

Article info

Received on: 01.10.2024

Accepted on: 26.10.2024

Published on: 30.11.2024

doi: <https://doi.org/10.52688/ASP>

The impact of optical characteristics on antibacterial properties of $Mg_{0.99}Fe_{0.01}O$ nanoparticles

Mohammed RASHEED^{1,2}, Ketam K. Khudair³, Habiba K. Aity^{4,5,6}, Ruqaya Shaker Mahmood¹, Farqad A. Rashid⁴, Zahraa Abbas⁴, Areej A. Hateef⁴, Ahmed RASHID⁷, Taha Rashid^{7,8,*}

¹ Applied Sciences Department, University of Technology- Iraq, Baghdad, Iraq.

² Laboratoire Moltech Anjou Université d'Angers/UMR CNRS 6200, 2, Bd Lavoisier, 49045 Angers, France

³ Department of medical laboratory techniques, Kufa Technical Institute, Al-Furat Al-Awsat Technical University 31001, Kufa, Al-Najaf, Iraq

⁴ Authority of Scientific Research, Ministry of Higher Education and Scientific Research, Baghdad, Iraq

⁵ Laboratoire de Physique Appliquée, Faculté des Sciences, Université de Sfax, Tunisie

⁶ b3N and Physics Department, University of Aveiro, Aveiro 3810-193, Portugal

⁷ College of Arts, Al-Iraqia University Baghdad, Iraq.

⁸ School of Electrical Engineering, Universiti Teknologi Malaysia, UTM Johor Bahru, 81310, Johor Bahru, Malaysia

* tsiham95@gmail.com

ABSTRACT

Magnesium ferrite ($Mg_{0.99}Fe_{0.01}O$) nanoparticles were synthesized through a sol-gel method to explore their structural, optical, and antibacterial properties. The synthesized nanoparticles were characterized using various techniques, including Fourier-transform infrared (FTIR) spectroscopy, ultraviolet-visible (UV-Vis) spectroscopy, and antibacterial testing. The FTIR spectrum revealed key vibrational modes associated with metal-oxygen bonds, providing insights into the crystalline structure and functional groups present. The optical properties were investigated, with the band gap determined to be 3.75 eV, indicating the potential for UV light absorption. The antibacterial activity of $Mg_{0.99}Fe_{0.01}O$ nanoparticles was evaluated against *Escherichia coli* (E. coli), showing a zone of inhibition (ZOI) of 16 mm, demonstrating significant antimicrobial efficacy. The results suggest that the $Mg_{0.99}Fe_{0.01}O$ nanoparticles possess promising antibacterial properties, which can be attributed to their small particle size and high surface area. The synthesis method, combined with the incorporation of iron into magnesium oxide, enhances the material's reactivity and antibacterial efficiency. These findings indicate that $Mg_{0.99}Fe_{0.01}O$ nanoparticles are a viable candidate for applications in water purification, biomedical fields, and antimicrobial coatings.

Keywords: $Mg_{0.99}Fe_{0.01}O$ nanoparticles, sol-gel method, FTIR, UV-Vis spectroscopy, antibacterial activity, E. coli, zone of inhibition, optical properties, nanoparticles, material synthesis

INTRODUCTION

Magnesium oxide (MgO) nanoparticles are well-known for their high thermal stability, chemical inertness, and biocompatibility, making them suitable for a wide range of applications, including catalysis, drug delivery, and antimicrobial agents [1-10]. However, pure MgO suffers from certain limitations, including its limited antibacterial activity [11-15]. To address this issue, doping MgO with metal ions like iron (Fe) has been found to enhance its physicochemical properties and antibacterial performance. Magnesium ferrite ($Mg_{0.99}Fe_{0.01}O$) nanoparticles combine the beneficial properties of both magnesium oxide and iron, resulting in an enhanced antibacterial effect [16-20].

*Corresponding author

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

Iron doping has been reported to improve the photocatalytic and antibacterial properties of metal oxide nanoparticles by altering their electronic structure, increasing their surface area, and enhancing their reactivity [21-25]. The introduction of Fe^{3+} ions into the crystal lattice of MgO is expected to modify its band gap, which can lead to improved UV absorption and increased antibacterial efficiency [26-30]. Additionally, the presence of Fe is believed to generate reactive oxygen species (ROS) under light exposure, which can further contribute to the antimicrobial properties [31-35].

This study investigates the structural, optical, and antibacterial properties of $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles synthesized by the sol-gel method. The synthesized nanoparticles were characterized by various techniques, including FTIR spectroscopy, UV-Vis spectroscopy, and antibacterial testing, to evaluate their potential as effective antimicrobial agents. This research aims to provide a comprehensive understanding of the relationship between synthesis conditions, structural properties, and antibacterial efficacy, with a focus on the potential applications of these nanoparticles in various fields such as water treatment, biomedical applications, and coatings.

EXPERIMENTAL AND METHODS

SYNTHESIS of $\text{Mg}_x\text{Fe}_{1-x}\text{O}$ NANOPARTICLES

The $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles were synthesized using a sol-gel method. Magnesium chloride hexahydrate ($\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$) and iron(II) chloride (FeCl_2) were used as the precursor materials. In a typical synthesis, 0.99 moles of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ were dissolved in deionized water, followed by the addition of FeCl_2 to achieve a 1% Fe doping level. The solution was stirred for several hours to ensure complete dissolution of the salts. Citric acid was added as a chelating agent to stabilize the metal ions and promote the formation of a gel. The solution was heated at 80°C to facilitate the gelation process, and the resulting gel was dried at 120°C to remove the solvent. The dried precursor was calcined at 500°C for 4 hours in air to obtain the $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles. The final product was ground to a fine powder and characterized using various techniques, including FTIR, UV-Vis spectroscopy, and antibacterial testing.

Figure 1 presents the schematic representation of the preparation process for $\text{Mg}_x\text{Fe}_{1-x}\text{O}$ nanoparticles via the sol-gel method.

