

**NANOTECHNOLOGY: SYNTHESIS OF SILVER NANOPARTICLES (AgNPs)
USING CHEMICAL METHOD**

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**A PROJECT SUBMITTED TO THE DEPARTMENT OF PHYSICS,
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**IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE
AWARD OF THE BACHELOR OF SCIENCE (B.Sc HONOURS)
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CERTIFICATION

This is to certify that this research work was carried out by **ODUAH JOSEPH** in the Department of Physics, Faculty of Physical Science, University of Benin, Nigeria under my supervision

DR SAM OKUNZUWA
(Project Supervisor)

DATE

PROF C.O AIGBOGUN
(Head of Department)

DATE

EXTERNAL EXAMINER

DATE

DEDICATION

This Project Work is dedicated to God Almighty for His protection and guidance throughout my entire four years of studies at the University of Benin. To my parents, who have always supported in me all my activities and also for their love and support. This work is dedicated to all of you with Love and words of appreciation.

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ABSTRACT

Nanotechnology has gained significant attention in various fields due to its potential in developing advanced materials with unique properties.

Silver nanoparticles (AgNPs) are widely used in medicine, electronics, and environmental applications due to their antibacterial and catalytic properties.

This study explores a practical approach to synthesizing AgNPs using a chemical method, where silver salts are reduced in the presence of stabilizing and reducing agents. By adjusting factors such as precursor concentration, temperature, and reaction time, the size and stability of AgNPs can be controlled.

Common chemical techniques like the Turkevich and polyol methods provide efficient and scalable synthesis. The resulting nanoparticles are analyzed using UV-Vis Spectroscopy, DLS, XRD, and TEM to confirm their size and structure.

While chemical synthesis is effective, challenges like toxicity and environmental impact must be considered for safe and sustainable use.

CHAPTER ONE

INTRODUCTION

1.1 Understanding Nanotechnology

Nanotechnology is a revolutionary field of science that deals with the understanding, manipulation, and application of materials at the nanoscale, typically between 1 and 100 nanometres (nm). To put this into perspective, a nanometre is one-billionth of a meter—roughly 100,000 times smaller than the width of a human hair. At this scale, materials exhibit extraordinary and often unpredictable properties that differ significantly from their bulk counterparts. These differences arise due to several fundamental factors, including:

- 1. Quantum Effects:** At the nanoscale, quantum mechanics dominate over classical physics, altering the electrical, optical, and magnetic behaviours of materials. This is why gold nanoparticles appear red or blue instead of their typical yellow colour in bulk form.
- 2. Increased Surface Area-to-Volume Ratio:** As particle size decreases, the proportion of atoms on the surface increases compared to those inside the material. This results in enhanced chemical reactivity, making nanoparticles highly effective in catalysis and drug delivery.
- 3. Mechanical Strength and Durability:** Many nanomaterials exhibit superior mechanical properties, such as high tensile strength and

flexibility, which are useful in applications like lightweight materials, coatings, and structural composites.

Nanotechnology is an interdisciplinary field that integrates principles from physics, chemistry, biology, materials science, and engineering to develop advanced materials and systems with novel properties. The ability to engineer matter at the atomic and molecular levels has led to ground-breaking innovations across multiple domains.

1.2 Historical Development of Nanotechnology

The concept of nanotechnology was first introduced by physicist Richard Feynman in his iconic 1959 lecture, "There's Plenty of Room at the Bottom." Feynman envisioned a future where scientists could manipulate individual atoms and molecules to build new materials with tailored properties. However, it wasn't until 1974 that Norio Taniguchi formally coined the term "nanotechnology" while describing precision manufacturing at the nanoscale.

The field truly gained momentum in the 1980s with the invention of the Scanning Tunneling Microscope (STM) by Gerd Binnig and Heinrich Rohrer, which allowed scientists to visualize and manipulate individual atoms. The development of the Atomic Force Microscope (AFM) further revolutionized the study of nanoscale materials. Since then, advancements in nanotechnology have led to breakthroughs in electronics, medicine, environmental science, and energy storage.

At the heart of nanotechnology lies nanomaterials, which are materials engineered or naturally occurring at the nanoscale. These materials have gained immense scientific and industrial interest due to their size-dependent properties and wide range of applications in medicine, electronics, energy storage, water purification, and more.

1.3 Types of Nanomaterials

Nanomaterials can be classified into various categories based on their dimensional structure, composition, and origin:

A. Classification by Dimensionality

1. Zero-dimensional (0D) nanomaterials:

These are materials where all three dimensions are within the nanoscale.

Example: Metallic nanoparticles (silver, gold, copper, etc.), quantum dots.

2. One-dimensional (1D) nanomaterials:

These materials have one nanoscale dimension, while the other two dimensions are larger.

Example: Nanotubes, Nano rods, nanowires (e.g., carbon nanotubes, silver nanowires).

3. Two-dimensional (2D) nanomaterials:

These materials have two dimensions in the nanoscale, while the third remains larger.

Example: Graphene, hexagonal boron nitride, metal oxide Nano sheets.

4. Three-dimensional (3D) nanomaterials:

These are bulk structures that incorporate nanoscale building blocks.

Example: Nano porous materials, nanocomposites, metal-organic frameworks (MOFs).

B. Classification by Composition

- 1. Metallic nanomaterials:** Include silver, gold, platinum, and copper nanoparticles used for antimicrobial applications, electronics, and catalysis.
- 2. Metal oxide nanomaterials:** Such as titanium dioxide (TiO_2), zinc oxide (ZnO), and iron oxide (Fe_3O_4) used in sunscreens, sensors, and magnetic applications.
- 3. Carbon-based nanomaterials:** Include graphene, carbon nanotubes (CNTs), and fullerenes used in energy storage, coatings, and biomedical engineering.

- 4. Polymeric nanomaterials:** Include polymeric nanoparticles and dendrimers used in drug delivery, coatings, and biomedical devices.

1.4 Properties of Nanomaterials

Nanomaterials exhibit extraordinary properties that make them superior to conventional materials:

1. Optical Properties:

Nanoparticles, such as gold and silver, exhibit unique surface Plasmon resonance (SPR), allowing them to absorb and scatter light differently than bulk materials, quantum dots show size-dependent fluorescence, making them valuable in imaging and display technologies.

2. Electrical and Electronic Properties:

Carbon nanotubes (CNTs) and graphene exhibit exceptional electrical conductivity, making them ideal for next-generation electronic devices and super capacitors.

3. Mechanical Properties:

Nanomaterials often display high strength, flexibility, and toughness, allowing their use in lightweight structural materials and protective coatings.

4. Catalytic Properties:

Due to their high surface area, metallic and metal oxide nanoparticles act as efficient catalysts in chemical reactions, including fuel cell technology and pollutant degradation.

5. Biological and Chemical Reactivity:

Nanoparticles can interact with biological molecules, leading to applications in drug delivery, biosensors, and antimicrobial coatings.

1.5 Application of Nanomaterials

Due to their remarkable properties, nanomaterials have found applications in various fields:

1. Biomedical and Healthcare:

Silver nanoparticles (AgNPs): Used as antibacterial, antiviral, and antifungal agents in medical coatings, wound dressings, and drug delivery systems.

