Research Article

Journal of Environmental Nanotechnology

Green Synthesis of Silver Nanoparticles for Studying their Physical and Antibacterial Properties

Sendian Khaleel Omar and Bilal K. Al-Rawi*

Department of Physics, College of Education for Pure Science, University of Anbar, Anbar, Iraq
Received: 17.01.2026 Accepted: 18.02.2026 Published: 30.03.2026
*sc.bilal_alrawi@uoanbar.edu.iq

ABSTRACT

In this study, Aloe vera leaf extract was used to synthesize silver nanoparticles from silver nitrate. Three different concentrations (10%, 15%, and 25%) of the silver nanoparticles were prepared by dissolving them in deionized water. The optimal concentration for biological applications was then determined. Various techniques were employed to analyze the silver nanoparticles, including ultraviolet-visible spectroscopy, zeta potential measurements, field-emission scanning electron microscopy, and X-ray diffraction (XRD). Confirmation of the synthesized silver nanoparticles was provided by the color change of the particles, which changed from colorless to yellow and ultimately to brown. UV–Vis spectroscopy revealed a blue shift in the surface plasmon absorption peak. The XRD data revealed the crystalline characteristics of the silver nanoparticles, which exhibited a face-centered cubic structure. Field-emission scanning electron microscopy results showed the formation of spherical nanoparticles with diameters less than 100 nm. Particle concentration measurements (15%) yielded a high-quality, well-distinguishable signal relative to the zeta potential. The optimal concentration was selected based on the above test to evaluate the antibacterial activity of the synthesized silver nanoparticles against *Staphylococcus epidermidis* and *Escherichia coli*. The results indicated that the inhibitory effect on bacterial growth was concentration-dependent, with higher silver concentrations exhibiting greater antibacterial activity.

Keywords: Silver nanoparticles; Green synthesis; Antibacterial activity; Aloe vera leaf extract.

1. INTRODUCTION

Nanotechnology focuses on particles measuring between 1 and 100 nanometers. The optical features coupled with their small size that confines electrons and facilitates easily observable quantum events result in a high surface-to-volume ratio of nanoparticles. Due to their wide range of potential applications in fields such as medicine, textiles, pharmaceuticals, water purification (thanks to their antibacterial properties), mineral adsorption, and insecticides, silver nanoparticles (AgNPs) are currently the subject of extensive research (Rautela *et al.*, 2019). The biological method for producing nanoparticles utilizes a diverse range of plant and microbial compounds, including those from bacteria and fungi (Jaffer *et al.*, 2021). Expensive chemical and physical methods are used to fabricate nanoparticles. The energy, chemicals, and solvents used in these processes are extremely harmful (Parashar *et al.* 2009). Therefore, new methods for the efficient and economical synthesis of nanoparticles using harmless and ecologically friendly components, including phytochemicals extracted from plants, must be developed (Thabit and Al-Rawi, 2023). Methods from the field of green chemistry can be helpful here. Green chemistry employs a range of approaches to minimize the use and production of harmful compounds. The rationale behind this strategy is to develop novel, eco-friendly chemical processes that avoid the use of potentially hazardous byproducts (Khathim *et al.* 2024). The majority of silver nanoparticles produced by biological methods originate from plants, bacteria, and fungi. The primary benefit of using plant extracts is that they are readily available, inherently safe, and non-toxic, which helps reduce the amount of silver ions (Behravan *et al.* 2019).

Researchers are particularly interested in silver nanoparticles due to their unique physical and chemical properties, which enable them to be utilized in various applications (Michael *et al.*, 2017). The process of biosynthesis of nanoparticles from different plant extracts isn't simple. Still, research has shown that proteins, phenols, and flavonoids, among other bioactive compounds, are essential for reducing metal ions and encasing the nanoparticles that are biosynthesized (Pirtarighat *et al.* 2019).