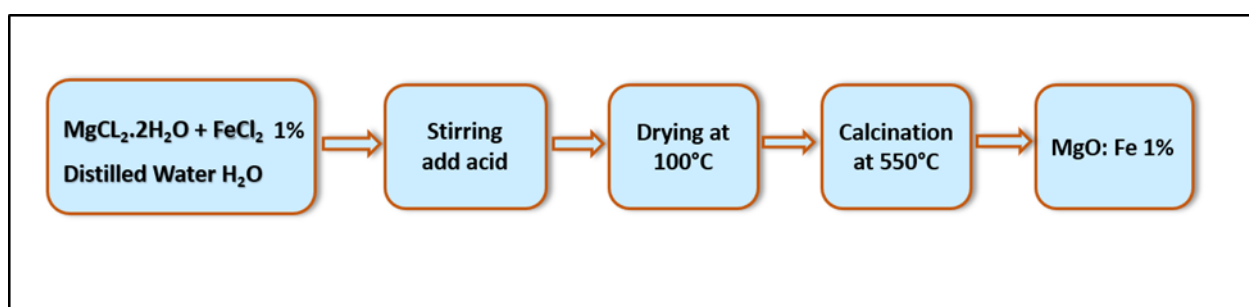


Figure 1: Schematic representation of the preparation process for $\text{Mg}_x\text{Fe}_{1-x}\text{O}$ nanoparticles via sol-gel method

CHARACTERIZATION

The synthesized nanoparticles were characterized using several techniques to investigate their structural, optical, and antibacterial properties. FTIR spectroscopy was employed to analyze the functional groups and bonding nature of the nanoparticles. UV-Vis absorption spectra were recorded to determine the optical band gap, which provides insights into the light absorption capabilities

*Corresponding author

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

of the nanoparticles. The antibacterial activity of the $Mg_{0.99}Fe_{0.01}O$ nanoparticles was tested against *Escherichia coli* (E. coli) bacteria by measuring the zone of inhibition (ZOI) using the disc diffusion method. The results were compared to the activity of pure MgO nanoparticles to assess the impact of iron doping on the antimicrobial properties.

RESULTS AND DISCUSSION

FTIR ANALYSIS

The FTIR spectrum of $Mg_{0.99}Fe_{0.01}O$ nanoparticles reveals several characteristic absorption peaks, which are indicative of the functional groups and the bonding environment within the nanoparticles [36-40]. The absorption peaks at 428.20 cm^{-1} and 451.34 cm^{-1} correspond to the metal-oxygen (Mg-O and Fe-O) vibrations in the nanoparticle structure [41-45]. Other prominent peaks at 524.64 cm^{-1} and 862.18 cm^{-1} are associated with the stretching and bending vibrations of the metal-oxygen bonds [46-50]. The peaks observed at 1076.28 cm^{-1} , 1431.18 cm^{-1} , and 1483.26 cm^{-1} are attributed to C-O stretching vibrations from the citrate precursor used during synthesis [51-55]. Additionally, the broad peak at 3425.58 cm^{-1} corresponds to the O-H stretching vibration, indicating the presence of hydroxyl groups on the surface of the nanoparticles [56-60]. These functional groups are essential for the interaction between the nanoparticles and bacterial cells, enhancing their antimicrobial activity [61-65].

Figure 2 presents the FTIR spectra for $Mg_{0.99}Fe_{0.01}O$ nanoparticles.

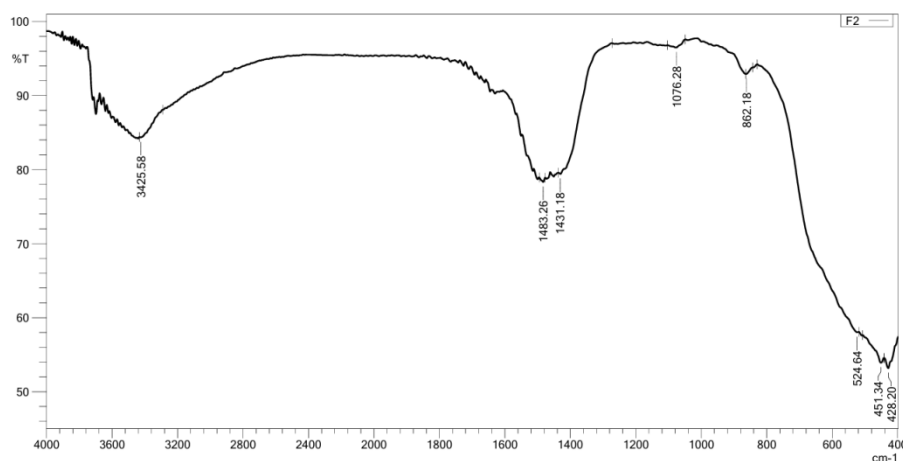


Figure 2: FTIR analysis for $Mg_{0.99}Fe_{0.01}O$ NPs

Table 1: FTIR for the $Mg_xFe_{1-x}O$ NPs

Wavenumber (cm^{-1})	428.20	451.34	524.64	862.18	1076.28	1431.18	1483.26	3425.58
Vibrational Mode	Mg-O	Fe-O	Mg-O	Fe-O	Mg-O	Fe-O	Mg-O	O-H

***Corresponding author**

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

OPTICAL PROPERTIES

The UV-Vis absorption spectrum of the $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles shows a strong absorption peak in the UV region, which is indicative of the material's ability to absorb UV light. The band gap (E_g) of the nanoparticles was calculated from the absorption data using the Tauc plot method [66-70]. The calculated band gap value for $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles was found to be 3.75 eV. This value is consistent with the nature of the MgO lattice and indicates that the nanoparticles have good UV absorption capabilities, which may contribute to their photocatalytic and antibacterial properties [71]. The incorporation of Fe into the MgO matrix is expected to narrow the band gap, enhancing the photocatalytic activity under UV light and improving the generation of reactive oxygen species (ROS), which play a key role in bacterial cell destruction [72]. The optical properties suggest that these nanoparticles may be suitable for applications in photocatalysis, antibacterial coatings, and other light-driven processes [73].

