4th International Electronic Conference on Applied Sciences, Online, 27 October- 10 November, 2023.

Synthesis, Characterization and Antimicrobial activity of Magnetite (Fe_3O_4) Nanoparticles by the Sol-Gel Method

Priyansh N Brahmbhatt[1*], Shivani R. Bharucha[1], Ashish Bhatt[1], Mehul S. Dave[1*]

Correspondence: priyansh@nvpas.edu.in ; mehul@nvpas.edu.in

[1] Natubhai V. Patel College of Pure & Applied Sciences, The C.V.M. University, Vallabh Vidyanagar-388 120, Anand, Gujarat, India.

ABSTRACT

Transition Metal Oxide (TMO) nanoparticles have emerged as promising materials for various applications including color imaging, magnetic recording media, soft magnetic materials, heterogeneous catalysis, and different field of biomedical science. Apart from the TMO, Fe_3O_4 nanoparticles hold great promise in a variety of biomedical uses such as drug delivery, cell separation, and MRI imaging. Magnetite (Fe_3O_4) nanoparticles exhibit their potential as antimicrobial agents due to their unique properties and interactions with microorganisms. This study focuses on the synthesis, characterization, and evaluation of the antimicrobial activity of magnetite (Fe_3O_4) nanoparticles prepared using the sol-gel method. The Fe_3O_4 nanoparticles were synthesized through a facile and cost-effective sol-gel route, involving the ferric nitrate and ethanol as precursors. Different characterization techniques, including Energy-Dispersive X-ray Spectroscopy (EDAX), X-ray diffraction (XRD), and UV-VIS NIR spectroscopy were employed to analyze the compositional analysis, crystalline structure, and optical properties of the nanoparticles. The EDAX and XRD analysis confirmed that the synthesized nanoparticles are near to stoichiometry and formation of single-phase magnetite nanoparticles. The obtained bandgap of synthesized nanoparticles is 5.03 eV. Furthermore, the synthesized Fe_3O_4 nanoparticles were evaluated for their antimicrobial efficacy against a panel of including both Gram-positive (e.g., Staphylococcus aureus) and Gram-negative (e.g., Enterobacter aerogenes) bacteria. Investigations into the nanoparticles biocompatibility and long-term effects would be crucial for their safe and effective utilization in real-world applications.

INTRODUCTION

Magnetite is natural mineral of iron. The multiple phases of iron oxides are important in academic and industrial research areas. Magnetite nanoparticles potential applications are color imaging, magnetic recording media, soft magnetic, ferrofluid, spintronics, heterogeneous catalysis and biomedical applications such as drug delivery, cell separation, imaging (MRI) and in vivo therapy technology[1,2]. Also, environmental application of magnetite nanoparticles is its widely used as an absorbent to purify water from impurities. Magnetite can synthesize using several methods including co-precipitation[3],micro-emulsion[4],thermal-decomposition[5], hydrothermal[6], ultrasonic[7], sol-gel[8] methods. However, sol-gel is economic, simple and most suitable synthesis method to prepare high quality metal oxide nanoparticles. Sol-gel method has good control for surface area of nanoparticles.