The Asphodelaceae family includes the succulent plant known as Aloe vera which derives its name from the thick, verdant leaves that have toothed edges and contain a gel rich in beneficial components (Mohammed *et al.* 2019). Aloe vera was specifically chosen as the reducing and stabilizing agent because of its rich and well-documented phytochemical profile, which enables an efficient, eco-friendly synthesis of nanoparticles. Aloe vera gel contains a variety of bioactive compounds such as phenolic compounds,

flavonoids, polysaccharides, anthraquinones, vitamins, amino acids, and organic acids.



Fig. 1: Iraqi Aloe vera extract used in the preparation of AgNPs

This study introduces a novel and ecofriendly method for synthesizing AgNPs. The technique relies on Aloe vera leaf extract, a natural reducing agent. The work focuses at studying the physical properties and antibacterial activity of the green synthesized AgNPs. The biomedical and environmental sectors may find this approach helpful.

2. METHODOLOGY

2.1 Collecting Materials

Silver nitrate was acquired from the manufacturer Thomas Baker in the UK, with a purity of 99.9%. The leaves of the Aloe vera plant were sourced from a farmer in Anbar, Iraq.

2.1.1 Aloe Vera Leaf Extract Preparation

The extraction of Aloe vera leaf extract involved collecting leaves from the Aloe vera plant in Al-Anbar (Fig. 1). The leaves were thoroughly washed with distilled water to eliminate dust particles and thereafter dried to remove any remaining moisture. The Aloe vera extract was made by chopping the leaves into small fragments followed by pulverization using a specialized machine. The liquid was extracted, filtered and centrifuged at 2000 rpm for 4 minutes to remove the heavy biomaterials. The extract was stored at room temperature for further use.

2.1.2 Preparation of Silver Nanoparticles

About 10 mL of the plant extract was heated to 60°C and added to 100 mL of 1 mM $AgNO_3$ solution. The solution changed color from light yellow to dark brown within 15 minutes. This color change served as preliminary proof of the formation of silver nanoparticles (Fig. 2).

3. RESULTS AND DISCUSSION

The synthesis of silver nanoparticles was confirmed by the color change of the solution. This optical property called surface plasmon resonance is exclusive to nanoparticles (Kafel and Turki, 2023).

Fig. 3 represents the absorbance spectrum of AgNPs prepared using Aloe vera and silver nitrate. The absorbance was analyzed in the wavelength range from 300 to 500 nm. Absorbance bands appear between 450 and 400 nm, a characteristic feature of silver nanoparticles due to the surface plasmon resonance phenomenon. This resonance occurs when electromagnetic waves interact with free electrons on the particle surface, leading to a collective oscillation of the electrons, thus producing strong light absorption at a specific wavelength. The absorbance increased with increasing nanosilver concentration, indicating an increase in the number of particles formed. In the sample

containing the highest nanosilver concentration (25 Ag), a more pronounced absorbance band appears, with a slight shift towards higher wavelengths (red shift). This shift indicates increased interaction between the particles and their proximity to one another, leading to a more pronounced collective plasmon effect. This finding is consistent with those of (Saeed, 2024), (Mohammed *et al.* 2024; Abed *et al.* 2023; Mazhir *et al.* 2022).

