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The Fascinating World of Silver Nanoparticles: Exploring Synthesis, Characterization, and their Crucial Role in Shaping Nanotechnology

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ABSTRACT

Nanotechnology has made significant advancements in diverse scientific disciplines, including medicinal, biological, and chemical sciences, in recent decades. The development of techniques for creating nanoparticles of varying sizes and shapes has contributed to the widespread application of nanotechnology in industries such as agriculture and medicine. Among the plethora of nanoparticles, silver nanoparticles have attracted considerable attention due to their unique chemical and physical properties. Extensive global research is currently underway to explore diverse methods of synthesizing nanoparticles, taking into account their specific applications, availability, and requirements. Each synthesis method offers distinct advantages and potential applications within the realm of chemistry. However, it is crucial to address concerns regarding the potential cytotoxicity of excessive silver nanoparticles and their impact on the environment if released without appropriate controls. Ongoing research efforts aim to develop technologies that maximize the benefits of silver nanoparticles while minimizing risks to both the environment and human health. This article provides a critical examination of various nanoparticle synthesis techniques, highlights the advantages of employing different sizes and forms, and explores potential applications of nanotechnology in the field of chemistry. The keywords associated with this review encompass silver nanoparticles, nanotechnology, synthesis, characterization, and applications in chemistry.

Research Highlights

- Due to considerable chemical and physical properties, silver nanoparticles are the subject of extensive research on a global scale.
- Silver nanoparticles have shown promise in the detection and identification of trace evidence in forensic investigations.
- They can be used as nanoprobes to enhance the visualization and analysis of fingerprints, bloodstains, fibers, and other types of evidence.
- The antimicrobial properties of silver nanoparticles make them valuable in preserving and protecting forensic evidence from degradation or contamination.
- Their unique optical properties enable improved detection and imaging of minute details in forensic samples.
- This article examines various techniques for creating nanoparticles, the benefits of using various sizes and forms, and finally how forensic can use nanotechnology.

GRAPHICAL ABSTRACT

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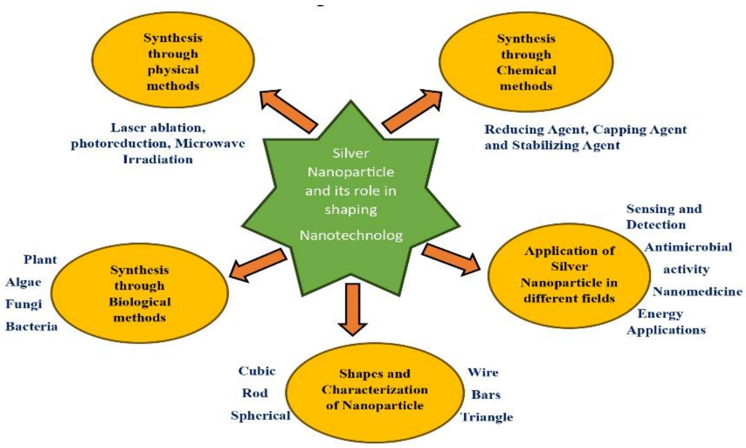

1. INTRODUCTION

Traditional optical microscopy is limited in its ability to study nanoparticles due to their size falling below the diffraction limit of visible light. These particles typically range in dimensions from 10 nm to 100 nm. To characterize nanomaterials, researchers rely on two main techniques: microscopic imaging and spectroscopic analysis. While imaging techniques employ various microscopy methods like ion or atomic force microscopy, examining these particles at the nanoscale has been made possible through innovative techniques. However, merely relying on imaging alone does not provide a comprehensive understanding of the chemical, structural, and optical properties of these materials. To address this, spectroscopic approaches have gained significance, offering solutions to these challenges. These spectroscopic methods provide valuable insights for elemental and structural research, opening up new avenues for investigating nanomaterials [1]. The green synthesis of nanoparticles offers a promising solution to address environmental problems, energy resource shortages, and dependence on chemically manufactured nanoparticles. Green nanoparticles are produced using safer and more controllable methods. These nanoparticles can be derived from various sources, including plants, algae, fungi, bacteria, seaweed, and other organisms. One of the key advantages of utilizing silver or gold nanoparticles derived from plant extracts is the ability to perform the synthesis in water at ambient temperature and atmospheric pressure. The term "bottom-up approach" refers to the process of assembling smaller components to create more complex aggregates, using nanoscale chemical or physical forces. On the other hand, the top-down approach involves the growth of smaller nanoscale particles from larger ones.