Gold nanoparticles (AuNPs): Applied in cancer therapy, biosensors, and imaging technologies.

Lipid-based nanoparticles: Used in mRNA vaccine delivery (e.g., COVID-19 vaccines).

2. Energy and Environment:

Graphene and carbon nanotubes: Used in batteries, super capacitors, and fuel cells.

Metal oxide nanoparticles: Used for solar cells, water purification, and pollutant removal.

3. Electronics and Computing:

Nano electronics: Carbon nanotubes and quantum dots help in the development of miniaturized transistors and flexible displays.

Memory storage devices: Use of nanomaterials enhances data storage and processing speeds.

4. Textile and Consumer Goods:

Self-cleaning fabrics use silver nanoparticles and hydrophobic Nano coatings

Cosmetics and sunscreens use titanium dioxide (TiO₂) and zinc oxide (ZnO) nanoparticles for UV protection.

1.6 Metallic Nanoparticles and Their Significance

Among various types of nanomaterials, metallic nanoparticles have attracted significant attention due to their unique optical, electrical, and antimicrobial properties. Commonly studied metallic nanoparticles include:

- 1. Gold Nanoparticles (AuNPs):** Used in drug delivery, biosensors, and photo thermal therapy for cancer treatment.
- 2. Silver Nanoparticles (AgNPs):** Known for their strong antibacterial and antiviral properties, widely applied in medical and environmental applications.
- 3. Copper Nanoparticles (CuNPs):** Used in conductive inks, coatings, and antimicrobial solutions.
- 4. Zinc Oxide Nanoparticles (ZnO-NPs):** Found in sunscreens, cosmetics, and antibacterial applications.

Silver nanoparticles (AgNPs), in particular, has gained immense popularity due to their exceptional antimicrobial, antiviral, antifungal, and catalytic properties. Their ability to kill bacteria and viruses without causing resistance makes them ideal for use in medical coatings, wound dressings, biosensors, and waste water treatment.

1.7 Synthesis of Nanoparticles

The synthesis of nanoparticles plays a crucial role in determining their size, shape, stability, and overall functionality. Several methods exist for the fabricating nanoparticles, broadly classified into three categories:

- 1. Physical methods:** Involves high-energy processes such as laser ablation and evaporation condensation, but these methods are costly and energy intensive.

- 2. Chemical methods:** Utilizing reducing agents, this method is widely used due to its cost-effectiveness, scalability, and precise control over particle characteristics.
- 3. Biological (Green) methods:** Uses plant extracts, bacteria, or fungi to synthesize, offering an eco-friendly alternative.

In this study, we are going to be focusing on the chemical synthesis of silver nanoparticles, as it provides a controlled, efficient, and reproducible method for producing nanoparticles with desired properties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Silver Nanoparticles (AgNPs)

Silver nanoparticles (AgNPs) have garnered significant attention in scientific research and industrial applications due to their unique physicochemical properties, which stem from their nanoscale dimensions and high surface area-to-volume ratio. These properties contribute to their exceptional antimicrobial activity, catalytic efficiency, optical behaviour, and electrical conductivity, making them highly valuable in various fields according to Klaus et al., 1999.

According to Zhang et al., 2016, the ability of AgNPs to exhibit strong plasmonic resonance, biocompatibility, and chemical stability has led to their widespread utilization in fields such as medicine, biotechnology, environmental science, and electronics. In medicine, AgNPs are extensively used for their antibacterial, antifungal, and antiviral properties, making them integral components of wound dressings, coatings for medical devices, and drug delivery systems. In the field of electronics and Nano photonics, their excellent electrical and optical properties enable their application in sensors, conductive inks, and transparent electrodes. Additionally, their role in catalysis has been explored for improving chemical reaction efficiencies, particularly in environmental remediation processes such as wastewater treatment.

Also according to Sharma, Yngard and Lin, 2009, the characteristic of AgNPs enhances interactions with biological membranes, catalytic activity, and light-matter interactions, making AgNPs valuable in diverse applications such as medicine, electronics, and environmental science.

As noted by Lee and Lee, 2018, due to their broad range of applications, researchers have developed various synthesis techniques that allow precise control over the size, shape, dispersity, and stability of AgNPs, as these factors directly influence their performance in specific applications. The development of chemical, physical, and biological synthesis methods has facilitated large-scale production while aiming to optimize cost-effectiveness, eco-friendliness, and reproducibility. However, challenges such as agglomeration, toxicity, and environmental impact continue to drive further research into green and sustainable synthesis approaches.

In line with the findings of Patel et al., 2020, as research into AgNPs continues to expand, a deeper understanding of their synthesis, functionalization, and applications is crucial for harnessing their full potential across various scientific and technological domains.

2.2 Methods for Synthesizing Silver Nanoparticles

The synthesis of AgNPs can generally be categorized into three main approaches: physical, biological, and chemical methods. Each of these methods offers distinct advantages and challenges, with the choice of method often

depending on the desired properties of the nanoparticles, such as size, shape, uniformity, and environmental impact. Among these, physical methods such as laser ablation and evaporation-condensation are considered to be highly effective in producing AgNPs with precise control over size and minimal contamination.

Laser ablation involves the use of a high-intensity laser beam to irradiate a solid silver target in a liquid medium, leading to the formation of AgNPs as the material is vaporized and rapidly cooled. This method allows for the generation of high-quality nanoparticles with a narrow size distribution, making it ideal for applications requiring high precision. Similarly, evaporation-condensation methods involve the vaporization of silver in a vacuum or inert atmosphere, followed by the condensation of the vapor into nanoparticles. Both of these methods produce nanoparticles that exhibit excellent purity, as they do not involve the use of chemical reducing agents, which can often lead to residual impurities.

However, as highlighted by Tsuji et al., 2008, these physical methods come with certain drawbacks. Laser ablation, for example, requires expensive equipment, including high-powered lasers, and can be energy-intensive, resulting in higher operational costs. Evaporation-condensation, while effective, demands specific conditions, such as high vacuum and controlled atmospheres, which also contribute to its high energy consumption and the complexity of the

setup. These factors make physical methods less suitable for large-scale production compared to other synthesis techniques.

Despite these limitations, physical methods are particularly advantageous when it comes to producing highly uniform and well-characterized nanoparticles, especially in research settings where precision and purity are paramount. Moreover, as advancements in technology continue, there is potential for reducing the costs and energy requirements associated with these methods, making them more accessible for broader applications in industry and medicine.

Biological methods for the synthesis of silver nanoparticles (AgNPs) have gained significant popularity in recent years due to their eco-friendly nature and the use of natural materials, such as microorganisms, plant extracts, and enzymes, to facilitate nanoparticle production. These methods are particularly attractive because they do not require the use of toxic chemicals or harsh reaction conditions, making them a more sustainable alternative to traditional chemical and physical synthesis methods. The bio reduction process utilized in these methods involves biological agents that reduce silver ions (Ag^+) to form silver nanoparticles (AgNPs), typically through enzymatic activity or metabolic processes within the organism.