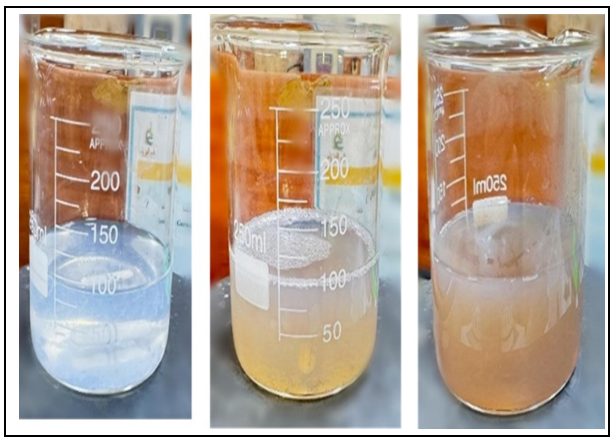


Fig. 2: Gradual change in the color of the solution

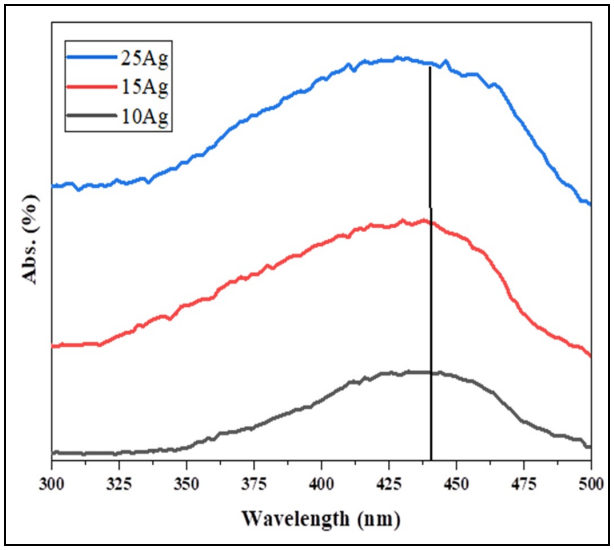


Fig. 3: UV-vis absorbance spectra of silver nanoparticles

Fig. 4 shows the energy gap values calculated from the Tauss relation for silver (Ag) solutions. There is a clear relationship between the energy gap and the concentration. The results showed that the electronic transition occurs in an indirect manner (indirect allowed transition). As the energy gap decreased with increasing silver ion concentration in the solution due to structural distortion and overlapping of energy levels, a reduction in the distance between the valence band and the conduction band occurred. This is consistent with the findings of Hussain and Al-Rawi (2024). Table 1 shows the energy gap values for silver solutions.

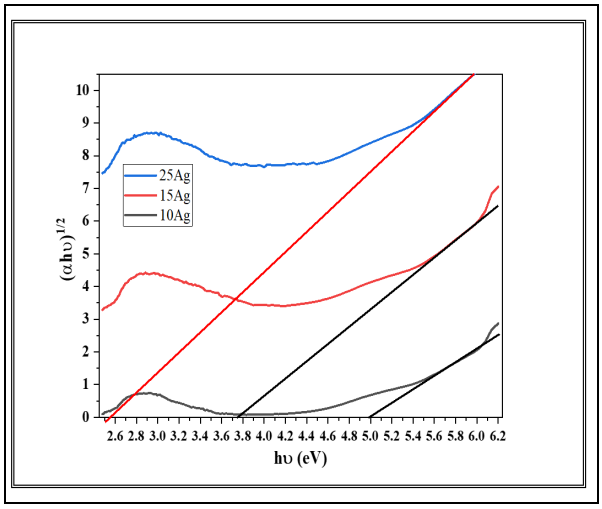


Fig. 4: Energy gap values of silver nanoparticles

Table 1. Energy gap values of silver nanoparticles

% Concentration	Energy Gap (ev)
25	3.85
15	3.95
10	4.00

The X-ray diffraction pattern of the isolated silver nanoparticles is shown in Fig. 5. Four distinct diffraction peaks were observed at 2θ angles of 38.15°, 44.30°, 64.53°, and 76.96°, which are due to the (111), (002), (022), and (113) reflection planes of the face-centered cubic (FCC) structure of silver. In addition to the Bragg peaks representing the silver nanocrystals, additional peaks were also observed at 2θ 27.89°, 32.24°, and 65.26°. These peaks originated from the organic compounds in the extract, which facilitate the reduction of silver ions and stabilize the resultant nanoparticles (Mohammed *et al.* 2024). The resulting X-ray diffraction pattern is consistent with a previously reported work (Abed *et al.* 2023).

Fig. 6 shows the FESEM image of the nanoparticles, which reveals that they are clumped and adhered to one another, making it impossible to distinguish them individually. This signifies the aggregation of nanoparticles due to the drying process. Agglomeration is the process by which nanoparticles aggregate into a cluster due to the weak attractive forces acting between them (Mazhir *et al.*, 2022). During the drying process of the silver nanoparticle solution, water molecules migrate from the center of the droplet to its periphery, resulting in the aggregation of solid particles along the droplet's edge. Additionally, the precursors sticking on to the surfaces of silver nanoparticles can cluster together, leading to agglomeration (Hussain and Al-Rawi, 2024).