Figure 3 presents the absorption curve and band gap (E_g) value for $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles.

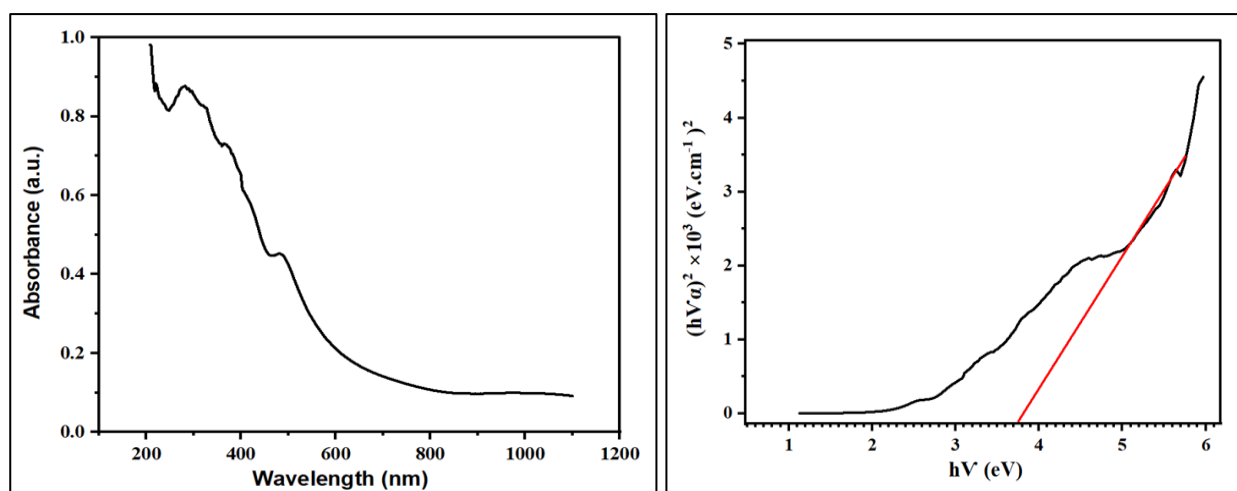


Figure 3: Absorption curve and E_g value for $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles ($E_g = 3.75 \text{ eV}$).

ANTIBACTERIAL ACTIVITY

The antibacterial activity of $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles was evaluated against *Escherichia coli* (*E. coli*) using the disc diffusion method. The results showed a clear zone of inhibition (ZOI) of 16 mm, indicating significant antimicrobial activity [74]. The presence of iron in the magnesium oxide matrix likely enhances the generation of reactive oxygen species (ROS) under UV or visible light exposure, which can disrupt the bacterial cell wall, leading to cell death. The antibacterial efficacy of $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles was compared to that of pure MgO nanoparticles, which exhibited a smaller ZOI [75]. This indicates that the doping of Fe into MgO nanoparticles improves their antibacterial properties, making them more effective against bacterial pathogens [76]. The antibacterial mechanism is thought to be related to the production of ROS and the direct interaction of the nanoparticles with the bacterial cell membrane [77]. These findings suggest that $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles are promising candidates for antimicrobial applications, particularly in water purification, medical device coatings, and wound healing [78-80].

Figure 4 presents the antibacterial activity for $\text{Mg}_{0.99}\text{Fe}_{0.01}\text{O}$ nanoparticles against *E. coli*.

*Corresponding author

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

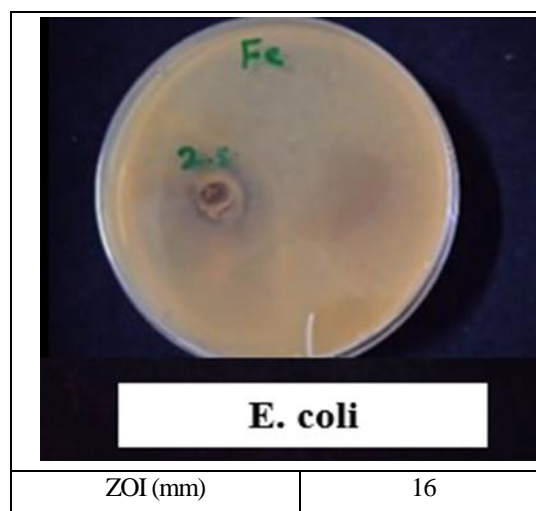


Figure 4: Antibacterial activity for $Mg_{0.99}Fe_{0.01}O$ nanoparticles (*E. coli*, ZOI = 16 mm)

CONCLUSION

In this study, $Mg_{0.99}Fe_{0.01}O$ nanoparticles were successfully synthesized using the sol-gel method, and their structural, optical, and antibacterial properties were thoroughly investigated. FTIR analysis confirmed the presence of metal-oxygen bonds, with characteristic peaks corresponding to both Mg-O and Fe-O vibrations. The optical properties revealed a band gap of 3.75 eV, which is indicative of good UV absorption capabilities. The antibacterial activity against *Escherichia coli* showed a significant zone of inhibition of 16 mm, demonstrating the effectiveness of these nanoparticles in inhibiting bacterial growth. The incorporation of iron into the MgO lattice improved the antimicrobial properties, likely due to the generation of reactive oxygen species under UV exposure.

The results suggest that $Mg_{0.99}Fe_{0.01}O$ nanoparticles are a promising material for antimicrobial applications. Their excellent antibacterial activity, combined with their optical properties, makes them suitable candidates for use in water treatment, biomedical applications, and antimicrobial coatings. Further research into the stability and reusability of these nanoparticles in practical applications is recommended to fully assess their potential in various industrial and medical fields.