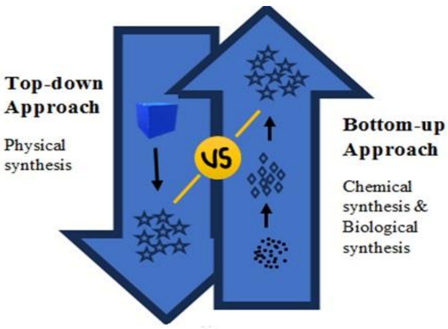

Fig. 1: Top-down and bottom-up approach.

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The remarkable properties of nanoparticles are significantly influenced by factors such as the manufacturing
process, interactions with stabilizers, nanoparticle size and shape, and interactions with the surrounding media. Consequently, achieving the desired superior properties of nanoparticles for various applications relies on the regulated synthesis of nanocrystals in different shapes.
Preparation of silver nanoparticle: synthesis, as its name suggests, refers to the process of getting nanoparticles ready for a certain use. The target field of the current research focuses on the production of nanoparticles, drug extraction, and drug detection using nanoparticles. There are numerous preparation techniques that have been documented for the creation of nanoparticles. Example includes biological synthetic techniques, microwave processing, ion sputtering, sol gel gamma irradiation, chemical reduction photochemical processes, and laser ablation.
Physical approaches for silver nanoparticle synthesis: two prominent physical processes employed in the synthesis of silver nanoparticles are evaporation-based condensation and laser ablation. When compared to chemical methods, physical approaches offer advantages such as enhanced uniformity and the absence of solvent contamination in the resulting thin films. However, physical methods do have certain drawbacks, including the time and energy requirements associated with using a tube furnace under pressure to achieve thermal stability, which can be quite significant due to the large space occupied by the tube in a recent study, researchers (referred to by their last names) investigated a novel approach for the synthesis of silver nanoparticles using laser ablation. The experimental procedure involved exposing an ag target to specific radiation in a controlled environment. By optimizing the laser pulse intensity and employing a lens to focus the laser beam onto the target, the researchers successfully produced silver nanoparticles within a short time frame. Notably, their findings highlighted the crucial influence of laser beam characteristics and focusing conditions on the resulting nanoparticles. These findings contribute to the ongoing advancements in nanoparticle synthesis techniques [2]. In recent studies on silver nanoparticle synthesis using laser ablation techniques, the influence of different solvents and laser parameters was examined. When ethanol was used instead of pure water, a decrease in the rate of nanoparticle formation was observed initially, but there was no significant change for higher laser impulses. Interestingly, higher laser pulse energy led to increased concentration and absorption of nanoparticles. The characteristics of the synthesized silver nanoparticles were controlled by multiple factors such as laser wavelength, ablation time, and energy. Particle size played a crucial role, as evidenced by the correlation between particle size and the laser's ability to focus a colloidal solution. Researchers discovered that the size of silver colloids decreased with an increase in the number of laser pulses at a wavelength of 1064 nm. Similar investigations were conducted for the production of gold colloids. Overall, these findings highlight the intricate relationship between particle size and laser irradiation, offering insights into the optimization of nanoparticle synthesis [3-5].

2. The benefit of using a laser for ablation is that no chemicals are utilized at any point in the process

Chemical-based Preparation of Silver Nanoparticles

Various techniques are employed for the synthesis of silver nanoparticles, including microemulsion, chemical reduction, UV photoinduced, initiated photoreduction, tollens procedures using polymers or polysaccharides, photoinduced, electrochemical synthesis, and microwave-assisted synthesis. Among these methods, chemical reduction is the most extensively studied approach. Capping agents are utilized to prevent the agglomeration of reduced silver ions and stabilize the nanoparticles. Several chemicals have been identified as effective reducing and capping agents in nanoparticle synthesis. Here is a compilation of different chemicals that have demonstrated efficacy in these roles.