METHODOLOGY

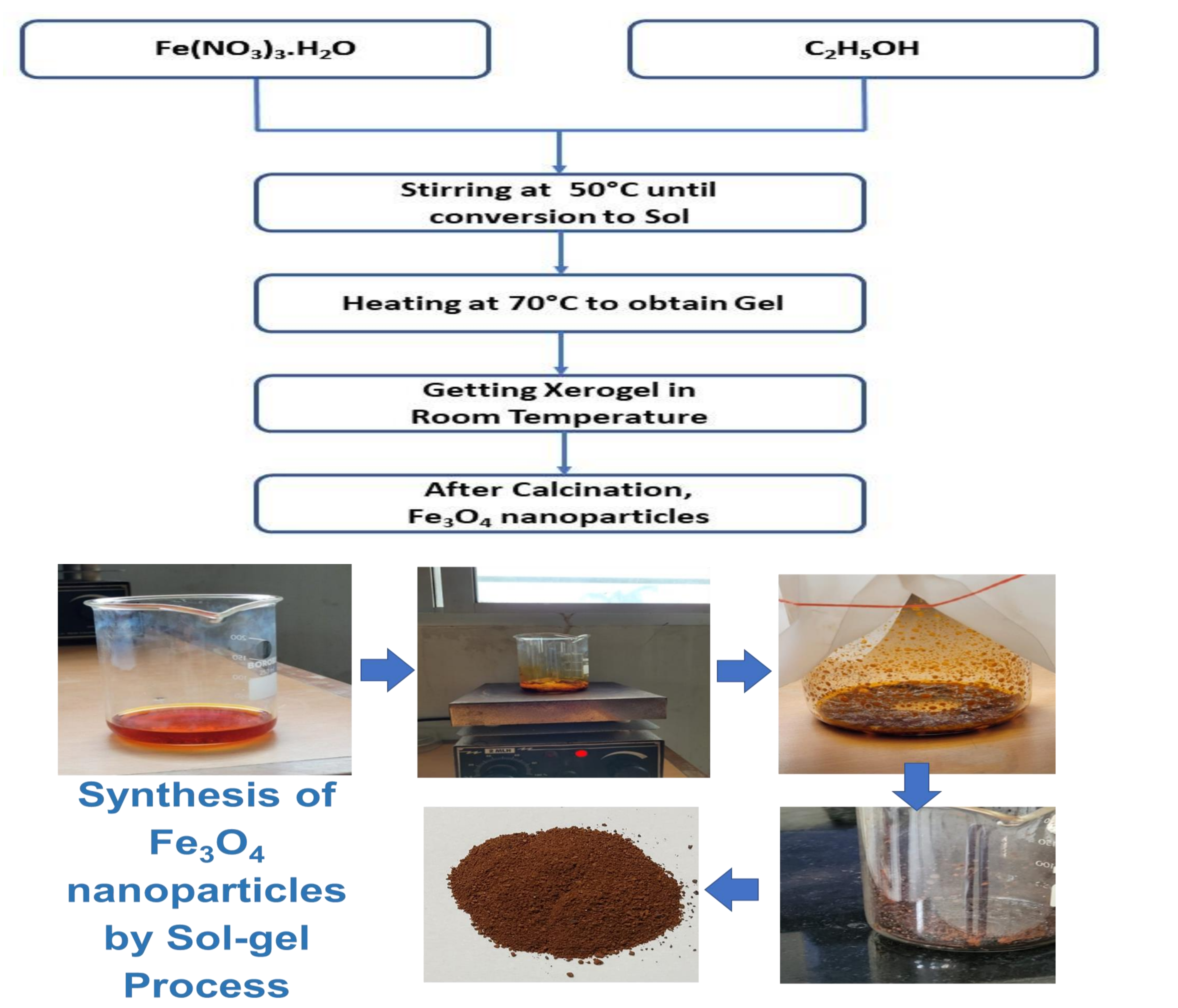

Fig.1 Schematic diagram of synthesis method of Magnetite NPs.

RESULTS & ANALYSIS

Element	Weight%	Atomic%
O K	24.7	53.38
Fe K	75.3	46.62

Table 1 Percentage of elements of Magnetite NPs.