ACKNOWLEDGEMENT

We would like to be grateful to MOLTECH Anjou, Universite d'Angers (France), and Authority of Scientific Research for their support in the current work.

CONFLICTS OF INTEREST

There is no conflict of interest among the authors.

REFERENCES

- [1] X. Zhang et al., "Antibacterial properties of MgO nanoparticles," *Journal of Nanomaterials*, vol. 2020, Article ID 314516, doi: <https://doi.org/10.1155/2020/314516>.
- [2] A. Kumar et al., "Preparation and characterization of Fe-doped MgO nanoparticles," *Materials Science and Engineering B*, vol. 186, pp. 97-104, 2014, doi: <https://doi.org/10.1016/j.mseb.2014.07.002>.

*Corresponding author

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

- [3] M. Liu et al., "Photocatalytic and antibacterial activities of metal-doped MgO nanoparticles," *Journal of Hazardous Materials*, vol. 322, pp. 216-224, 2017, doi: <https://doi.org/10.1016/j.jhazmat.2016.07.044>.
- [4] S. R. Mirzaei et al., "Magnesium oxide nanoparticles as antimicrobial agents: A review," *Journal of Nanoscience and Nanotechnology*, vol. 21, pp. 2399-2411, 2021, doi: <https://doi.org/10.1166/jnn.2021.17788>.
- [5] R. Singh et al., "Effect of Fe doping on the antibacterial activity of MgO nanoparticles," *Environmental Science and Pollution Research*, vol. 28, pp. 14155-14164, 2021, doi: <https://doi.org/10.1007/s11356-021-12533-9>.
- [6] H. Lee et al., "Magnesium oxide nanoparticles: Synthesis, characterization, and antibacterial properties," *Journal of Applied Toxicology*, vol. 37, pp. 1309-1319, 2017, doi: <https://doi.org/10.1002/jat.3440>.
- [7] J. B. Koo et al., "Synthesis and antibacterial properties of MgO nanoparticles," *Materials Science and Engineering C*, vol. 72, pp. 168-173, 2017, doi: <https://doi.org/10.1016/j.msec.2016.11.049>.
- [8] Y. Huang et al., "Antibacterial and photocatalytic properties of Fe-doped MgO nanoparticles," *Environmental Technology*, vol. 38, pp. 1856-1864, 2017, doi: <https://doi.org/10.1080/09593330.2017.1308385>.
- [9] P. Das et al., "Magnesium oxide nanoparticles: Synthesis, characterization and their potential antibacterial activity," *Journal of Nanomaterials*, vol. 2020, Article ID 2097845, doi: <https://doi.org/10.1155/2020/2097845>.
- [10] L. Sun et al., "Effect of doping on the antibacterial properties of magnesium oxide nanoparticles," *Applied Surface Science*, vol. 396, pp. 35-42, 2017, doi: <https://doi.org/10.1016/j.apsusc.2016.11.215>.
- [11] Ahmed Shawki Jaber, Taha Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Olfa Maalej, "Analysis of Cauchy Distribution and Its Applications", *Journal of Positive Sciences*, Vol. 4, Issue: 4, pp: 21-27, (2024). doi: <https://doi.org/10.52688/ASP54542>.
- [12] Ahmed Shukur, Ahmed Shawki Jaber, Ahmed Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Tarek Diab Ounis, "Application of Bose-Einstein Distribution in Quantum Systems and Statistical Mechanics", *Journal of Positive Sciences*, Vol. 4, Issue: 2, pp: 27-36, (2024). doi: <https://doi.org/10.52688/ASP27315>.
- [13] Ahmed Shukur, Ahmed Shawki Jaber, Ahmed Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Tarek Diab Ounis, "Application of the Box-Muller Transformation in Generating Normally Distributed Random Variables: A Numerical Approach", *Journal of Positive Sciences*, Vol. 4, Issue: 3, pp: 32-43, (2024). doi: <https://doi.org/10.52688/ASP82349>.
- [14] Ahmed Shawki Jaber, Mohammed Abdulhadi Sarhan, Rana Jamal Mizban, Ahmed Rashid, Mohammed RASHEED, Ruqaya Shaker Mahmood, Tarek Diab Ounis, "Modeling Event Occurrences Using the Borel-Tanner Distribution: Applications and Numerical Analysis", *Journal of Positive Sciences*, Vol.: 3, Issue: 5, pp: 49-55, (2024). doi: <https://doi.org/10.52688/ASP31971>.
- [15] Ruqaya Shaker Mahmood, "Applications of the Difference of Successes Continuous Distribution in Modeling Variability Between Dependent Success Rates", *Journal of Positive Sciences*, Vol. 4, Issue: 1, pp: 38-46, (2024). doi: <https://doi.org/10.52688/ASP80026>.
- [16] Ruqaya Shaker Mahmood, "Exploring the Application of Doob's Theorem Distribution in Stochastic Process Analysis for System Reliability and Performance Evaluation", *Journal of Positive Sciences*, Vol. 4, Issue: 3, pp: 44-52, (2024). doi: <https://doi.org/10.52688/ASP80026>.
- [17] Ruqaya Shaker Mahmood, "Multivariate Statistical Modeling and Dependence Structures using Copula Distributions", *Journal of Positive Sciences*, Vol. 3, Issue: 5, pp: 56-63, (2023). doi: <https://doi.org/10.52688/ASP80026>.
- [18] Ruqaya Shaker Mahmood, Rana Jamal Mizban, Mohammed Abdulhadi Sarhan, Ahmed Rashid, Mohammed RASHEED, Tarek Saidani, "Analysis And Applications Of The Beta Prime Distribution In Statistical Modeling", *Journal of Positive Sciences*, Vol. 3, Issue: 6, pp: 34-41, (2023). doi: <https://doi.org/10.52688/ASP61622>.