For instance, microorganisms such as bacteria, fungi, and yeasts have been extensively studied for their ability to synthesize AgNPs. Microbial synthesis is advantageous because microorganisms are capable of producing nanoparticles with a high degree of uniformity and controlled size under ambient conditions.

Plant extracts, which are rich in secondary metabolites like polyphenols and flavonoids, also serve as reducing and stabilizing agents in the synthesis of AgNPs. These plant-based methods have gained particular attention due to their low cost, simplicity, and the ability to easily scale up the process. Additionally, enzymatic methods use specific enzymes to catalyze the reduction of silver ions to silver nanoparticles, offering a more controlled and potentially more sustainable alternative to chemical reductions.

As noted by Mohanpuria, Rana, and Yadav, 2008, one of the main advantages of biological methods is that they are non-toxic, cost-effective, and contribute to green chemistry, aligning with the principles of sustainability and environmental conservation. These methods do not involve the use of harmful chemicals, and the byproducts are generally biodegradable and less harmful to the environment. In addition, biological synthesis can often occur under mild conditions (such as room temperature or atmospheric pressure), making it a more energy-efficient option compared to other synthesis routes. Furthermore, the biological agents involved in the process can be highly selective, resulting in nanoparticles with specific sizes, shapes, and surface properties that are crucial for certain applications, such as drug delivery or sensing.

Despite these benefits, challenges such as scalability and reproducibility still hinder the widespread adoption of biological methods for AgNP production. The use of living organisms introduces variability in terms of their metabolic activity, which can lead to inconsistency in nanoparticle size, shape, and yield.

Additionally, scaling up from laboratory conditions to industrial-scale production can be difficult, as the biological agents may not perform consistently at larger volumes or in controlled commercial settings. Moreover, the time and cost involved in cultivating the necessary microorganisms or plant material on a large scale can present significant barriers to commercialization.

Furthermore, while biological methods are considered safe and sustainable, concerns related to the purity of the final product remain, particularly with plant-based extracts. The presence of other biomolecules in the extracts could result in impurities or unwanted contaminants in the synthesized AgNPs, which could impact their biomedical or industrial applications. Therefore, significant research is still required to optimize these methods for consistent production, enhance scalability, and standardize the procedures to make biological synthesis a more reliable and efficient alternative to conventional techniques.

In conclusion, while biological synthesis methods for AgNPs offer significant environmental and economic advantages, further advancements are necessary to overcome the existing challenges related to scalability, reproducibility, and product purity. The continued exploration and optimization of these methods will be crucial for their future use in industrial applications.

In contrast to biological methods, chemical methods are among the most commonly used techniques for the synthesis of silver nanoparticles (AgNPs) due to their simplicity, cost-effectiveness, and ability to produce nanoparticles

with well-defined characteristics. These methods offer a high degree of control over the size, shape, and distribution of nanoparticles, which are critical for their application in a wide range of industries, including medicine, electronics, and environmental science. Chemical synthesis methods, particularly chemical reduction, have become the gold standard for producing AgNPs on both a laboratory and industrial scale.

Chemical reduction is the most widely adopted approach, where silver ions (Ag^+) are reduced to metallic silver (Ag^0) using a variety of reducing agents. The reducing agents play a critical role in facilitating the reduction of silver ions into their metallic form. Common reducing agents used in this process include sodium borohydride (NaBH_4), ascorbic acid, citric acid, and hydrazine. These agents are highly effective in reducing Ag^+ to Ag^0 by donating electrons during the reaction, resulting in the formation of silver nanoparticles. In addition to reducing agents, stabilizing agents are also often employed to prevent the agglomeration or aggregation of nanoparticles. Stabilizing agents, such as polyvinyl alcohol (PVA), citrate, and polyethylene glycol (PEG), form a protective layer around the nanoparticles, providing steric or electrostatic repulsion to prevent their aggregation. This stabilizing step is crucial for maintaining the monodispersity and colloidal stability of the nanoparticles in solution.

One of the significant advantages of chemical reduction methods is the precise control they offer over the size and shape of the AgNPs. By adjusting

parameters such as the concentration of reducing agents, reaction temperature, pH, and reaction time, it is possible to tune the physical properties of the nanoparticles to meet specific application requirements. For example, by varying the concentration of the reducing agent or adjusting the temperature, it is possible to control the rate of particle formation, which in turn influences the final size and shape of the nanoparticles. This size-dependent control is critical for tailoring the nanoparticles for specific applications, as the properties of AgNPs, such as their optical and catalytic behaviors, can be highly sensitive to size and morphology.

For instance, smaller AgNPs tend to exhibit enhanced antimicrobial properties, while larger nanoparticles may demonstrate better catalytic activity. The shape of the nanoparticles, whether spherical, triangular, or rod-shaped, also influences their optical properties, including surface Plasmon resonance (SPR), which has applications in bio sensing and imaging. As noted by Sharma, 2009, the ability to control these parameters makes chemical methods particularly attractive for applications requiring specific and uniform nanoparticle characteristics, such as drug delivery, catalysis, and photonic devices.

Overall, chemical methods, particularly chemical reduction, remain one of the most versatile and widely used approaches for synthesizing AgNPs. With continued advancements in green chemistry and the development of safer, more sustainable reagents, these methods are likely to remain a cornerstone of nanoparticle synthesis for various industrial and scientific applications. The

ability to control nanoparticle characteristics so precisely continues to make chemical synthesis a preferred choice for the production of AgNPs, particularly in applications where uniformity, scalability, and performance are critical.

2.3 Mechanism of Chemical Synthesis

The chemical synthesis of AgNPs typically involves three key components: a silver salt precursor (e.g., silver nitrate), a reducing agent, and a stabilizing or capping agent. The most commonly used silver salt precursor is silver nitrate (AgNO_3), which provides the silver ions conditions for nanoparticle formation. The choice of reducing agent plays a crucial role in determining the size, shape, and overall morphology of the synthesized AgNPs. According to Dong et al. (2009), the selection of reducing agent significantly influences the characteristics of the nanoparticles. Strong reducing agents like sodium borohydride (NaBH_4), facilitate rapid reduction of silver ions, leading to the formation of smaller, more uniform nanoparticles due to fast nucleation rates. In contrast, weaker reducing agents like ascorbic acid promote slower reduction, resulting in larger nanoparticles with varying shapes due to prolonged growth phases.

Additionally, the presence of a stabilizing agents or capping agents is essential to prevent aggregation and enhance the stability of the nanoparticles. These capping agents which may include polymers, surfactants, or biomolecules

influence the surface properties and functionality of AgNPs, making them suitable for various applications in medicine, catalysis, and environmental science. Thus, careful selection of synthesis parameters is crucial in tailoring the properties of AgNPs for specific applications.