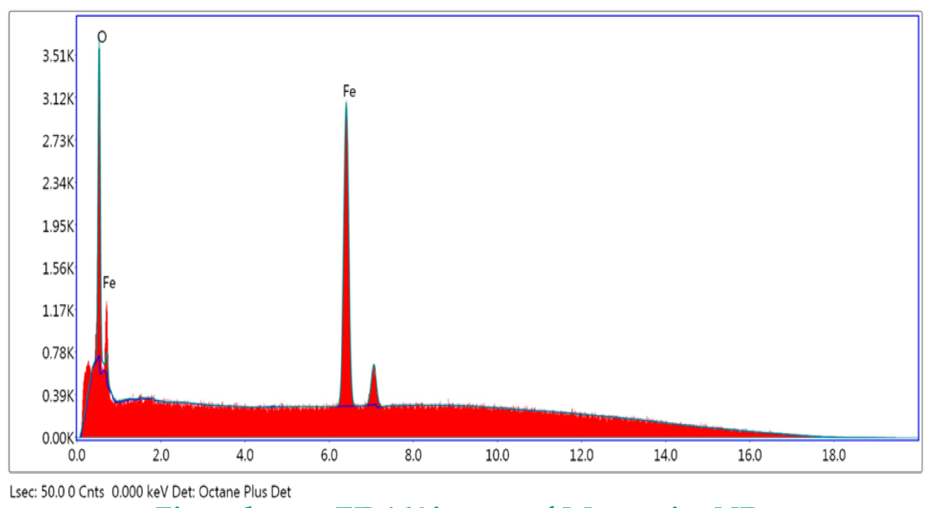

Fig.2 shows EDAX image of Magnetite NPs.

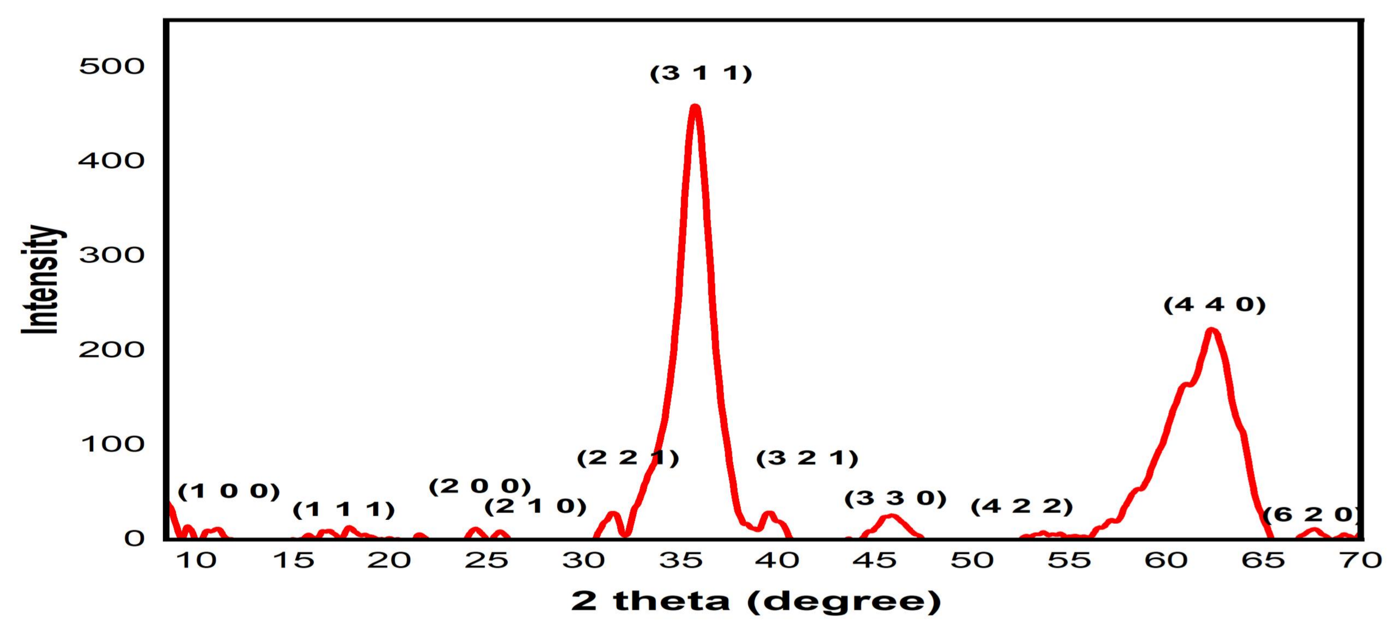

Fig.3 shows XRD pattern of Magnetite NPs.

In order to describe elemental composition of magnetite (Fe_3O_4) nanoparticles, EDAX characterization was employed. In table 1 shows that the EDAX analysis of magnetite nanoparticles. EDAX image of magnetite nanoparticles shown in Fig. 2. XRD was employed for structural property. XRD pattern of magnetite (Fe_3O_4) nanoparticles as shown in Fig. 3. crystal structure of obtained magnetite (Fe_3O_4) nanoparticles is cubic and the lattice parameter obtained is a=b=c = 8.409 A^0 .