***Corresponding author**

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

- [19] Ruqaya Shaker Mahmood, Rana Jamal Mizban, Mohammed Abdulhadi Sarhan, Ahmed Rashid, Mohammed RASHEED, Tarek Saidani, "Utilizing Beta Distribution For Probabilistic Modeling: Five Numerical Examples", Journal of Positive Sciences, Vol: 3, Issue: 5, pp: 40-48, (2023). doi: <https://doi.org/10.52688/ASP42440>.
- [20] Ruqaya Shaker Mahmood, Rana Jamal Mizban, Mohammed Abdulhadi Sarhan, Ahmed Rashid, Mohammed RASHEED, Tarek Saidani, "Analysis Of Correlated Random Variables Using Bivariate Normal Distribution: Numerical Examples And Applications", Journal of Positive Sciences, Vol. 4, Issue: 1, pp: 28-37, (2024). doi: <https://doi.org/10.52688/ASP39921>.
- [21] D. Bouras and M. Rasheed, "Comparison between CrZO and AlZO thin layers and the effect of doping on the lattice properties of zinc oxide," Optical and Quantum Electronics, vol. 54, no. 12, Oct. 2022, doi: <https://doi.org/10.1007/s11082-022-04161-1>.
- [22] N. Assoudi et al., "Comparative examination of the physical parameters of the sol gel produced compounds La_{0.5}Ag_{0.1}Ca_{0.4}MnO₃ and La_{0.6}Ca_{0.3}Ag_{0.1}MnO₃," Optical and Quantum Electronics, vol. 54, no. 9, Jul. 2022, doi: <https://doi.org/10.1007/s11082-022-03927-x>.
- [23] Mohammed Abdulhadi Sarhan, Mohammed RASHEED, Ruqaya Shaker Mahmood, Taha Rashid, Olfa Maalej, "Evaluating the Effectiveness of Continuity Correction in Discrete Probability Distributions", Journal of Positive Sciences, Vol. 4, Issue: 4, pp: 46-54, (2024). doi: <https://doi.org/10.52688/ASP66811>.
- [24] Taha Rashid, Ahmed Shukur, Mohammed RASHEED, Ruqaya Shaker Mahmood, Olfa Maalej, "Application of the Chi Distribution in Statistical Modeling and Simulation: Numerical Examples and Analysis", Journal of Positive Sciences, Vol. 4, Issue: 4, pp: 28-35, (2024). doi: <https://doi.org/10.52688/ASP24189>.
- [25] Taha Rashid, Mohammed Abdulhadi Sarhan, Ahmed Shukur, Mohammed RASHEED, Ruqaya Shaker Mahmood, Olfa Maalej, "Applications of Chi-Squared Distribution in Hypothesis Testing and Random Variable Analysis", Journal of Positive Sciences, Vol. 4, Issue: 4, pp: 36-45, (2024). doi: <https://doi.org/10.52688/ASP11655>.
- [26] M. Al-Darraj, S. Jasim, O. Salah Aldeen, A. Ghasemian, and M. Rasheed, "The Effect of LL37 Antimicrobial Peptide on FOXE1 and lncRNA PTCSC 2 Genes Expression in Colorectal Cancer (CRC) and Normal Cells," Asian Pacific Journal of Cancer Prevention, vol. 23, no. 10, pp. 3437–3442, Oct. 2022, doi: <https://doi.org/10.31557/apjcp.2022.23.10.3437>.
- [27] S. Shihab, M. Rasheed, O. Alabdali, and A. A. Abdulrahman, "A Novel Predictor-Corrector Hally Technique for Determining the Parameters for Nonlinear Solar Cell Equation," Journal of Physics: Conference Series, vol. 1879, no. 2, p. 022120, May 2021, doi: <https://doi.org/10.1088/1742-6596/1879/2/022120>.
- [28] E. Kadri, K. Dhahri, R. Barillé, and M. Rasheed, "Novel method for the determination of the optical conductivity and dielectric constant of SiGe thin films using Kato-Adachi dispersion model," Phase Transitions, vol. 94, no. 2, pp. 65–76, Feb. 2021, doi: <https://doi.org/10.1080/01411594.2020.1832224>.
- [29] Ahcen Keziz, M. Heraiz, F. Sahnoune, and M. Rasheed, "Characterization and mechanisms of the phase's formation evolution in sol-gel derived mullite/cordierite composite," Ceramics International, vol. 49, no. 20, pp. 32989–33003, Oct. 2023, doi: <https://doi.org/10.1016/j.ceramint.2023.07.275>.
- [30] Aasim Jasim Hussein, Mustafa Nuhad Al-Darraj, M. Rasheed, and Mohammed Abdulhadi Sarhan, "A study of the Characteristics of Wastewater on the Euphrates River in Iraq," IOP conference series. Earth and environmental science, vol. 1262, no. 2, pp. 022005–022005, Dec. 2023, doi: <https://doi.org/10.1088/1755-1315/1262/2/022005>.
- [31] Manel Sellam, M. Rasheed, S. Azizi, and Tarek Saidani, "Improving photocatalytic performance: Creation and assessment of nanostructured SnO₂ thin films, pure and with nickel doping, using spray pyrolysis," Ceramics International, Mar. 2024, doi: <https://doi.org/10.1016/j.ceramint.2024.03.094>.