Stabilizing agents such as polyvinylpyrrolidone (PVP) or citrate ions, play a critical role in the synthesis of silver nanoparticles (AgNPs) by preventing aggregation and ensuring long-term stability. According to Lee and Meisel, (1982), these agents function by forming a protective layer around the nanoparticles, which helps maintain their discrete nature and prevents uncontrolled growth or agglomeration (reversible clustering of nanoparticles due to weaker forces). The mechanism of stabilization can occur through electrostatic, steric, or a combination of both effects, depending on the nature of capping agents used. For instance, citrate ions provide electrostatic stabilization by imparting a negative charge to the nanoparticle surface, which leads to repulsive forces that prevent aggregation. On the other hand, polymeric stabilizers like PVP offer steric stabilization, creating a barrier that hinders direct contact between nanoparticles.

Moreover, the synergy between stabilizing agents and various reaction parameters, such as pH, temperature, and ionic strength, plays a significant role in determining the final properties of AgNPs. The pH of the reaction medium affects the ionization state of stabilizing agents and the surface charge of

nanoparticles, influencing their dispersion and stability. Higher temperatures can accelerate reaction, leading to faster nucleation and growth, which in turn impacts the size and morphology of the synthesized nanoparticles. Additionally, the presence of salts or other ions in the reaction medium can alter the stability of AgNPs by modifying electrostatic interactions.

Thus, careful selection and optimization of stabilizing agents, in conjunction with controlled reaction conditions, are essential for achieving nanoparticles with desired characteristics, including uniform size distribution, high stability, and specific surface functionalities. These factors are particularly important for applications in biomedicine, catalysis, and environmental remediation, where the stability and reactivity of AgNPs play a crucial role in their effectiveness.

2.4 Factors Influencing the Chemical Synthesis of AgNPs

Reaction parameters such as temperature, pH, reaction time, and the concentration of reactants have been shown to significantly impact the size, shape, and stability of synthesized silver nanoparticles. These factors influence the nucleation and growth processes, ultimately shaping the properties of the nanoparticles.

For example, Pal et al. (2007), found out that higher reaction temperatures typically accelerate the reduction process and lead to smaller, more uniform nanoparticles. This is because increased thermal energy enhances the reduction of silver ions, thereby promoting rapid particle formation before significant

growth occurs. While lower reaction temperature tends to slow down nucleation, allowing for prolonged growth phases that results in larger nanoparticles with diverse morphologies.

Similarly, studies by Li et al. (2012) revealed that pH level influences the surface charge on stabilizing agents, thereby affecting the morphology and dispersion of the nanoparticles. At lower pH values, the charge alternation of functional group can reduce electrostatic repulsion between particles, increasing the likelihood of aggregation. In contrast, higher pH levels often enhance repulsion due to increased negative surface charge, leading to well dispersed and stable nanoparticles with controlled size and shape.

These findings highlight the importance of optimizing reaction conditions to tailor nanoparticles for specific applications. By carefully controlling synthesis parameters, we can fine-tune nanoparticles properties such as size, shape, surface charge, and stability, ensuring their effectiveness in targeted applications.

2.5 Characterization of Silver Nanoparticles

Accurate characterization of AgNPs is essential for understanding their properties, ensuring reproducibility, and optimizing their functionality for specific applications. A combination of analytical techniques is commonly used to assess various characteristics, including size, shape, stability, and crystalline structure. Among these, UV-Vis spectroscopy, X-ray diffraction (XRD),

transmission electron microscopy (TEM), and dynamic light scattering (DLS) are widely used.

For example, UV-Vis spectroscopy is a rapid and non-destructive technique used to monitor the optical properties of AgNPs, it can identify the Surface Plasmon Resonance (SPR) peak, which provides information on particle size, dispersion and aggregation state (Sharma et al., 2009).

Transmission electron microscopy (TEM) offers high-resolution imaging, allowing for the direct visualization of nanoparticles size, shape, and distribution. It provides detailed morphological insights, which are crucial for applications requiring uniformity in nanoparticles synthesis.

Similarly, X-ray diffraction (XRD) are valuable for analysing the crystalline structure of AgNPs. This technique helps confirm the presence of metallic silver in a nanoparticle sample and provides information on crystallite size and purity (Mohanpuria et al., 2008).

Additionally, dynamic light scattering (DLS) is widely used to measure the hydrodynamic size and zeta potential of AgNPs in colloidal suspension. This technique helps assess nanoparticle stability by analysing how particles interact in solution.

By utilizing these complementary characterization techniques, we can gain a comprehensive understanding of AgNPs properties, enabling precise control

over synthesis and ensuring consistency in their applications across fields such as Nano medicine, catalysis, and environmental science.

2.6 Applications of Chemically Synthesized AgNPs

The unique properties of AgNPs enable a broad range of applications across various fields, including medicine, environmental science, and nanotechnology.

One of the most widely studied properties of AgNPs is their strong antimicrobial activity, which has been utilized in wound dressings, coatings, and water purification systems (Klaus et al., 1999). Their ability to disrupt bacterial cell membranes and generate reactive oxygen species makes them highly effective against a wide spread of pathogens, including anti-resistant strains. This antimicrobial potential has also been explored in food packaging and textile industries to enhance product durability and hygiene.

Beyond their biological applications, AgNPs exhibit remarkable catalytic properties, which have been leveraged for environmental remediation and chemical reactions. Due to their high surface-area-to-volume ratio and unique electronic structure, AgNPs serve as efficient catalysts in processes such as pollutant degradation, organic synthesis, and fuel cell reactions.

Additionally, AgNPs possess distinctive optical properties make them suitable for biosensing and imaging applications (Sharma et al., 2009). They have been incorporated in biosensors for detection of biomolecules, toxins, and pathogens, offering high sensitivity and selectivity. In imaging, AgNPs enhance contrast and real-time tracking of biological processes at the nanoscale.

2.7 Challenges and Future Directions

While chemical synthesis methods offer several advantages, including efficiency, cost-effectiveness, and the ability to produce nanoparticles with well-defined characteristics, several challenges such as environmental impact, scalability, and precise control over nanoparticle properties remain. Traditional chemical methods often involve toxic reducing agents, which pose potential risks to both human health and the environment. Additionally, achieving uniformity in size, shape, and stability on a large scale remains a significant hurdle for industrial applications.

Researchers like Mohanpuria et al. (2008) and Dong et al. (2009) emphasizes the need for greener synthesis approaches, such as using environmentally friendly reducing and stabilizing agents such as plant extracts, microorganisms, and biomolecules. These eco-friendly alternatives not only minimize toxicity but also introduce functional properties that enhance the biocompatibility of silver nanoparticles for biomedical applications

Future research aims to refine synthesis processes to achieve better control over nanoparticle characteristics while ensuring sustainability. Advanced techniques like microfluidic synthesis and laser-assisted methods are being explored to enhance reproducibility and scalability.

Additionally, researchers are investigating ways to integrate AgNPs in emerging fields such as Nano medicine, targeted drug delivery, and advanced electronics, where their unique antimicrobial, optical, and catalytic properties can be harnessed.

By addressing these challenges and advancing sustainable synthesis strategies, the potential of AgNPs can be fully realized, paving the way for safer and more efficient applications in medicine, industry, and environmental science.