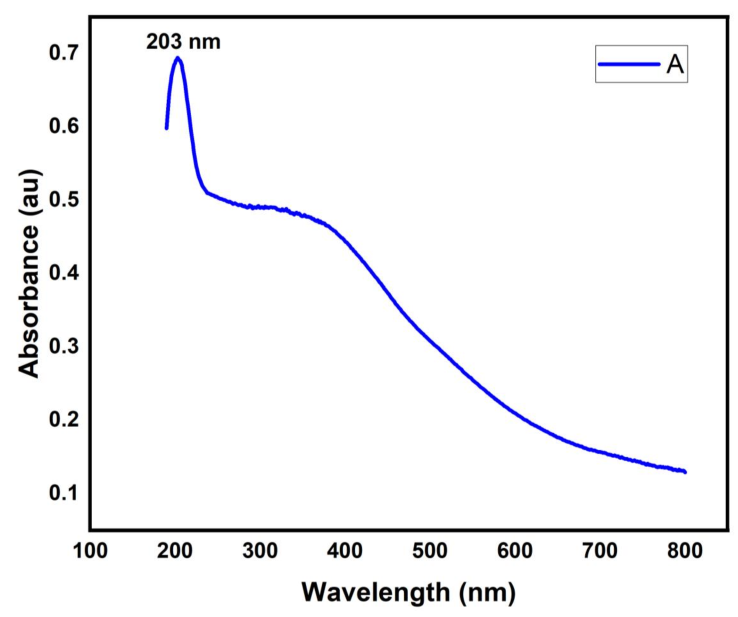

Fig.4 shows graph of absorption coefficient against wavelength of Magnetite NPs.

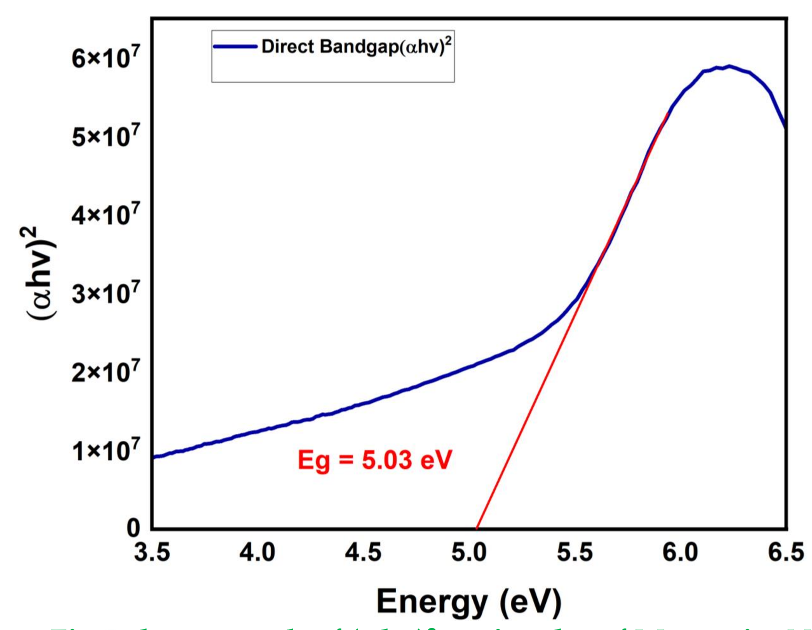

Fig.5 shows graph of $(\alpha h\nu)^2$ against hν of Magnetite NPs..