Reducing Agents

Reducing agents are utilized to facilitate the reduction of metal ions into nanoparticles during synthesis. They provide electrons to the metal ions, leading to their conversion into metallic nanoparticles. Some commonly used reducing agents include:
a. **Sodium Borohydride ($NaBH_4$):** $NaBH_4$ is a popular reducing agent known for its ability to efficiently reduce metal ions, including silver and gold ions, to form corresponding nanoparticles.

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b. **Ascorbic Acid**: Also known as Vitamin C, ascorbic acid acts as a reducing agent in nanoparticle synthesis. It has a strong reducing property and can effectively convert metal ions into nanoparticles.

c. **Hydroxylamine**: Hydroxylamine is another commonly employed reducing agent, particularly in the synthesis of noble metal nanoparticles. It is capable of reducing metal ions and facilitating nanoparticle formation.

d. **Polyols**: Polyols, such as ethylene glycol and glycerol, can act as both reducing agents and solvents in certain nanoparticle synthesis methods. They provide a reducing environment and help stabilize the formed nanoparticles.

e. Sodium citrate: Similar to citric acid, sodium citrate is utilized as both a reducing agent and a capping agent. It aids in the reduction of silver ions to silver nanoparticles while preventing their agglomeration.

Capping Agents

Capping agents play a crucial role in nanoparticle synthesis by preventing the agglomeration or growth of nanoparticles. They bind to the nanoparticle surface, creating a protective layer that stabilizes the nanoparticles. Some commonly used capping agents include:

a. Citrate: Sodium citrate is frequently used as a capping agent, particularly in the synthesis of gold nanoparticles. It adsorbs onto the nanoparticle surface, providing stability and preventing agglomeration.

b. PVP (Polyvinylpyrrolidone): PVP is a versatile capping agent used in the synthesis of various nanoparticles. It forms a protective layer around the nanoparticles, preventing their aggregation and enhancing their stability.

c. CTAB (Cetyltrimethylammonium Bromide): CTAB is a surfactant commonly employed as a capping agent for the synthesis of silver nanoparticles. It aids in stabilizing the nanoparticles by forming a positively charged layer on their surface.

d. Silica: Silica nanoparticles can act as capping agents for other nanoparticles. They form a shell around the core nanoparticles, providing stability and protection.

Stabilizing Agents

Stabilizing agents are essential in nanoparticle synthesis as they prevent agglomeration or aggregation of nanoparticles, ensuring their stability and dispersibility. Stabilizing agents can include surfactants, polymers, proteins, biomolecules, inorganic salts, and ligands. They interact with the nanoparticle surface, creating a barrier that inhibits particle-particle interactions.

Surfactants, such as CTAB and SDS, form a protective layer around the nanoparticles, preventing their agglomeration. Polymers like PVA and PEG provide steric hindrance, preventing particle aggregation. Proteins and biomolecules like BSA and DNA can bind to the nanoparticle surface, stabilizing them through interactions. Inorganic salts like NaCl and sodium citrate interact with the nanoparticle surface, providing stability. Ligands, such as thiol-containing compounds and amines, can bind to the nanoparticle surface and control their surface properties.

The choice of reducing, capping, and stabilizing agents depends on the specific synthesis method, desired nanoparticle properties, and intended applications. It is important to select appropriate agents to achieve the desired characteristics and stability of the nanoparticles.

Various chemicals, including silver nitrate and silver sulphate, are used as metal precursors in the synthesis of silver nanoparticles. Different reducing agents, such as hydrazine, formaldehyde, and ascorbic acid, are employed to reduce the metal precursors and produce nanoparticles. The size of the nanoparticles can be controlled by adjusting the concentrations of the reducing agents and stabilizers like SDS. Additionally, the choice of reducing agent should be balanced with the redox potential to prevent rapid nucleation or aggregation. Studies have shown the influence of surfactant and reducing agent concentrations, with ascorbic acid being highlighted for its role in particle dispersion and agglomeration control. Overall, the selection and manipulation of chemicals in nanoparticle synthesis are crucial for achieving desired characteristics [6,7].

Advantages of chemical-based synthesis

- **Versatility**: Chemical methods provide a wide range of options for the synthesis of silver nanoparticles. Various reducing agents, stabilizers, and metal precursors can be employed, allowing for flexibility in controlling the size, shape, and properties of the nanoparticles.