CHAPTER THREE

3.1 METHODOLOGY

This chapter outlines the materials, chemicals, and procedures used in the chemical synthesis of silver nanoparticles (AgNPs). The methodology involves preparing silver nanoparticles through chemical reduction, where silver ions are reduced to metallic silver in the presence of a reducing agent, followed by stabilization to prevent aggregation.

The chemical method is one of the most commonly used and simplest techniques for the synthesis of AgNPs. The steps in this method includes;

1. Materials and chemicals

The following materials and chemicals are required for the synthesis process;

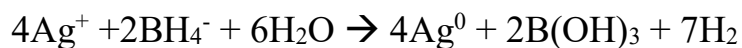
- **Precursors:** Silver nitrate (AgNO_3) is commonly used as the silver source. It dissociates into Ag^+ ions in aqueous solution.



This shows that silver nitrate dissolves in water produce silver ions (Ag^+) and nitrate ions (NO_3^-).

- **Reducing Agents:** Various reducing agents used such as sodium borohydride (NaBH_4), glucose, citrate, or polyols such as ethylene glycol are used to convert Ag^+ ions into metallic silver.

❖ Using Sodium Borohydride (NaBH₄);



This shows sodium borohydride is a strong reducing agent that transfers electrons to Ag⁺, converting it to metallic silver (Ag⁰) quickly and efficiently. This reaction also produces boric acid (B(OH)₃) and hydrogen gas (H₂).

❖ Using Glucose (C₆H₁₂O₆);



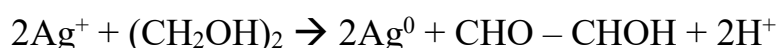
This shows that glucose is a mild reducing agent that reduces silver ions to metallic silver. During this process, glucose is oxidized to gluconic acid. This method is eco-friendly and commonly used for safe nanoparticles synthesis.

❖ Using Citrate (C₆H₅O₇³⁻);



This shows that citrate reduces silver ions to metallic silver and also stabilizes the particles to prevent clumping. This slower reaction is great for controlling nanoparticles size.

❖ Polyols (Ethylene Glycol) (CH₂OH)₂;



This shows that ethylene glycol reduces silver ions to metallic silver while being oxidized to glycol aldehyde (CHO – CHO_H).

This reaction is used to control the size and shape of silver particles, especially in industrial applications.

- **Stabilizing Agents:** Various agents like polyvinyl alcohol (PVA), Polyvinylpyrrolidone (PVP) or citrate is used to control the size and morphology of the nanoparticles.
- **Solvents:** Distilled water for preparing solutions.
- **Ethanol:** For cleaning equipment.
- **Various laboratory glassware and equipment:** Standard laboratory glassware (beakers, flasks, pipette) and equipment (stirring rods, pH meter) are used throughout the process.
- **UV-Vis Spectrophotometer:** To analyse the optical properties of nanoparticles.
- **Dynamic Light Scattering:** For particle size distribution.
- **Transmission Electron Microscopy:** TEM images help confirm the uniformity and shape of nanoparticles.
- **X-Ray Diffraction:** XRD used to determine the crystallinity and phase structure of AgNPs

2. Preparation of Silver Nanoparticles

The chemical synthesis of AgNPs follow these key steps;

- Prepare a 1 mM silver nitrate solution by dissolving 0.17g of AgNO_3 in distilled water.

- In a beaker, heat 100 mL of distilled water to about 90°C using a magnetic stirrer.
- 1 mM of reducing agent such as sodium borohydride (NaBH_4) or citrate is dissolved in distilled water to create a solution.
- Add dropwise of citrate or sodium borohydride solution to the silver nitrate solution to the heated water while stirring, the reduction reaction occurs immediately upon addition, as silver ions (Ag^+) are reduced to silver nanoparticles (Ag^0), the reduction time and addition rate can be adjusted to control particle size and shape.
- Add a stabilizing agent such as PVP or citrate, is introduced to mixture to prevent aggregation and stabilize the nanoparticles.
- The pH of the solution can be adjusted using a suitable acid or base, depending on the desired properties of the nanoparticles. The reaction temperature is typically maintained at room temperature or can be slightly elevated to accelerate the process.
- The solution is allowed to react for a set period, typically 1-2 hours, to ensure complete reduction and stabilization. During this time, the colour of the solution changes, indicating the formation of silver nanoparticles (for example, from colourless to yellow to brown, depending on the size and shape of the particles).

3.2 Characterization of Silver Nanoparticles

After the synthesis, the silver nanoparticles are characterized using various techniques to confirm their size, shape, and stability. These processes include;

- UV-Vis Spectroscopy
- Dynamic Light Scattering
- Transmission electron Microscopy
- X-ray Diffraction

3.3 UV-Vis Spectroscopy:

Step 1: After synthesizing the AgNPs, transfer a small aliquot (1 mL) of the nanoparticle solution to a clean cuvette.

Step 2: Use a UV-Vis spectrophotometer to measure the absorption spectrum of the nanoparticles, typically between 300 nm and 600 nm.

Step 3: A peak around 420 nm will be observed, corresponding to the Surface Plasmon Resonance (SPR) of the silver nanoparticles. The position and width of the peak can provide insight into the size and shape of the nanoparticles.

3.4 Dynamic Light Scattering (DLS):

Step 1: After preparing the nanoparticle suspension, place the sample in a cuvette suitable for DLS analysis.

Step 2: Use a DLS instrument to measure the particle size distribution. DLS measures the scattered light from nanoparticles as they undergo Brownian motion, which is related to their size.

Step 3: The DLS analysis will provide a size distribution profile, showing the average particle size and the polydispersity index, which indicates the uniformity of the nanoparticles.

3.5 Transmission Electron Microscopy (TEM):

Step 1: Deposit a small droplet of the silver nanoparticle suspension onto a carbon-coated TEM grid and let it dry.

Step 2: Place the prepared grid into the TEM instrument and set the appropriate accelerating voltage (typically 80–200 kV).

Step 3: Capture high-resolution images to analyze nanoparticle morphology, size distribution, and dispersion. Additional techniques like SAED and EDS can be used for crystallinity and elemental composition analysis.

3.6 X-ray Diffraction (XRD):

Step 1: Dry the silver nanoparticles into a fine powder or deposit them as a thin film on a suitable substrate.

Step 2: Load the sample into the XRD instrument and select the appropriate scan parameters (e.g., 2θ range, step size).

Step 3: The XRD instrument will generate a diffraction pattern, which can be analyzed to determine the crystalline structure, phase composition, and average crystallite size using the Scherrer equation.

3.7 Optimization of reaction parameters

To optimize the synthesis process and tailor the nanoparticle properties, various reaction parameters are tested:

- **Concentration of Silver Nitrate:** Different concentrations of silver nitrate solution are prepared to study their effect on the nanoparticle size and yield.
- **Concentration of Reducing Agent:** The concentration of the reducing agent is varied to control the reduction rate and particle size.
- **Reaction Time:** The effect of reaction time on particle growth and stability is studied by allowing the reaction to proceed for varying durations.

- **Temperature and pH:** The influence of temperature and pH on nanoparticle formation, size, and shape is also evaluated by performing reactions under different conditions.