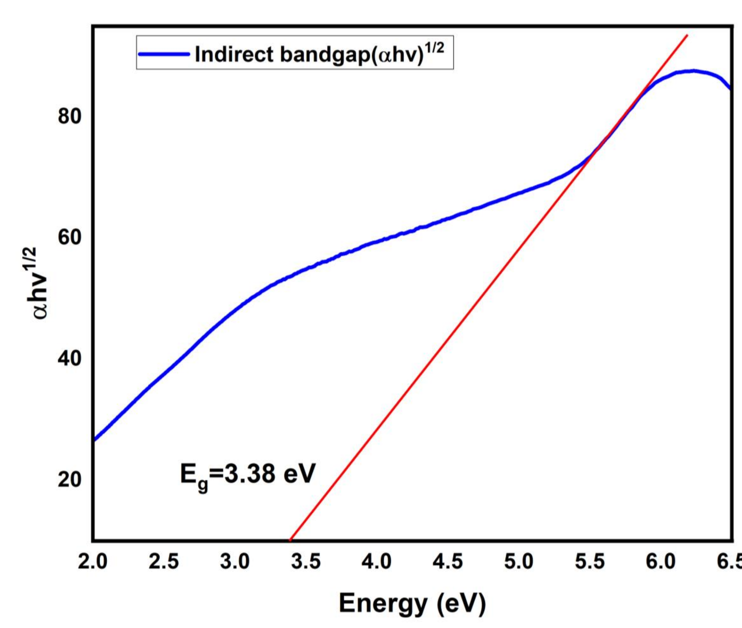

Fig.6 shows graph of $(\alpha h\nu)^{1/2}$ against hν of Magnetite NPs.

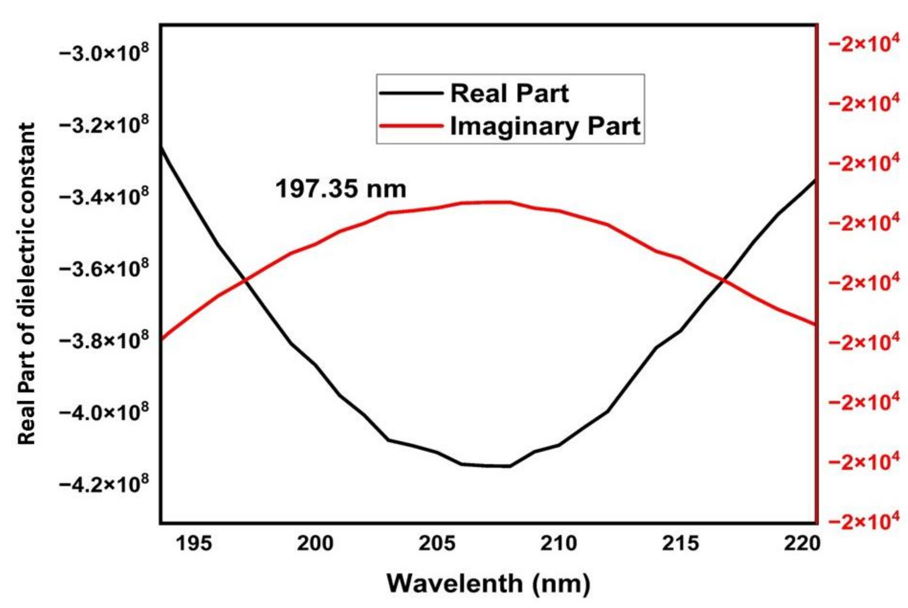

Fig.7 shows graph of complex dielectric constant against wavelength of Magnetite NPs.

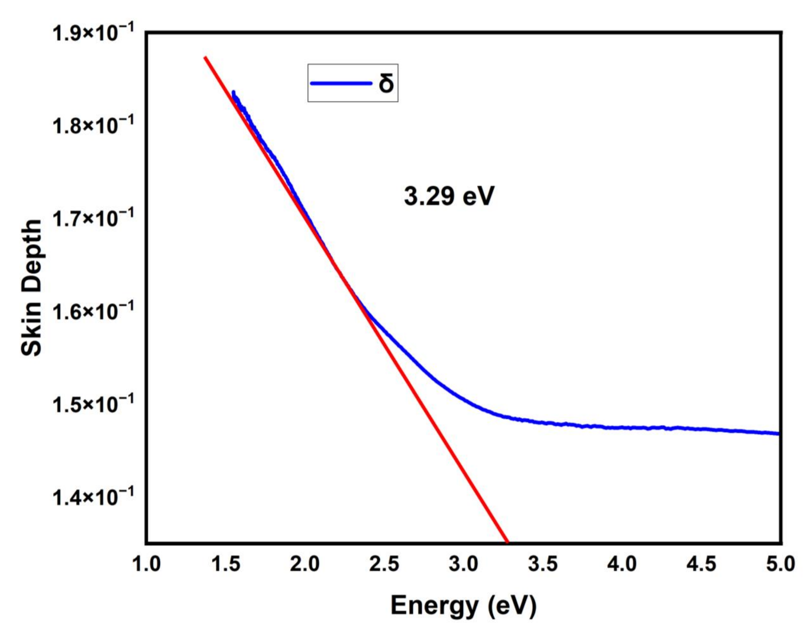

Fig.8 shows graph of skin depth against hν of Magnetite NPs.