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- **Control over Particle Characteristics**: Chemical methods offer precise control over the synthesis conditions, enabling the manipulation of parameters such as reaction time, temperature, and concentration. This control allows for the fine-tuning of particle size, uniformity, and purity, resulting in nanoparticles with desired characteristics.
- **Scalability**: Chemical-based synthesis methods are often scalable, making it possible to produce silver nanoparticles in large quantities for industrial applications. The reproducibility of the chemical processes ensures consistent quality and performance of the nanoparticles.
- **Efficiency**: Chemical-based methods can yield high conversion rates, leading to a higher production yield of silver nanoparticles. This efficiency is crucial for cost-effective and sustainable nanoparticle manufacturing.
- **Tailored Functionalization:** Chemical synthesis allows for the introduction of functional groups or surface modifications during the nanoparticle preparation. This capability enables the attachment of ligands, biomolecules, or other entities onto the nanoparticle surface, facilitating their use in various applications such as catalysis, sensing, and drug delivery.
- **Compatibility with Additives:** Chemical methods can incorporate additives or dopants into the nanoparticle synthesis, enabling the production of hybrid nanoparticles with enhanced properties or specific functionalities.

Chemical reduction is widely employed for the preparation of silver nanoparticles due to its simplicity and versatility. This method allows for precise adjustment of parameters such as dispersant, feed rate, molar ratio, and concentration to achieve the desired particle size, shape, and dispersion. One of the major advantages of chemical synthesis is the high efficiency and absence of particle aggregation compared to other methods. Moreover, it offers cost-effectiveness, shorter synthesis time, and the ability to be carried out at room temperature in a standard laboratory environment without the need for expensive equipment. Through careful control of substrate concentrations, this approach enables precise control over the size of colloidal particles.

Biological methods

Numerous publications highlight the growing interest in greener approaches for nanoparticle synthesis, drawing experts worldwide. Green synthesis offers advantages over conventional methods, including enhanced stability, cost-effectiveness, safety, and ease of production. By utilizing natural sources like plants, algae, fungi, and bacteria, biological processes for nanoparticle synthesis are preferred, as they are biodegradable and align with green technologies. These biological substances serve as both stabilizing and reducing agents, further enhancing the stability of the resulting nanoparticles.

Synthesis from plants

Utilizing plant extracts for nanoparticle manufacturing is both economical and environmentally responsible. Additionally, plants and their products are readily available throughout the year and can be used in the synthesis of nanoparticles.

Numerous types of plants and plant extracts are employed to make nanoparticles, according to studies [9-13]. Examples include the marigold flower, beet root, mangosteen, spirogyra varieties, holy basil, olive, melia dubia, Solanum trilobatum, and erythrina indica are a few examples [14-18].

Numerous plants have demonstrated potential for nanoparticle synthesis, contributing to the field of green nanotechnology. Some other notable examples include Aloe vera, Neem (Azadirachta indica), Tulsi (Ocimum sanctum), Turmeric (Curcuma longa), Green Tea (Camellia sinensis), Rosemary (Rosmarinus officinalis) [19], Solanum Nigrum [20], Aloe vera extract [20,21], and Plant extract of Shikakai or Reetha [22]. These plants contain various bioactive compounds that act as reducing and stabilizing agents during nanoparticle synthesis. The approximate size of nanoparticles produced by these plants ranges from 10 to 100 nanometers, depending on the specific plant extract and synthesis conditions. Their ability to produce nanoparticles within this size range makes them suitable for a wide range of applications.

In a study by Shakeel Ahmed and his team, they found that nanoparticles can be synthesized using aqueous leaf extracts of the Azadirachta indica plant. The synthesis process involves using aqueous extracts of plants mixed

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with metal precursors in the form of salts. In this particular study, neem leaves were boiled in distilled water, filtered, and chilled before use. The addition of plant extract to metal salt solutions resulted in a color change, indicating the formation of silver nanoparticles [18]. Silver nanoparticles can be synthesized using aqueous extracts of medicinal plants such as balsamina and lantana camara, which are commonly used as wound dressings in Indonesia. The addition of plant extracts to the metal salt solutions resulted in a color change, indicating the formation of silver nanoparticles. Balsamina leaves changed the solution's color to tan, while lantana camara extract changed it to grey-brown. The presence of polyphenolic components like flavonoids and terpenoids in the plant extracts helped stabilize and reduce silver ions.