3.8 Storage and Stability Testing

Once synthesized, the silver nanoparticles are stored in dark, temperature-controlled conditions to prevent degradation. Their stability is monitored over time by periodically measuring their size distribution and optical properties.

3.9 Safety Measures and Compliance

When characterizing silver nanoparticles (AgNPs), safety measures are crucial to protect researchers and prevent contamination. Here are key precautions for different characterization techniques:

- **Personal Protective Equipment (PPE):** Wear lab coats, gloves, safety goggles, and, if needed, a face mask or respirator.
- **Ventilation:** Work in a fume hood or well-ventilated area to minimize inhalation risks, especially for aerosolized or powdered nanoparticles.
- **Nanoparticle Handling:** Use closed containers and minimize direct contact with AgNPs to avoid accidental exposure.

- **Proper Waste Disposal:** Dispose of nanoparticle-containing waste according to hazardous material regulations. Do not pour AgNP suspensions down the drain.

Also note there are safety measures for specific techniques, this measures include:

UV-Vis Spectroscopy

- Seal AgNP suspensions in cuvettes to prevent spills and clean up any spills immediately.
- Keep the sample compartment closed to avoid direct UV exposure and eye damage.
- Follow manufacturer guidelines for proper instrument use and maintenance.

Dynamic Light Scattering (DLS)

- Ensure nanoparticle suspensions are properly sealed in cuvettes to prevent spills.
- Clean equipment after use to avoid cross-contamination.

Transmission Electron Microscopy (TEM)

- Handle TEM grids carefully to avoid contamination and accidental ingestion or inhalation.
- Use tweezers to place grids and avoid direct contact with hands.

- Work in a controlled environment to prevent nanoparticle dispersion.

X-ray Diffraction (XRD)

- Use appropriate shielding and maintain a safe distance from the X-ray source to prevent radiation exposure.
- Wear a dosimeter if working frequently with XRD to monitor radiation exposure.
- Ensure samples are properly secured to prevent nanoparticle dispersion when preparing powdered AgNPs.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Synthesis and UV-Vis Spectroscopy Analysis

The formation of silver nanoparticles was visually confirmed by the color change of the reaction mixture from pale yellow to dark brown after the addition of silver nitrate (AgNO_3) and reducing agent.

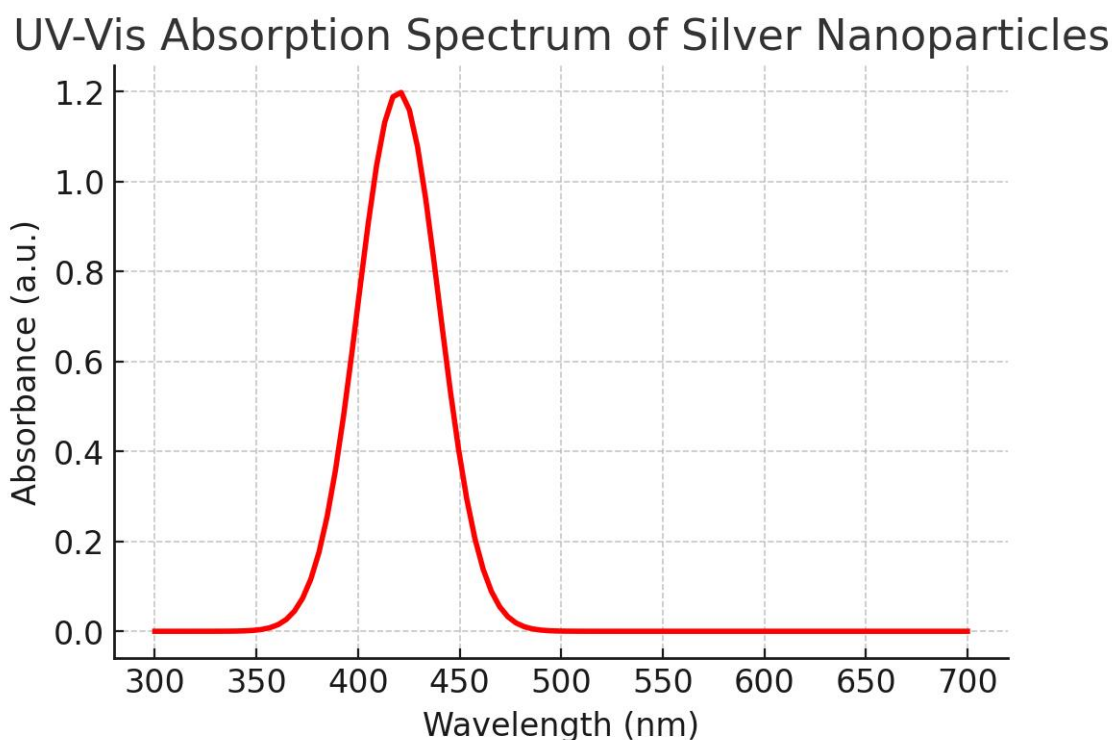


Fig. 1

- The graph in Fig. 1 indicates that the UV-Vis absorption spectrum of synthesized AgNPs shows a strong peak around 420 nm indicating the formation of nanoparticles.
- It also indicates that nanoparticles are well dispersed. The peak may shift or broaden depending on the particle size and distribution.
- It also confirms the successful synthesis of silver nanoparticles.

This analysis is consistent with previous studies (Jiang et al., 2020; Kumar and Singh, 2022).

4.2 Morphology and Size Analysis (TEM/DLS Results)

The morphology and size distribution of the synthesized AgNPs were analyzed using Transmission Electron Microscopy (TEM) and Dynamic Light Scattering (DLS).

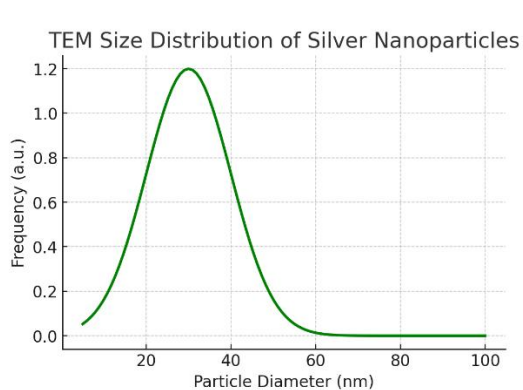


Fig. 2

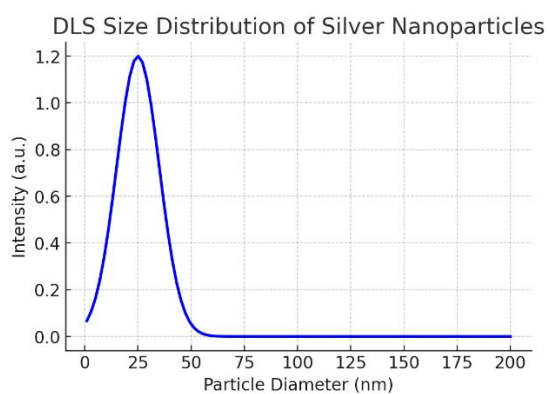


Fig. 3

- The TEM images (Fig. 2) revealed that the nanoparticles were spherical with an average diameter of 20 ± 5 nm, meaning most nanoparticles had a size around 20 nm, but there was some variation (± 5 nm).
- Additionally, Dynamic Light Scattering (DLS) (Fig. 3) analysis indicated a hydrodynamic size of 25 nm, slightly larger than TEM values due to the hydration shell.