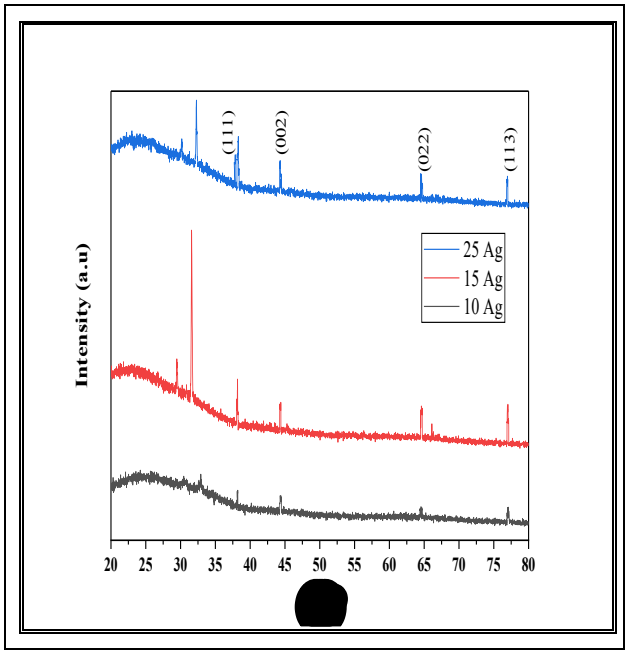


Fig. 5: X-ray diffraction pattern of silver nanoparticles

Fig. 7 shows the zeta potential of silver particles, including a comparative zeta potential study of silver nanoparticles dissolved in deionized water at different concentrations (20, 15, and 10%). Curves for 25 Ag look wider than that of 15 Ag. One of the many ways in which the zeta potential distribution widens is by raising the ionic strength. Raising the ionic strength shortens the Debye length and enhances the screening of surface charges. Scanning electron micrographs showed that particles of sizes 10 and 25 exhibited more aggregation than particles of size 15%. When the ionic strength increases and the electrical double layer thickness decreases, the zeta potential drops. The magnitude of the impact of increasing particle size can be seen by comparing respective SEM images (Mustafa and Turki, 2024). In other words, the sample in the 10% solution exhibited a weak signal.

In contrast, a broad and robust peak was observed when the size of the secondary particles remained around 30 nm in a 15% solution, and a large particle agglomerated to approximately 200 nm in a 25% solution. Comparing the silver solution at concentrations of 10% and 20% with 15% reveals a noticeable change in the peak of the zeta potential distribution. The signal was of good quality and easily discernible when the particle concentration was measured at 15%. This is because the dispersion of agglomerates makes determining the zeta potential even more difficult, and they can also widen the distribution curve of the zeta potential. Because of the formation, the zeta potential changes. This could be due to a charged layer that gets adsorbed or because the slip plane moves as a result of the adsorption of large molecules. The zeta potential variations observed, resulting from a change in the location of the slip plane, partially explain the increase in solution concentration. The zeta potential for the 15% solution is more discernible than the zeta potentials for the 10% and 20% solutions when the zeta potential measurements are combined with data regarding the surface properties of the secondary particles, such as their thickness, structure, composition, and the molecules in the solution (Al-Rawi and Mazhir, 2023; Selvaraj *et al.* 2013; Mohammed *et al.* 2024; Mulenos *et al.* 2020).