Synthesis from Algae

The production of nanoparticles using algae has garnered attention in scientific studies. Algae, such as Spirulina, Chlorella, and Dunaliella, have been explored for their capability to synthesize silver nanoparticles. The process involves combining an aqueous solution containing the algae extract with a silver precursor solution. This interaction results in the reduction of silver ions and the subsequent formation of silver nanoparticles. The characteristics of the nanoparticles can be influenced by factors such as the concentration of the algae extract and the specific reaction conditions. The green synthesis of silver nanoparticles utilizing algae presents a sustainable and environmentally friendly approach with potential applications in various fields, including medicine and catalysis.

Other varieties of spice algae include Chlorella vulgaris [23,24], Spirulina platensis [25], Sargassum algae wightii [26], Kappaphycus alvarezii, and Chaetoceros calcitrans, in addition to Chlorella salina, Isochrysis gablbana, and Tetraselmis gracilis [27], Gracilaria corticate are some examples of species that can be used to synthesise silver nanoparticles.

Researchers have explored the synthesis of gold and silver nanoparticles using algae, specifically Chondrus crispus, Spirogyra insignis, Isochrysis galbana, Tetraselmis gracilis, Chlorella salina, and Chaetoceros calcitrans. The color change of the solution indicated the formation of nanoparticles, and factors like pH and light exposure influenced their size and formation efficiency. These findings contribute to the understanding of algae-mediated nanoparticle synthesis and its potential applications [27,28].

The creation of silver nanoparticles using polysaccharides, Sargassum wightii grevillea (size- 8 to 27 nm), Caulerpa racemose (size- 10 nm), Chaetomorpha linun, (size- 3 to 44 nm), Gelidium amansii, (size- 27 to 54 nm) obtained from marine macroalgae has also been described in certain studies [29-32].

Synthesis from fungi

Researchers have investigated the synthesis of silver nanoparticles using fungi. The specific fungal species employed in these studies and the experimental conditions varied. The formation of silver nanoparticles was indicated by observable color changes in the reaction mixture. Factors such as the type of fungi, reaction conditions, and concentration of silver ions influenced the size, shape, and stability of the nanoparticles produced. These studies provide valuable insights into the potential of fungi as a bioresource for nanoparticle synthesis.

Fungi have been utilized for the synthesis of silver nanoparticles due to their high protein production, ease of manipulation, low toxicity, and stability. Algal synthesis is advantageous for improved stability and bioactivity. Fungi offer resistance to metals and require no additional steps for extraction. Fungal strains are preferred for their metal bioaccumulation capabilities. The synthesis process involves culturing fungi on agar, transferring to a liquid medium, and then transferring the biomass to water for compound release. The filtrate is mixed with $AgNO_3$ solution and heated during incubation. Incubation should occur in complete darkness for approximately a day [33,34].

- Hulikere et al. [35] demonstrated that marine endophytes, specifically Cladosporium cladosporioides, can synthesize nanoparticles. The bioactive compounds present in marine endophytic fungus contribute to the production of nanoparticles, confirmed by a color change in the metal salt solution.
- Tyagi et al. used the entomopathogenic fungus Beauveria bassiana to synthesize silver nanoparticles [36]. The nanoparticles exhibited antimicrobial activity, which was compared to antibiotics and combinations of AgNP and antibiotics. Reduction of

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Ag^+ resulted in a color change, indicating nanoparticle formation with maximum absorbance observed at 450 nm.

There are numerous fungi that can be employed to create primarily silver nanoparticles that are round. For instance, Fusarium oxysporum [37].

1. Verticillium [38]
2. Forsythia fumigatus
3. Penicillium fellutanum [39]
4. Aspergillus flavus [40]
5. Fusarium semitectum [41]
6. Changeable alternaria
7. Rhizopus stolonifera [42]
8. Chrysosporium phanerochaete [43]

Synthesis through bacteria

In addition to fungi or algae, bacteria have been used to produce silver nanoparticles. There are multiple types of bacteria which can be used to produce nanoparticles of different shapes. Examples Klebsiella pneumoniae, E. coli, as well as Enterobacter cloacae and Bacillus licheniformis [44], B. subtilis [45], Pseudomonas stutzeri AG259 [46] etc.