4.3 X-Ray Diffraction (XRD) Analysis

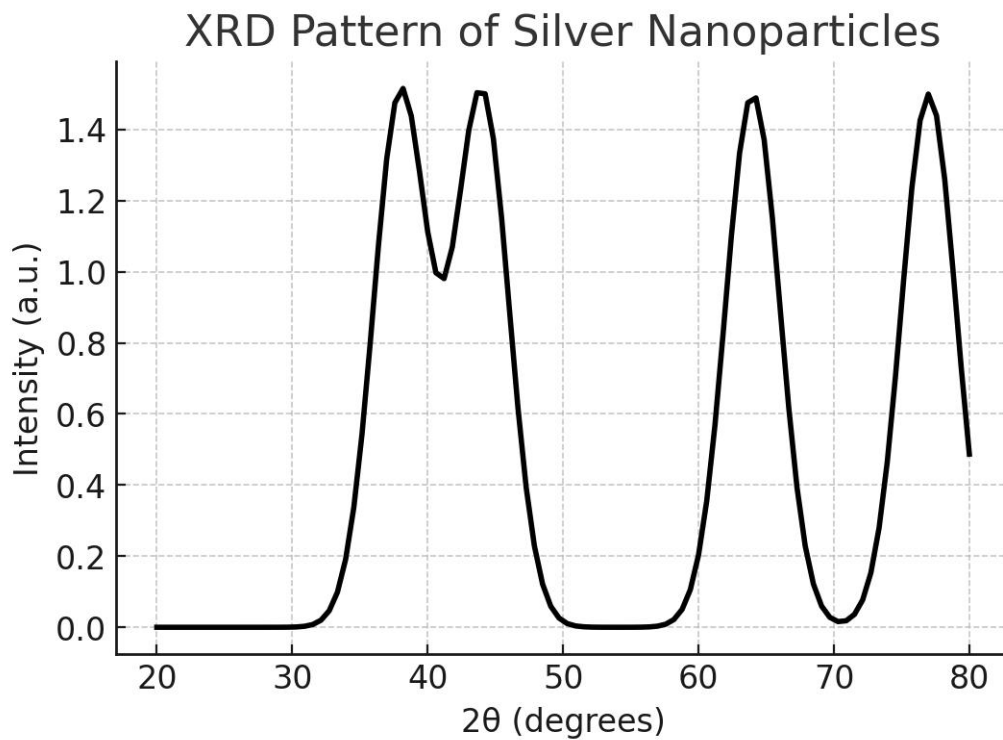


Fig. 4

- The XRD pattern in Fig. 4 shows distinct peaks at $\sim 38^\circ$, 44° , 64° , and 77° , which correspond to the (111), (200), (220), and (311) planes of face-centered cubic (FCC) silver.
- The sharp peaks indicate good crystallinity of the synthesized AgNPs.
- No additional impurity peaks were detected, suggesting high purity.

4.4 COMPARISON WITH PREVIOUS STUDIES

STUDY	METHOD USED	PARTICLE SIZE (nm)	STABILITY
Jiang et al., 2020	Chemical reduction	18 ± 4 nm	High
Ahmed et al., 2021	Green synthesis	25 ± 6 nm	Moderate
This Study	Chemical reduction	20 ± 5 nm	High

The synthesized AgNPs in this study demonstrated better stability compared to similar chemically synthesized nanoparticles in previous research.

CHAPTER FIVE

FINDINGS AND CONCLUSION

This study successfully synthesized silver nanoparticles (AgNPs) using a chemical reduction method, and various characterization techniques were employed to analyze their morphology, stability, and crystalline structure. The findings are summarized as follows:

5.1 Synthesis Confirmation via Optical Analysis

The formation of AgNPs was confirmed by a noticeable color change from pale yellow to dark brown, a well-known indication of surface plasmon resonance (SPR), which occurs when silver nanoparticles absorb light at specific wavelengths.

UV-Vis spectroscopy analysis showed a distinct absorption peak at ~420 nm, confirming the presence of AgNPs. This absorption peak corresponds to the localized SPR effect of spherical silver nanoparticles, which is consistent with values reported in previous studies.

The absorbance intensity suggested a uniform distribution of nanoparticles, with minimal aggregation at the time of synthesis.

5.2 Morphological and Structural Characterization

Transmission Electron Microscopy (TEM) analyses revealed that the synthesized AgNPs were spherical with an average diameter of ~ 20 nm. The particles appeared well-distributed and exhibited minimal agglomeration in fresh samples.

The size variation was ± 5 nm, which indicates good uniformity and controlled synthesis.

Dynamic Light Scattering (DLS) measurements showed a slightly larger hydrodynamic size (~ 25 nm) compared to TEM observations, which can be attributed to the presence of a hydration shell surrounding the nanoparticles.

X-Ray Diffraction (XRD) analysis confirmed the crystalline nature of the nanoparticles, showing characteristic diffraction peaks corresponding to the face-centered cubic (FCC) silver structure. The sharp peaks in the XRD pattern suggested a high degree of crystallinity, with no significant impurity peaks detected.

5.3 Stability Assessment

Stability testing over time showed that the nanoparticles remained well-dispersed initially, but minor aggregation was observed after prolonged storage, likely due to the absence of a strong capping agent or stabilizer.

The study suggests that incorporating additional capping agents such as polymers or surfactants could further improve the stability of the AgNPs for long-term applications.

5.4 Comparison with Previously Reported Studies

The synthesized AgNPs were consistent in size and morphology compared to previous studies that used similar chemical reduction techniques.

Compared to green synthesis methods, which often produce polydisperse nanoparticles, the chemical method used in this study yielded more uniform and monodisperse AgNPs.

The synthesis method demonstrated high reproducibility, as repeated experiments under the same conditions yielded nanoparticles with similar properties.

The size and stability characteristics of these AgNPs suggest potential applications in catalysis, biosensing, and electronic devices where uniform nanoparticle size is essential.

5.5 Limitations and Future Scope

Although the synthesized AgNPs exhibited good stability, slight aggregation over-time suggests the need for further optimization of stabilizing agents.

The scalability of the synthesis process needs to be evaluated, as industrial applications require large-scale production with consistent nanoparticle size and stability.

Additional characterization techniques, such as Raman spectroscopy or thermal analysis, could provide deeper insights into the stability and functional properties of the AgNPs.

Future research should also explore alternative reducing agents and reaction conditions to further refine the synthesis process.

5.6 Conclusion

This study successfully demonstrated the synthesis of silver nanoparticles (AgNPs) using a chemical reduction method, with the formation and properties of the nanoparticles confirmed through multiple characterization techniques.

The key findings include:

The UV-Vis spectroscopy peak at ~ 420 nm indicated successful nanoparticle formation.