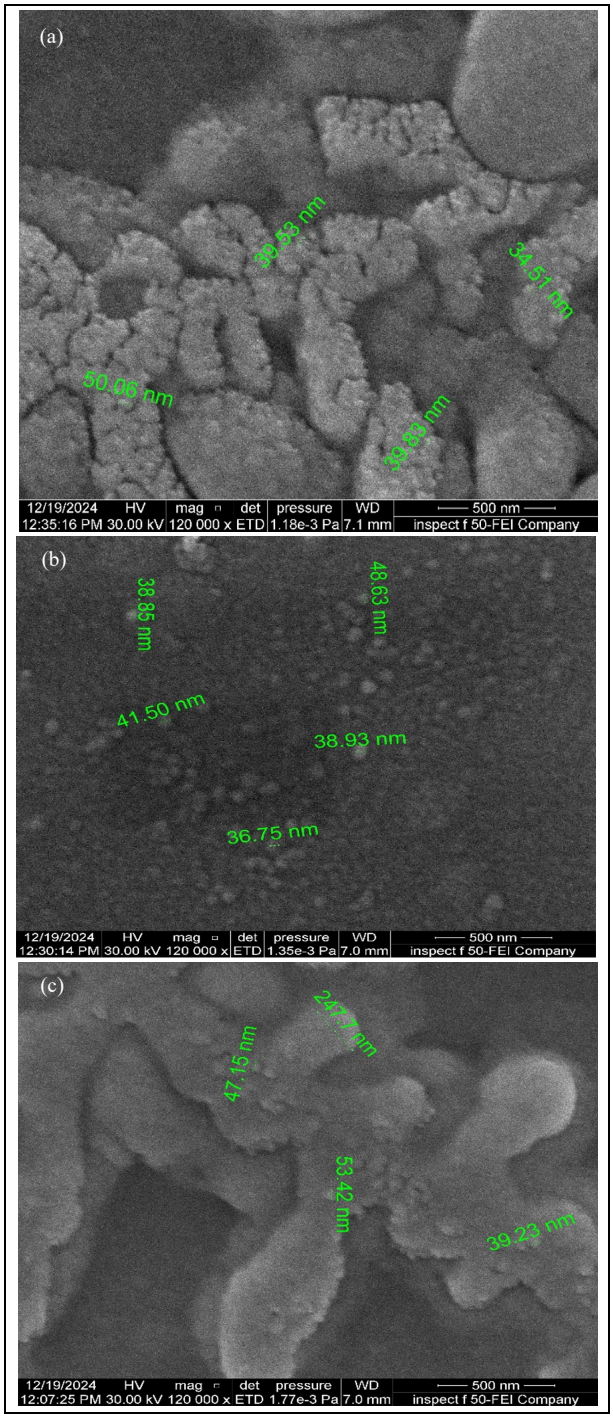


Fig. 6: Size determination by FESEM of silver nanoparticles for concentrations: (a) 10%, (b)15% and (c)25%

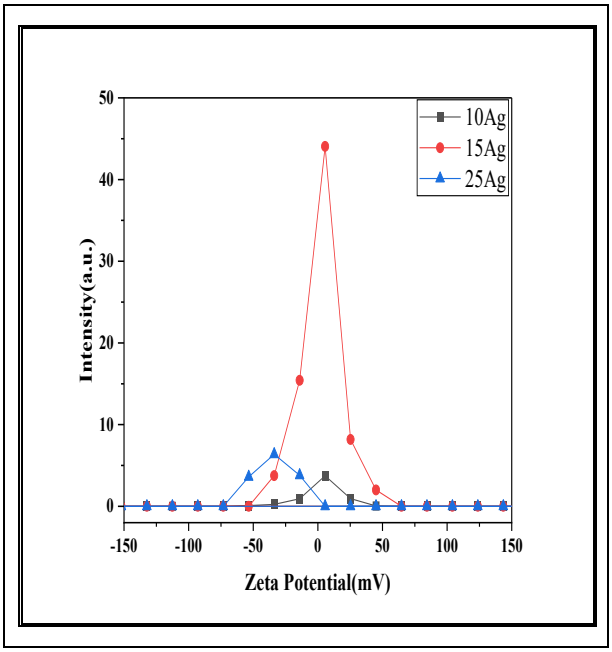


Fig. 7: Zeta potential of AgNPs at different concentrations

Numerous medical, health, and environmental fields have extensively utilized silver nanoparticles (Al-Rawi and Ramizy, 2019). Fig. 8 shows the results of testing the effectiveness of silver nanoparticles made with an Aloe vera extract against the bacteria *Staphylococcus epidermis* and *Escherichia coli*. The microbial cell undergoes structural changes, which ultimately lead to the death of the microorganisms (Al-Rawi and Alijanabi, 2021). Table 2 shows that the antibacterial activity of silver nanoparticles against the selected bacteria.