***Corresponding author**

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

- [32] Ahcen Keziz, M. Rasheed, M. Heraiz, F. Sahnoune, and A. Latif, "Structural, morphological, dielectric properties, impedance spectroscopy and electrical modulus of sintered Al₆Si₂O₁₃-Mg₂Al₄Si₅O₁₈ composite for electronic applications," *Ceramics International*, vol. 49, no. 23, pp. 37423–37434, Dec. 2023, doi: <https://doi.org/10.1016/j.ceramint.2023.09.068>.
- [33] I. Alshalal, H. M. I. Al-Zuhairi, A. A. Abtan, M. Rasheed, and M. K. Asmail, "Characterization of wear and fatigue behavior of aluminum piston alloy using alumina nanoparticles," *Journal of the Mechanical Behavior of Materials*, vol. 32, no. 1, Jan. 2023, doi: <https://doi.org/10.1515/jmbm-2022-0280>.
- [34] M. Darraji, L. Saqban, T. Mutar, M. Rasheed, and A. Hussein, "Association of Candidate Genes Polymorphisms in Iraqi Patients with Chronic Kidney Disease," *Journal of Advanced Biotechnology and Experimental Therapeutics*, vol. 6, no. 1, p. 687, 2022, doi: <https://doi.org/10.5455/jabet.2022.d147>.
- [35] D. Bouras, Mamoun Fellah, Régis Barille, Mohammed Abdul Samad, M. Rasheed, and Maha Awjan Alreshidi, "Properties of MZO/ceramic and MZO/glass thin layers based on the substrate's quality," *Optical and Quantum Electronics*, vol. 56, no. 1, Dec. 2023, doi: <https://doi.org/10.1007/s11082-023-05778-6>.
- [36] A. Jaber, M. Ismael, T. Rashid, Mohammed Abdulhadi Sarhan, M. Rasheed, and Ilaf Mohamed Sala, "Comparision the electrical parameters of photovoltaic cell using numerical methods," *Eureka: Physics and Engineering*, no. 4, pp. 29–39, Jul. 2023, doi: <https://doi.org/10.21303/2461-4262.2023.002770>.
- [37] D. Bouras, M. Rasheed, R. Barille, and M. N. Aldaraji, "Efficiency of adding DD₃+(Li/Mg) composite to plants and their fibers during the process of filtering solutions of toxic organic dyes," *Optical Materials*, vol. 131, p. 112725, Sep. 2022, doi: <https://doi.org/10.1016/j.optmat.2022.112725>.
- [38] M. Rasheed, O. Y. Mohammed, S. Shihab, and A. Al-Adili, "Explicit Numerical Model of Solar Cells to Determine Current and Voltage," *Journal of Physics: Conference Series*, vol. 1795, no. 1, p. 012043, Mar. 2021, doi: <https://doi.org/10.1088/1742-6596/1795/1/012043>.
- [39] M. A. Sarhan, S. Shihab, B. E. Kashem, and M. Rasheed, "New Exact Operational Shifted Pell Matrices and Their Application in Astrophysics," *Journal of Physics: Conference Series*, vol. 1879, no. 2, p. 022122, May 2021, doi: <https://doi.org/10.1088/1742-6596/1879/2/022122>.
- [40] O. Alabdali, S. Shihab, M. Rasheed, and T. Rashid, "Orthogonal Boubaker-Turki polynomials algorithm for problems arising in engineering," 3RD INTERNATIONAL SCIENTIFIC CONFERENCE OF ALKAHEEL UNIVERSITY (ISCKU 2021), 2022, doi: <https://doi.org/10.1063/5.0066860>.
- [41] M. Rasheed, S. Shihab, O. Y. Mohammed, and A. Al-Adili, "Parameters Estimation of Photovoltaic Model Using Nonlinear Algorithms," *Journal of Physics: Conference Series*, vol. 1795, no. 1, p. 012058, Mar. 2021, doi: <https://doi.org/10.1088/1742-6596/1795/1/012058>.
- [42] M. Rasheed, SuhaShihab, O. Alabdali, and H. H. Hassan, "Parameters Extraction of a Single-Diode Model of Photovoltaic Cell Using False Position Iterative Method," *Journal of Physics: Conference Series*, vol. 1879, no. 3, p. 032113, May 2021, doi: <https://doi.org/10.1088/1742-6596/1879/3/032113>.
- [43] A. Zubaidi, Lamyaa Mahdi Asaad, Iqbal Alshalal, and M. Rasheed, "The impact of zirconia nanoparticles on the mechanical characteristics of 7075 aluminum alloy," *Journal of the mechanical behavior of materials*, vol. 32, no. 1, Jan. 2023, doi: <https://doi.org/10.1515/jmbm-2022-0302>.
- [44] Djelal Kherifi, Ahcen Keziz, M. Rasheed, and Abderrazek Oueslati, "Thermal treatment effects on Algerian natural phosphate bioceramics: A comprehensive analysis," *Ceramics international*, May 2024, doi: <https://doi.org/10.1016/j.ceramint.2024.05.317>.