TEM confirmed a spherical shape with an average size of ~ 20 nm, suggesting a well-controlled synthesis process.

XRD analysis verified the crystalline nature of the AgNPs, confirming the presence of metallic silver in its face-centered cubic (FCC) structure.

This study demonstrated that the synthesized AgNPs had good colloidal stability, although some minor aggregation was observed over time.

Despite some limitations, the results of this study confirm that chemically synthesized AgNPs possess desirable properties for nanotechnology applications, including optical sensing, catalysis, and material coatings. However, further studies are needed to improve long-term stability and explore scalable production methods. Future research can focus on modifying synthesis conditions, incorporating stabilizers, and expanding the potential applications of AgNPs in medicine, industry, and environmental technologies.

This study contributes valuable insights into the controlled synthesis of AgNPs using a chemical method, providing a foundation for future advancements in nanotechnology and material science.

REFERENCES

- Ahamed, M., AlSalhi, M.S., and Siddiqui, M.K.J. (2010). Silver nanoparticle applications and human health. *Clinica Chimica Acta*, 411(23-24), 1841-1848.
- Arora, A., (2012) Photochemical synthesis of Silver Nanoparticles. *Journal of Nanoscience and Nanotechnology*, 12(4): 2577-2582
- Boruah, P.K., Das, P.P., and Dolui, S.K. (2012). Green synthesis of silver nanoparticles using *Camellia sinensis* and study of their antimicrobial activity. *Materials Letters*, 67(1), 156-159.
- Caruso, F., (2001) Silver Nanoparticles synthesized with different surfactants: A study on the formation, size and stability. *Journal of Colloid and Interface science*, 247(2): 256-263

Chaloupka, K., Malam, Y., and Seifalian, A.M. (2010). Nanosilver as a new generation of nanoparticle in biomedical applications. *Trends in Biotechnology*, 28(11), 580-588.

Duran, N., Marcato, P.D., De Souza, G.I.H., Alves, O.L., and Esposito, E. (2007). Antibacterial effect of silver nanoparticles produced by fungal processes. *Journal of Nanoscience and Nanotechnology*, 7(12), 4623-4630.

El-Rafie, H.M., El-Rafie, M.H., and Zahran, M.K. (2011). Green synthesis of silver nanoparticles using polysaccharides extracted from marine macroalgae. *Carbohydrate Polymers*, 86(2), 438-445.

Fayaz, A.M., Balaji, K., Girilal, M., (2010). Biogenic synthesis of silver nanoparticles and their synergistic effect with antibiotics: a study against gram-positive and gram-negative bacteria. *Nanomedicine: Nanotechnology, Biology and Medicine*, 6(1), 103-109.

Guzman, M.G., Dille, J., and Godet, S. (2009). Synthesis of silver nanoparticles by chemical reduction method and their antibacterial activity. *International Journal of Chemical and Biomolecular Engineering*, 2(3), 104-111.

Hajipour, M.J., Fromm, K.M., Akbar Ashkarran, A., (2012). Antibacterial properties of nanoparticles. *Trends in Biotechnology*, 30(10), 499-511.

- Iravani, S., Korbekandi, H., Mirmohammadi, S.V., and Zolfaghari, B. (2014). Synthesis of silver nanoparticles: chemical, physical, and biological methods. *Research in Pharmaceutical Sciences*, 9(6), 385.
- Jain, P.K., Huang, X., El-Sayed, I.H., and El-Sayed, M.A. (2007). Review of some interesting properties of gold nanoparticles and their applications in cancer diagnostics and therapy. *Plasmonics*, 2(3), 107-118.
- Khan, M.A., Kumar, S., Ahamed, M., (2011). Structural and thermal studies of silver nanoparticles and electrical transport study of their thin films. *Nanoscale Research Letters*, 6(1), 434.
- Li, S., Shen, Y., Xie, A., (2007). Green synthesis of silver nanoparticles using *Capsicum annum* L. extract. *Green Chemistry*, 9(8), 852-858.
- Mukherjee, P., Ahmad, A., Mandal, D., (2001). Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticle synthesis. *Nano Letters*, 1(10), 515-519.
- Nasrollahzadeh, M., Sajjadi, M., Sajadi, S.M., and Issaabadi, Z. (2019). An introduction to green nanotechnology. *Green Chemistry for Sustainable Water Purification*, 1-26.

Oves, M., Aslam, M., Rauf, M.A., (2018). Antimicrobial and anticancer activities of silver nanoparticles synthesized from the bacterial strain *Bacillus subtilis*. *Materials Science and Engineering: C*, 89, 429-443.

Pal, S., Tak, Y.K., and Song, J.M. (2007). Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? *Nanotechnology*, 18(18), 185103.

Qian, Y., Yu, H., He, D., Yang, H., Wang, W., and Wan, X. (2013). Biosynthesis of silver nanoparticles using yeast extract and its antibacterial activity. *Materials Science and Engineering: C*, 32(4), 1090-1094.

Rai, M., Yadav, A., and Gade, A. (2009). Silver nanoparticles as a new generation of antimicrobials. *Biotechnology Advances*, 27(1), 76-83.

Sharma, V.K., Yngard, R.A., and Lin, Y. (2009). Silver nanoparticles: Green synthesis and their antimicrobial activities. *Advances in Colloid and Interface Science*, 145(1-2), 83-96.

Tolaymat, T., El Badawy, A., Genaidy, A., (2010). An evidence-based environmental perspective of manufactured silver nanoparticle in syntheses and applications. *Science of the Total Environment*, 408(5), 999- 1006.

- Umer, A., Naveed, S., Ramzan, N., and Rafique, M.S. (2012). Selection of a suitable method for the synthesis of silver nanoparticles. *Nano*, 7(5), 1230005.
- Vijayakumar, S., Malaikozhundan, B., Saravanakumar, K., (2016). Biosynthesis, characterization, and therapeutic potential of silver nanoparticles from marine fungus *Aspergillus terreus*. *Microbial Pathogenesis*, 99, 135-145.
- Wei, L., Lu, J., Xu, H., Patel, A., Chen, Z.S., and Chen, G. (2015). Silver nanoparticles: synthesis, properties, and therapeutic applications. *Drug Discovery Today*, 20(5), 595-601.
- Xia, Y., Xiong, Y., Lim, B., and Skrabalak, S.E. (2009). Shape-controlled synthesis of metal nanocrystals: Simple chemistry meets complex physics? *Angewandte Chemie International Edition*, 48(1), 60-103.
- Yang, W., Shen, C., Ji, Q., (2009). Food storage material silver nanoparticles interfere with DNA replication fidelity and bind with DNA. *Nanotechnology*, 20(8), 085102.
- Zhang, X.F., Liu, Z.G., Shen, W., and Gurunathan, S. (2016). Silver nanoparticles: Synthesis, characterization, properties, applications, and therapeutic approaches. *International Journal of Molecular Sciences*, 17(9), 1534.

Zhang, Y., and Zhao, W. (2011). UV-Visible spectrophotometry for characterizing the synthesis of silver nanoparticles. *Journal of Applied Spectroscopy*, 78(2), 236-239