3. SHAPES AND CHARACTERIZATION OF SILVER NANOPARTICLES

The shape and sizes of the nanoparticles have a considerable impact on their properties. Stabilizer and the technique of preparation are also countable. Both non- spherical (planar) and three-dimensional topics are covered in several works.

Cubic shape- The synthesis of silver nanoparticles with a cubical shape involves the use of specific reagents and conditions. Ethylene glycol and PVP are commonly employed as reducing agents and stabilizers, respectively. By controlling the temperature during the synthesis process, typically around 161 °C, cubic-shaped silver nanoparticles can be obtained. Deviations from the cubic shape may occur when the temperature is altered. This method offers control over the shape and morphology of the nanoparticles, allowing for tailored applications in various fields. Another study employed ethylene glycol, PVP, and HCl to successfully create silver cubes at a specific temperature. Additionally, Siekkinen et al. developed an alternative and faster method for synthesizing silver nanoparticles [47-49].

Rod shape- Silver nanoparticles with an elongated rod-like shape can be characterized by techniques such as TEM, scanning electron microscopy (SEM), and aspect ratio analysis.. Rod-shaped silver nanoparticles can be synthesized using thermal, photochemical, and electro-based template methods. The addition of citrate, $NaBH_4$, ascorbic acid, and CTAB promotes the growth of nanorods. The proportions of PVP and silver nitrate can be adjusted to control the diameter and length of the nanorods. Different studies have successfully demonstrated the creation of nanorods with specific plasmon peaks using various reducing agents such as potassium tartaric acid [50,51].

Nano-wires- silver nanoparticles with wire-like shapes can be synthesized through electrochemical deposition techniques, template-assisted synthesis, and seed-mediated growth. Electrochemical methods involve applying an electric current to a silver electrode in an electrolyte solution. Template-assisted synthesis utilizes porous templates for silver ion deposition, while seed-mediated growth involves the synthesis and subsequent growth of silver nanowire seeds. These methods allow control over the shape and size of the resulting nanowires, enabling the production of silver nanoparticles with wire-like structures [52,53].

- ***Bars and triangular (pyramid) shaped***- Various methods can be employed to synthesize silver nanoparticles with bar, triangular, and pyramid shapes. These include seed-mediated growth using silver nanospheres as templates and controlling reaction conditions, as well as using specific templates or molds to guide the shape formation. Adjusting concentrations of reducing agents and stabilizers allows for shape control. These techniques offer versatility in tailoring silver nanoparticles for diverse applications in nanotechnology [54,55].
- ***Spherical shape***- The synthesis of silver nanoparticles with a spherical shape can be achieved through the reduction of silver ions in a solution using a reducing agent such as sodium borohydride or citrate. The presence of stabilizing agents like polyvinylpyrrolidone (PVP) or capping agents helps in controlling the size and stability of the

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nanoparticles, resulting in a spherical shape. Other techniques such as microwave-assisted synthesis or green synthesis using plant extracts have also been employed to produce spherical silver nanoparticles. These nanoparticles find extensive applications in areas such as catalysis, electronics, and biomedical sciences.

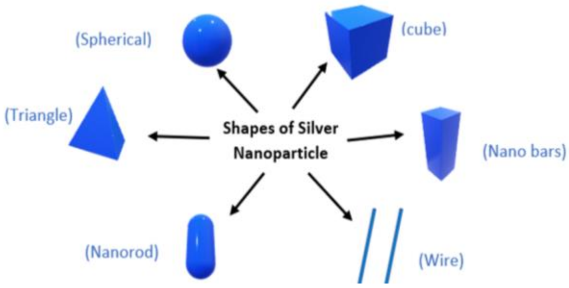

Fig. 2: Shows graphical representation of the different shapes of nanoparticle.