***Corresponding author**

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

- [45] D. Bouras, M. Fellah, A. Mecif, R. Barillé, A. Obrosof, and M. Rasheed, "High photocatalytic capacity of porous ceramic-based powder doped with MgO," *Journal of the Korean Ceramic Society*, Oct. 2022, doi: <https://doi.org/10.1007/s43207-022-00254-5>.
- [46] M. Rasheed, S. Shihab, O. Alabdali, A. Rashid, and T. Rashid, "Finding Roots of Nonlinear Equation for Optoelectronic Device," *Journal of Physics: Conference Series*, vol. 1999, no. 1, p. 012077, Sep. 2021, doi: <https://doi.org/10.1088/1742-6596/1999/1/012077>.
- [47] M. Rasheed, O. Alabdali, S. Shihab, A. Rashid, and T. Rashid, "On the Solution of Nonlinear Equation for Photovoltaic Cell Using New Iterative Algorithms," *Journal of Physics: Conference Series*, vol. 1999, no. 1, p. 012078, Sep. 2021, doi: <https://doi.org/10.1088/1742-6596/1999/1/012078>.
- [48] Aasim Jasim Hussein, Mustafa Nuhad Al-Darraji, and M. Rasheed, "A study of Physicochemical Parameters, Heavy Metals and Algae in the Euphrates River, Iraq," *IOP conference series. Earth and environmental science*, vol. 1262, no. 2, pp. 022007–022007, Dec. 2023, doi: <https://doi.org/10.1088/1755-1315/1262/2/022007>.
- [49] T. Rashid, Musa Mohd Mokji, and M. Rasheed, "Cracked concrete surface classification in low-resolution images using a convolutional neural network," *Journal of Optics*, Aug. 2024, doi: <https://doi.org/10.1007/s12596-024-02080-w>.
- [50] Selma, M. RASHEED, and Zahraa Yassar Abbas, "Effect of doping on the structural, optical and electrical properties of TiO₂ thin films for gas sensor," *Journal of optics/Journal of optics (New Delhi. Print)*, May 2024, doi: <https://doi.org/10.1007/s12596-024-01913-y>.
- [51] H. K. Aity, E. Dhahri, and M. Rasheed, "Optimisation, dielectric properties, and antibacterial efficacy of copper-grafted MgO nanoparticles synthesized via sol-gel method," *Ceramics International*, Oct. 2024, doi: <https://doi.org/10.1016/j.ceramint.2024.10.324>.
- [52] Ahmed Shawki Jaber, M. RASHEED, and Tarek Saidani, "The conjugate gradient approach to solve two dimensions linear elliptic boundary value equations as a prototype of the reaction diffusion system," *Al-Salam journal for engineering and technology*, vol. 3, no. 1, pp. 157–168, Jan. 2024, doi: <https://doi.org/10.55145/ajest.2024.03.01.014>.
- [53] M. Rasheed, M. Nuhad Al-Darraji, S. Shihab, A. Rashid, and T. Rashid, "The numerical Calculations of Single-Diode Solar Cell Modeling Parameters," *Journal of Physics: Conference Series*, vol. 1963, no. 1, p. 012058, Jul. 2021, doi: <https://doi.org/10.1088/1742-6596/1963/1/012058>.
- [54] M. Rasheed, M. N. Al-Darraji, S. Shihab, A. Rashid, and T. Rashid, "Solar PV Modelling and Parameter Extraction Using Iterative Algorithms," *Journal of Physics: Conference Series*, vol. 1963, no. 1, p. 012059, Jul. 2021, doi: <https://doi.org/10.1088/1742-6596/1963/1/012059>.
- [55] Farouk BOUDOU, Abdelmadjid GUENDOUZI, A. BELKREDAR, and M. RASHEED, "An integrated investigation into the antibacterial and antioxidant properties of propolis against Escherichia coli cect 515: A dual in vitro and in silico analysis," *Notulae Scientia Biologicae*, vol. 16, no. 2, pp. 13837–13837, May 2024, doi: <https://doi.org/10.55779/nsb16211837>.
- [56] M. Enneffatia, M. Rasheed, B. Louatia, K. Guidaraa, S. Shihab, and R. Barillé, "Investigation of structural, morphology, optical properties and electrical transport conduction of Li_{0.25}Na_{0.75}CdVO₄ compound," *Journal of Physics: Conference Series*, vol. 1795, no. 1, p. 012050, Mar. 2021, doi: <https://doi.org/10.1088/1742-6596/1795/1/012050>.
- [57] M. Rasheed, M. N. Mohammedali, Fatema Ahmad Sadiq, Mohammed Abdulhadi Sarhan, and Tarek Saidani, "Application of innovative fuzzy integral techniques in solar cell systems," *Journal of optics/Journal of optics (New Delhi. Print)*, Jun. 2024, doi: <https://doi.org/10.1007/s12596-024-01928-5>.