Table 2. Antibacterial activity of silver nanoparticles synthesized by aloe vera extract

AgNPs Concentration	Inhibition Zone(mm)	
	Staphylococcus epidermis	*Escherichia coli*
25	17	17
15	16	15
10	15	14

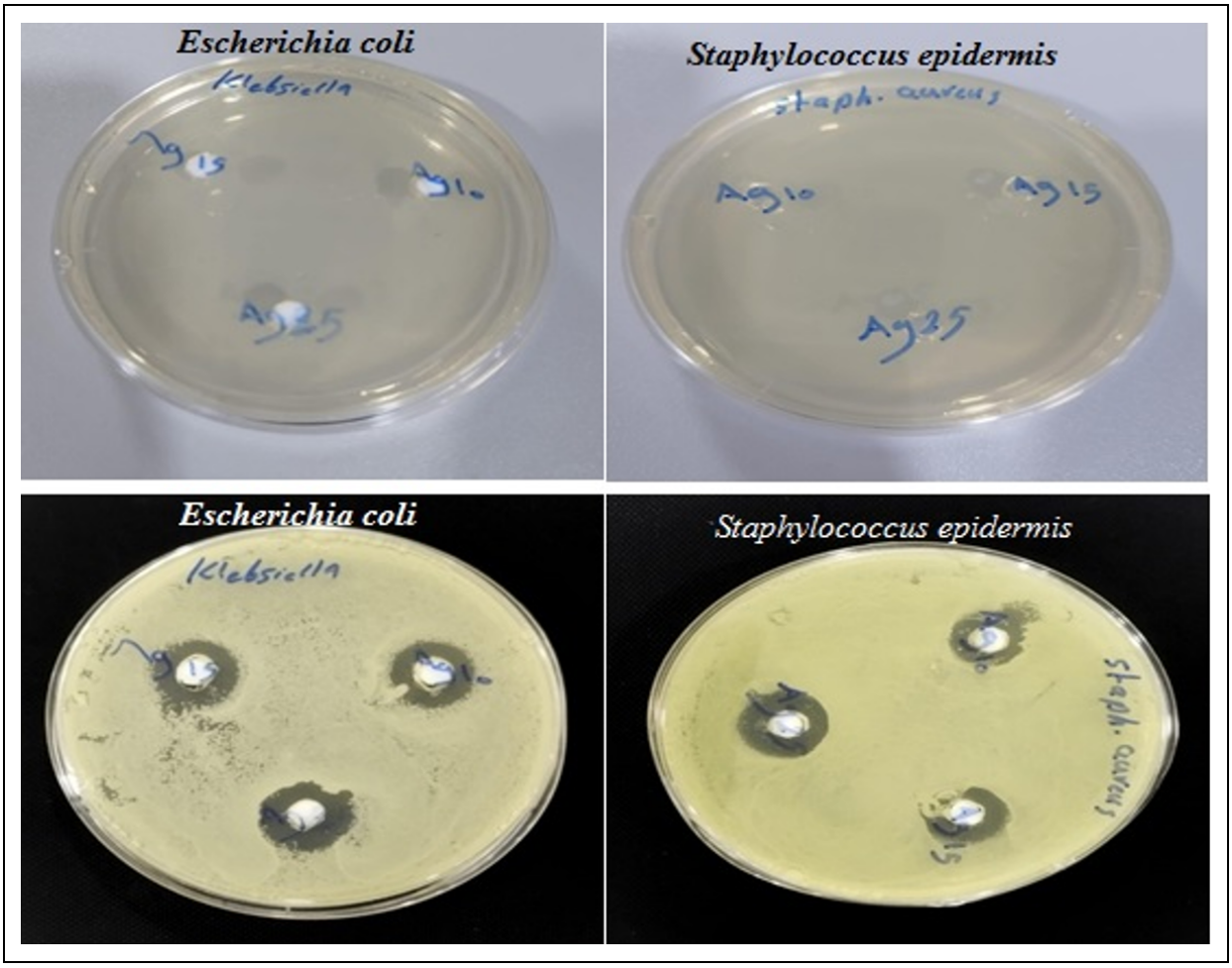


Fig. 8: The antibacterial activity of Ag NPs produced by the green technique against gram-negative bacteria and positive control, respectively, on the right