4. Applications of Silver Nanoparticles

- **Antimicrobial Activity**: Silver nanoparticles exhibit strong antimicrobial properties and have been used in various biomedical applications, including wound dressings, antibacterial coatings, and disinfectants.
- **Electronics and Optoelectronics**: Silver nanoparticles are utilized in electronics and optoelectronic devices for their excellent electrical conductivity and optical properties. They are used in conductive inks, printed electronics, and as components in sensors and displays.
- **Catalysis**: Silver nanoparticles act as efficient catalysts in various chemical reactions. Their high surface area and unique surface properties make them effective catalysts for organic synthesis and environmental remediation.
- **Nanomedicine**: Silver nanoparticles have shown promise in nanomedicine for drug delivery, bioimaging, and therapeutic applications. They can be functionalized with biomolecules to target specific cells or tissues for enhanced treatment efficacy.
- **Surface Coatings**: Silver nanoparticles are used in surface coatings to provide antimicrobial properties to a wide range of materials, including textiles, plastics, and medical devices. These coatings help prevent the growth of bacteria and fungi.
- **Environmental Remediation**: Silver nanoparticles are employed in environmental remediation processes for water and air purification. They can efficiently remove pollutants and contaminants, making them valuable in addressing environmental challenges.
- **Sensing and Detection**: Silver nanoparticles exhibit unique optical properties that make them suitable for sensing and detection applications. They are used in biosensors, chemical sensors, and plasmonic-based detection systems.
- **Energy Applications**: Silver nanoparticles are explored in energy-related applications such as solar cells, fuel cells, and catalytic converters, where their high electrical conductivity and catalytic properties are advantageous.

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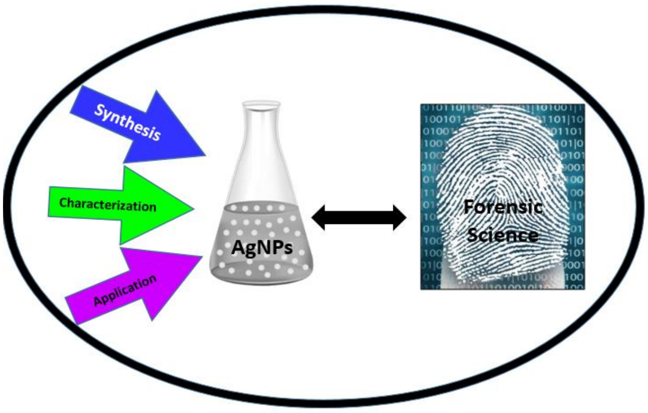

Fig. 3: Applications of silver nanoparticle

Overall, the versatility and distinctive properties of silver nanoparticles make them valuable in various nanotechnology applications, contributing to advancements in fields such as healthcare, electronics, energy, and environmental sustainability.

CONCLUSION

In conclusion, the realm of silver nanoparticles (AgNPs) presents a captivating journey into the dynamic landscape of nanotechnology. The synthesis methods explored in this review underscore the versatility and ingenuity involved in tailoring AgNPs for various applications. The intricate interplay between synthesis parameters, such as reducing agents, stabilizers, and reaction conditions, serves as a testament to the complexity of engineering AgNPs with desired properties. Characterization techniques play a pivotal role in unraveling the physicochemical attributes and morphological features that underpin the unique behavior of AgNPs at the nanoscale. Through spectroscopic, microscopic, and analytical methods, researchers gain a comprehensive understanding of AgNPs' structure, size distribution, and surface chemistry. The multifaceted applications of AgNPs across diverse sectors, including medicine, electronics, catalysis, and environmental remediation, highlight their indispensability in shaping nanotechnology. The exceptional antibacterial properties of AgNPs hold immense promise in revolutionizing the field of healthcare, while their catalytic prowess contributes to sustainable energy conversion and environmental preservation. Furthermore, AgNPs' integration into advanced materials and devices fuels innovation, amplifying their significance in modern technological advancements. As we delve into the fascinating world of silver nanoparticles, it becomes evident that continued exploration and research are crucial to unlocking their full potential. The intricate relationships between synthesis strategies, structural attributes, and functional performance provide a stimulating avenue for further inquiry. By harnessing the knowledge gained from this review, researchers can drive the development of tailored AgNPs with enhanced properties, ultimately paving the way for transformative breakthroughs in nanotechnology. Amidst the ever-evolving landscape of scientific discovery, silver nanoparticles stand as a testament to humanity's relentless pursuit of understanding and harnessing the boundless possibilities at the nanoscale.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not Applicable

HUMAN AND ANIMAL RIGHTS

Research Involving Humans

NA

Research Involving Animals

NA

Research Involving Plants

NA

CONSENT FOR PUBLICATION

All authors given their consent to publish this article.

AVAILABILITY OF DATA AND MATERIALS

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Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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CONFLICT OF INTEREST

Author declares that there is no conflict of interest.

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