smith A. T., LaChance A. M., Zeng S., Liu, B., & Sun L. Synthesis, properties, and applications of graphene oxide/reduced graphene oxide and their nanocomposites. Nano Materials Science, (2019); 1(1): 31-47.

[44] Ghauri F. A., Raza M. A., Baig M. S., & Ibrahim S. Corrosion study of the graphene oxide and reduced graphene oxide-based epoxy coatings. Materials Research Express, (2017); 4(12): 125601.

[45] Qamer S., Romli M. H., Che-Hamzah F., Misni N., Joseph N. M., Al-Haj N. A., & Amin-Nordin S. Systematic review on biosynthesis of silver nanoparticles and antibacterial activities: Application and theoretical perspectives. Molecules, (2021); 26(16): 5057.

[46] Kaabipour S., & Hemmati S. A review on the green and sustainable synthesis of silver nanoparticles and one-dimensional silver nanostructures. Beilstein Journal of Nanotechnology, (2021); 12(1): 102-136.

[47] Nicosia A., Vento F., Pellegrino A. L., Ranc V., Piperno A., Mazzaglia A., & Mineo P. Polymer-based graphene derivatives and microwave-assisted silver nanoparticles decoration as a potential antibacterial agent. Nanomaterials, (2020); 10(11): 2269.

[48] Quinteros M. A., Aiassa Martínez I. M., Dalmasso P. R., & Páe, P. L. Silver nanoparticles: biosynthesis using an ATCC reference strain of Pseudomonas aeruginosa and activity as broad spectrum clinical antibacterial agents. International journal of biomaterials, 2016.

[49] Chandrakala V., Aruna V., & Angajala G. Review on metal nanoparticles as nanocarriers: Current challenges and perspectives in drug delivery systems. Emergent Materials, (2022); 5(6): 1593-1615.

[50] Gherasim O., Puiu R. A., Bîrcă A. C., Burdușel A. C., & Grumezescu A. M. An updated review on silver nanoparticles in biomedicine. Nanomaterials, (2020); 10(11): 2318.

[51] Yaqoob A. A., Umar K., & Ibrahim M. N. M. Silver nanoparticles: various methods of synthesis, size affecting factors and their potential applications–a review. Applied Nanoscience, (2020); 10: 1369-1378.

[52] Vimbela G. V., Ngo S. M., Fraze C., Yang L., & Stout D. A. Antibacterial properties, and toxicity from metallic nanomaterials. International journal of nanomedicine, (2017); 3941-3965.

[53] Watmode D.S, Kubde J. A, Hatwar P. R, Bakal R. L. and Kohale N. B. A review on liposome as a drug delivery system for antibiotics. GSC Biological and Pharmaceutical Sciences, 2024, 28(01), 017–029

[54] Kern W. V., & Rieg S. Burden of bacterial bloodstream infection a brief update on epidemiology and significance of multidrug-resistant pathogens. Clinical Microbiology and Infection, (2020); 26(2): 151-157.

[55] Saldana C. S., Vyas D. A., & Wurcel A. G. Soft tissue, bone, and joint infections in people who inject drugs. Infectious Disease Clinics, (2020); 34(3): 495-509.

[56] Li, Y., Leung, P., Yao, L., Song, Q. W., & Newton, E. (2006). Antimicrobial effect of surgical masks coated with nanoparticles. Journal of Hospital Infection, (2006); 62(1): 58-63.

[57] Rodrigues MP, Pinto PN, Dias RR, Biscoto GL, Salvato LA, Millán RD, Orlando RM, Keller KM. The antimicrobial applications of nanoparticles in veterinary medicine: A comprehensive review. 2023;12(6):958.

[58] Salleh A., Naomi R., Utami N. D., Mohammad A. W., Mahmoudi E., Mustafa N., & Fauzi M. B. The potential of silver nanoparticles for antiviral and antibacterial applications: A mechanism of action. Nanomaterials, (2020); 10(8): 1566.

[59] Gavas S., Quazi S., & Karpiński T. M. Nanoparticles for cancer therapy: current progress and challenges. Nanoscale research letters, (2021); 16(1): 173.

[60] Balmain, A., Gray, J., & Ponder, B. The genetics and genomics of cancer. Nature genetics, (2003); 33(3): 238-244.

[61] Sourabh Dwivedi, Maqsood A. Siddiqui, Nida N. Farshori, Maqusood Ahamedd, Javed Musarrat, Abdulaziz A. Al-Khedhairya. Synthesis, characterization and toxicological evaluation of iron oxide nanoparticles in human lung alveolar epithelial cells. Colloids and Surfaces B: Biointerfaces.2014; 122: 209–215.

[62] Ratan Z. A., Haidere M. F., Nurunnabi M. D., Shahriar S. M., Ahammad A. S., Shim Y. Y., & Cho J. Y. Green chemistry synthesis of silver nanoparticles and their potential anticancer effects. Cancers, (2020); 12(4): 855.