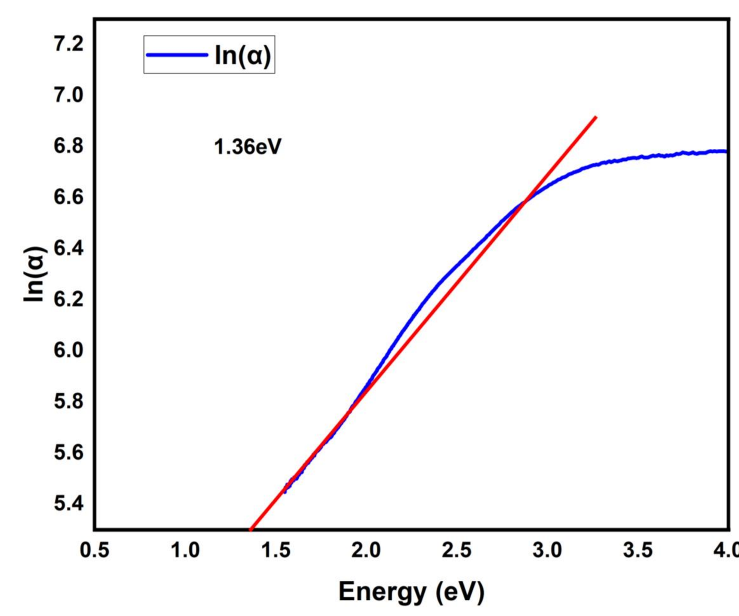

Fig.9 shows graph of lnα against hν of Magnetite NPs..

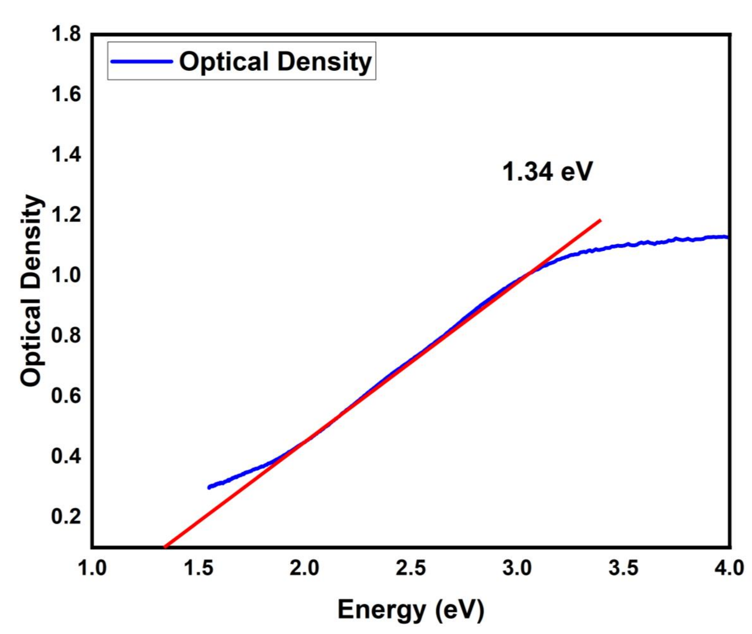

Fig.10 shows graph of optical density against hν of Magnetite NPs.