4. CONCLUSION

An eco-friendly and cost-effective green synthesis method was employed to produce silver nanoparticles using Iraqi Aloe vera leaf extract as the reducing agent. The synthesized nanoparticles were evaluated for antibacterial activity against *Escherichia coli* and *Staphylococcus epidermidis*, showing clear zones of inhibition. UV–Vis spectroscopy confirmed nanoparticle formation, while XRD analysis revealed characteristic FCC silver peaks. The FESEM images showed predominantly spherical nanoparticles. Variations in extract concentration influenced particle size and crystal structure. The results confirm that green-synthesized silver nanoparticles are stable and exhibit strong antibacterial activity.

DATA AVAILABILITY STATEMENT

The data underlying the results presented in the study are available within the manuscript.

ETHICS APPROVAL

Ethics approval not required.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

COPYRIGHT

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).



REFERENCES

Abed, H. A., Al-Rashid, S. N. T. and Mazhir, S. N., The Optical and Structural Properties of the Fe@Au Core–Shell Nanoparticles Prepared by PLAL, *Int. Nanosci.,* 22(6), 2330005(2023). https://doi.org/10.1142/s0219581x23300055

Al-Rawi, B. K. and Aljanabi, S. M. H., Modeling the Physical Properties of ZnO Nanoparticles with Selective Hydrogen Using DFT, *Int. J. Nanosci.*, 20(1), 2150011(2021). https://doi.org/10.1142/s0219581x21500113

Al-Rawi, B. K. and Mazhir, S. N., Evaluation of Antimicrobial Agents of Ag-ZnO Core-Shell Prepared by Micro-Jet Plasma Technique, *Int. J. Nanosci.*, 22(5), 2350044(2023). https://doi.org/10.1142/S0219581X23500448

Al-Rawi, B. K. and Ramizy, A., Modeling the Vibrational Properties of InSb Diamondoids and Nanocrystals Using Density Functional Theory, *J. Inorg. Organomet. Polym. Mater.*, 29(3), 645–650(2019). https://doi.org/10.1007/s10904-018-1037-y

Behravan, M., Panahi, A. H., Naghizadeh, A., Ziaee, M., Mahdavi, R. and Mirzapour, A., Facile green synthesis of silver nanoparticles using Berberis vulgaris leaf and root aqueous extract and its antibacterial activity, *Int. J. Biol. Macromol.*, 124, 148-154(2019). https://doi.org/10.1016/j.ijbiomac.2018.11.101

Hussain, A. M. and Al-Rawi, B. K., Synthesis and Characterizations of Physical and Antibacterial Properties of the Ag Nanoparticles by Exploding Wire Technique, *Int. J. Nanosci.*, 23(3), 2350075(2024). https://doi.org/10.1142/S0219581X23500758

Jaffer, Z. J., Mazhir, S. N., Khalaf, M. K. and Hanon, M. S., Synthesis and Surface Characterization of PMMA Polymer Films in Pure Oxygen, Argon, and Nitrogen Glow Discharge Plasma. *J. Phys. Conf. Ser.,* 1829, 012010(2021). http://dx.doi.org/10.1088/1742-6596/1829/1/012010

Kafel, A. and Turki, A. S.N., Examining the impact of quantum confinement energy on the optical characteristics of zinc sulfide and gallium nitrate in the ultraviolet spectral range, *Chalcogenide. Lett.*, 20(6), 423–429(2023). https://doi.org/10.15251/cl.2023.206.423

Khathim, S. E., Al-Rawi, B. K. and Khalaf, M. K., Surface Modification of NiTi Alloy with Sputtered Tantalum Coatings to Improve its Hardness, Corrosion Resistance and Biocompatibility, *Int. J. Nanosci*., 23(3), 2350073(2024). http://dx.doi.org/10.1142/S0219581X23500734