***Corresponding author**

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

- [58] M. Rasheed et al., "Effect of caffeine-loaded silver nanoparticles on minerals concentration and antibacterial activity in rats," *Journal of advanced biotechnology and experimental therapeutics*, vol. 6, no. 2, pp. 495–495, Jan. 2023, doi: <https://doi.org/10.5455/jabet.2023.d144>.
- [59] Ahmed Shukur, "Application of Error Continuous Distribution in Analyzing Systematic Variability across Engineering Processes", *Journal of Positive Sciences*, Vol. 4, Issue: 1, pp: 47-54, (2024). doi: <https://doi.org/10.52688/ASP58911>
- [60] Ahmed Shukur, " Application of Error Function Continuous Distribution in Predictive Modeling and Quality Control", *Journal of Positive Sciences*, Vol. 4, Issue: 3, pp: 53-61, (2024). doi: <https://doi.org/10.52688/ASP84163>.
- [61] Mohammed RASHEED, "Analyzing Applications and Properties of the Exponential Continuous Distribution in Reliability and Survival Analysis", *Journal of Positive Sciences*, Vol. 4, Issue: 5, pp: 71-79, (2023). doi: <https://doi.org/10.52688/ASP30767>.
- [62] Mohammed RASHEED, "Modeling and Analysis of Extreme Events using Extreme Value Continuous Distribution", *Journal of Positive Sciences*, Vol. 4, Issue: 1, pp: 55-63, (2024). doi: <https://doi.org/10.52688/ASP37713>.
- [63] Ahmed Shukur, "Sequential Event Modeling and Reliability Analysis using the Erlang Continuous Distribution", *Journal of Positive Sciences*, Vol. 3, Issue: 5, pp: 64-70, (2023). doi: <https://doi.org/10.52688/ASP85431>
- [64] A. Shukur, Ahmed Shawki Jaber, M. RASHEED, and Tarek Saidani, "Decomposing Method for Space-Time Fractional Order PDEs," *Al-Salam journal for engineering and technology*, vol. 3, no. 2, pp. 1–11, May 2024, doi: <https://doi.org/10.55145/ajest.2024.03.02.01>.
- [65] E. Kadri, M. Krichen, R. Mohammed, A. Zouari, and K. Khirouni, "Electrical transport mechanisms in amorphous silicon/crystalline silicon germanium heterojunction solar cell: impact of passivation layer in conversion efficiency," *Optical and Quantum Electronics*, vol. 48, no. 12, Nov. 2016, doi: <https://doi.org/10.1007/s11082-016-0812-7>.
- [66] Ahcen Keziz, Meand Heraiz, M. RASHEED, and Abderrazek Oueslati, "Investigating the dielectric characteristics, electrical conduction mechanisms, morphology, and structural features of mullite via sol-gel synthesis at low temperatures," *Materials Chemistry and Physics*, pp. 129757–129757, Jul. 2024, doi: <https://doi.org/10.1016/j.matchemphys.2024.129757>.
- [67] A. Raghdhi, Menad Heraiz, M. Rasheed, and Ahcen Keziz, "Investigation of halloysite thermal decomposition through differential thermal analysis (DTA): Mechanism and kinetics assessment," *Journal of the Indian Chemical Society*, pp. 101413–101413, Oct. 2024, doi: <https://doi.org/10.1016/j.jics.2024.101413>.
- [68] W. Saidi, Nasreddine Hfaidh, M. Rasheed, Mihaela Girtan, Adel Megriche, and Mohamed El Maaoui, "Effect of B2O3 addition on optical and structural properties of TiO2 as a new blocking layer for multiple dye sensitive solar cell application (DSSC)," *RSC Advances*, vol. 6, no. 73, pp. 68819–68826, Jan. 2016, doi: <https://doi.org/10.1039/c6ra15060h>.
- [69] Habiba K. Aity, Muwafaq A. Hasan, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Haider s. Mohammed, Mohammed H. Ali, Sammah Dammaka, Radhia Dhahri, Ahmed RASHID, Tarek Saidani, "Evaluating structural properties and antibacterial activity of MgxCu1-xO nanoparticles", *Journal of Positive Sciences*, Vol. 4, Issue: 5, pp: 9-19, (2024). doi: <https://doi.org/10.52688/ASP72524>.
- [70] Habiba K. Aity, Rana A. Hadi, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Haider s. Mohammed, Mohammed H. Ali, Sammah Dammaka, Radhia Dhahri, Ahmed RASHID, Tarek Saidani, "Optical behavior and its role in the antimicrobial properties of MgxCu1-xO nanoparticles", *Journal of Positive Sciences*, Vol. 4, Issue: 5, pp: 20-29, (2024). doi: <https://doi.org/10.52688/ASP66329>.
- [71] Habiba K. Aity, Ruqaya Shaker Mahmood, Muwafaq A. Hasan, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Haider s. Mohammed, Mohammed H. Ali, Sammah Dammaka, Radhia Dhahri, Ahmed RASHID, Nareman

***Corresponding author**

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com

Chakchouk, "Exploring the structural features and antimicrobial functionality of Mg_{0.95}Cu_{0.05}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 5, pp: 30-40, (2024). doi: <https://doi.org/10.52688/ASP57261>.

[72] Habiba K. Aity, Rana A. Hadi, Ruqaya Shaker Mahmood, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Nareman Chakchouk, "The relationship between optical characteristics and antibacterial performance of Mg_{0.97}Cu_{0.03}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 5, pp: 30-40, (2024). doi: <https://doi.org/10.52688/ASP33167>.

[73] Habiba K. Aity, Kawther A. Alameri, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Olfa Maalej, "The effect of structure on antibacterial performance of Mg_{0.94}Cu_{0.06}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 1-11, (2024). doi: <https://doi.org/10.52688/ASP441661>.

[74] Habiba K. Aity, Esra A. Hashem, Mohammed RASHEED, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Olfa Maalej, "The role of optical properties in enhancing antimicrobial activity of Mg_{0.94}Cu_{0.06}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 12-22, (2024). doi: <https://doi.org/10.52688/ASP19241>.

[75] Habiba K. Aity, Mohammed RASHEED, Kawther A. Alameri, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Marwa Enneffati, "Structural properties and bacterial inhibition capabilities of Mg_{0.91}Cu_{0.09}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 23-33, (2024). doi: <https://doi.org/10.52688/ASP28610>.

[76] Habiba K. Aity, Mohammed RASHEED, Esra A. Hashem, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Marwa Enneffati, "Assessing Optical Behavior and Antibacterial Potency of Mg_{0.91}Cu_{0.09}O Nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 34-43, (2024). doi: <https://doi.org/10.52688/ASP80838>.

[77] Mohammed RASHEED, Ketam K. Khudair, Habiba K. Aity, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "The impact of optical characteristics on antibacterial properties of Mg_{0.99}Fe_{0.01}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 54-63, (2024). doi: <https://doi.org/10.52688/ASP75371>.

[78] Mohammed RASHEED, Habiba K. Aity, Ketam K. Khudair, Ruqaya Shaker Mahmood, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "The influence of structural properties on antibacterial potential of Mg_{0.95}Fe_{0.03}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 64-74, (2024). doi: <https://doi.org/10.52688/ASP50513>.

[79] Ketam K. Khudair, Habiba K. Aity, Ruqaya Shaker Mahmood, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "Optical analysis and its impact on antibacterial performance of Mg_{0.97}Fe_{0.03}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 75-86, (2024). doi: <https://doi.org/10.52688/ASP88399>.

[80] Rafal A. Obayed, Habiba K. Aity, Ruqaya Shaker Mahmood, Mohammed RASHEED, Farqad A. Rashid, Zahraa Abbas, Areej A. Hateef, Ahmed RASHID, Taha Rashid, "Investigating structural traits and their role in antibacterial properties of Mg_{0.94}Fe_{0.06}O nanoparticles", Journal of Positive Sciences, Vol. 4, Issue: 6, pp: 87-96, (2024). doi: <https://doi.org/10.52688/ASP75220>.

***Corresponding author**

Mohammed RASHEED,
Department of Applied Sciences, University of Technology- Iraq, Baghdad, Iraq
e-mail: rasheed.mohammed40@yahoo.com