Mazhir, S. N., Ali, A. H., Abdalameer, N. K. Qasim, S. A., ZnO: Fe_3O_4 Nanoparticles Produced by Cold Plasma: Synthesis, Characterization and Anti-Microbial Activity, *Inter. J. Nanosci.,* 21, 3, 2250021(2022). https://doi.org/10.1142/S0219581X22500211

Michael, N., Naumih, M. N., Dickson, M. A. and Eric, M., Green Synthesis and Characterization of Silver Nanoparticles Using Citrullus lanatus Fruit Rind Extract, *Int. J. Anal. Chem.,* 2017, 1-9(2017). https://doi.org/10.1155/2017/8108504

Mohammed, S. A. J., Al-Haddad, R. M. S. and Al-Rawi, B. K., NIR laser effect on cancer cell lines activity by using Fe_3O_4@Cu@SiO_2 core–shell nanoparticles, *J. Opt.,* 54, 414–421 (2024). https://doi.org/10.1007/s12596-024-01676-6.

Mohammed, S. A. J., Al-Haddad, R. M. S. and Al-Rawi, B. K., structural and optical properties of magnetite nanoparticles prepared by green method for biophysics applications, Nanoscience and Technology, 15(2), 95–105(2024). https://doi.org/10.1615/NanoSciTechnolIntJ.2023048382

Mohammed, S. A. J., Al-Rawi, B. K., Al-Haddad, R. M. S., Fe_3O_4@SiO_2Core-Shell Nanoparticles: Synthesis, Characterization Prepared by Green Method for Iraqi Aloe vera Extract, *Int. J. Nanosci.*, 22(2), 2350009(2023). https://doi.org/10.1142/S0219581X23500096

Mulenos, M. R., Lujan, H., Pitts, L. R. and Sayes, C. M., Silver Nanoparticles Agglomerate Intracellularly Depending on the Stabilizing Agent: Implications for Nanomedicine Efficacy, *Nanomater*. 10(10):1953(2020). https://doi.org/10.3390/nano10101953

Mustafa, A. and Turki, A. S., Cohesive energy model for the optical properties in nanostructured materials of zinc sulfide and cadmium selenide, *Chalcogenide. Lett.*, 21(5), 407–411(2024). https://doi.org/10.15251/cl.2024.215.407

Parashar, K., Saxena, S. and Srivastava, A., Parthenium leaf extract mediated synthesis of silver nanoparticles: a novel approach for weed utilization, *Dig. J. Nanomater. Biostruct.*, 4(1), 45-50(2009).

Pirtarighat, S., Ghannadnia, M. and Baghshahi, S. Green synthesis of silver nanoparticles using the plant extract of Salvia Spinosa grown in vitro and their antibacterial activity assessment, *J. Nanostruct. Chem.,* 9, 1-9(2019). http://dx.doi.org/10.1007/s40097-018-0291-4

Rautela, A., Rani. J. and Debnath, M., Green synthesis of silver nanoparticles from Tectona grandis seeds extract: characterization and mechanism of antimicrobial action on different microorganisms, *J. Anal. Sci. Technol.,* 10, 5(2019). http://dx.doi.org/10.1186/s40543-018-0163-z

Saeed, A., Study of the variations of quantum confinement energy with the exciton Bohr radius of zinc selenide, *Nanosci. Technol.*, 15(3), 21 - 27(2024). http://dx.doi.org/10.1615/NanoSciTechnolIntJ.2023048643

Selvaraj, M., Roopan, S., Rohit., Madhumitha, G., Abdul, A. A., Kamaraj, C., Bharathi, A. and Surendra, T., Low-cost and eco-friendly phyto-synthesis of silver nanoparticles using Cocos nucifera coir extract and its larvicidal activity, *Ind. Crops. Prod.,* 43, 631-635(2013). https://doi.org/10.1016/J.INDCROP.2012.08.013

Thabit, W. S. and Al-Rawi, B. K., The Effect of Atomization Force on the Structural Properties of NiTi Thin Films, *Int. J. Nanosci*., 22(2), 2350005(2023), https://doi.org/10.1142/S0219581X23500059