In order to describe the optical property of magnetite (Fe_3O_4) nanoparticles, UV-visible spectroscopy was employed. Fig.4 shows absorption peak with a lower absorption wavelength of 203 nm. Direct optical bandgap is shown in Fig. 5, which obtained is 5.03 eV. Indirect optical bandgap is shown in Fig.6, which obtained is 3.38 eV. Fig. 8 shows plot of skin depth against energy(hν), which is obtained is 3.29 eV. The Urbach energy is calculated by ln α against Energy (hν) plot, which is shown in Fig.9. The Urbach energy of magnetite (Fe_3O_4) nanoparticles is 1.36 eV. Fig. 10 shows the plot of the optical density (D_{opt}) against the incident photon energy (hν), which is obtained is 1.34 eV.

relation between the absorption coefficient (α) and the incident photon energy (hν) can be given by

$$\alpha h\nu = \alpha_0 (h\nu - E_g)^n$$

optical density can be estimated by

$$D_{opt} = \alpha t$$

skin depth (δ) is related to the absorption coefficient (α) given by

$$\delta = \frac{1}{\alpha}$$

Urbach energy is calculated by

$$\alpha = \alpha_0 \exp(\frac{E}{E_U})$$

Where,
α_0 is band tailing parameter,
Eg is the optical energy gap,
n is constant,
t is the thickness of the sample [11].

ANTIMICROBIAL ACTIVITY

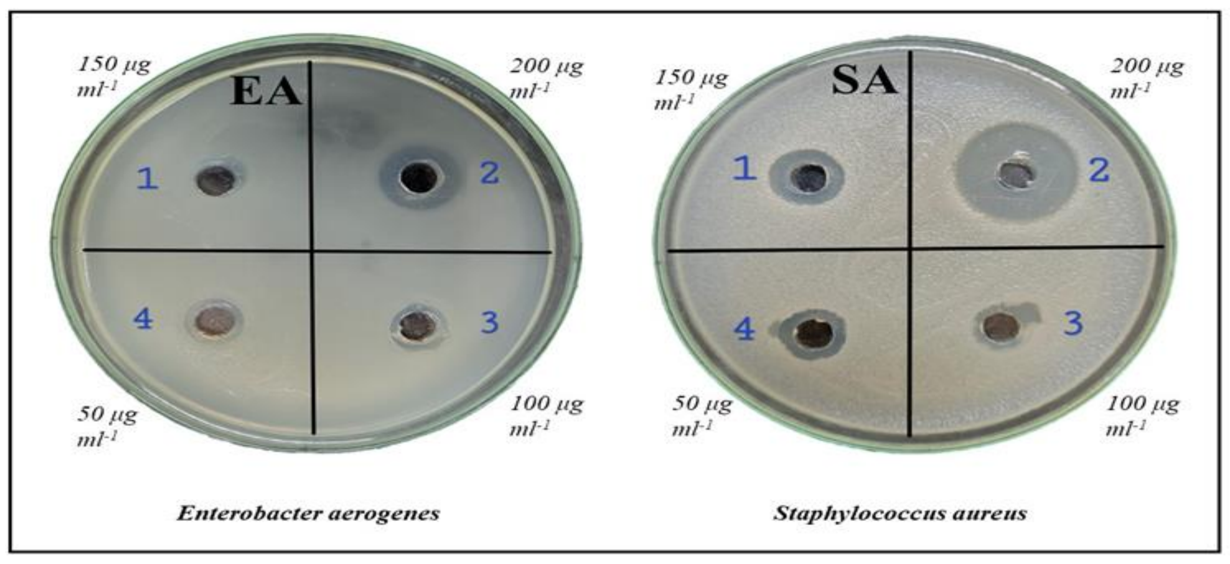

Fig.11 (a) Antimicrobial activity of(Fe_3O_4)NPs against Enterobacter aerogenes and Staphylococcus aureus.

Antimicrobial activity of (Fe_3O_4) nanoparticles was assessed by agar well diffusion method. The bacterial cultures *Staphylococcus aureus* and *Enterobacter aerogenes* were poured over N-agar plates with 1% (W/V) top agar. For the antimicrobial activity concentration of Fe_3O_4 NPs were selected – 200 ug ml^{-1}, 150 ug ml^{-1}, 100 ug ml^{-1}, and 50 ug ml^{-1}.Fig.11(a) shows effectively inhibited the growth of *Enterobacter aerogenes* and *Staphylococcus aureus* at higher concentrations. The result indicates that magnetite have potential to be used as a bacteriostatic as well as bactericidal agent.

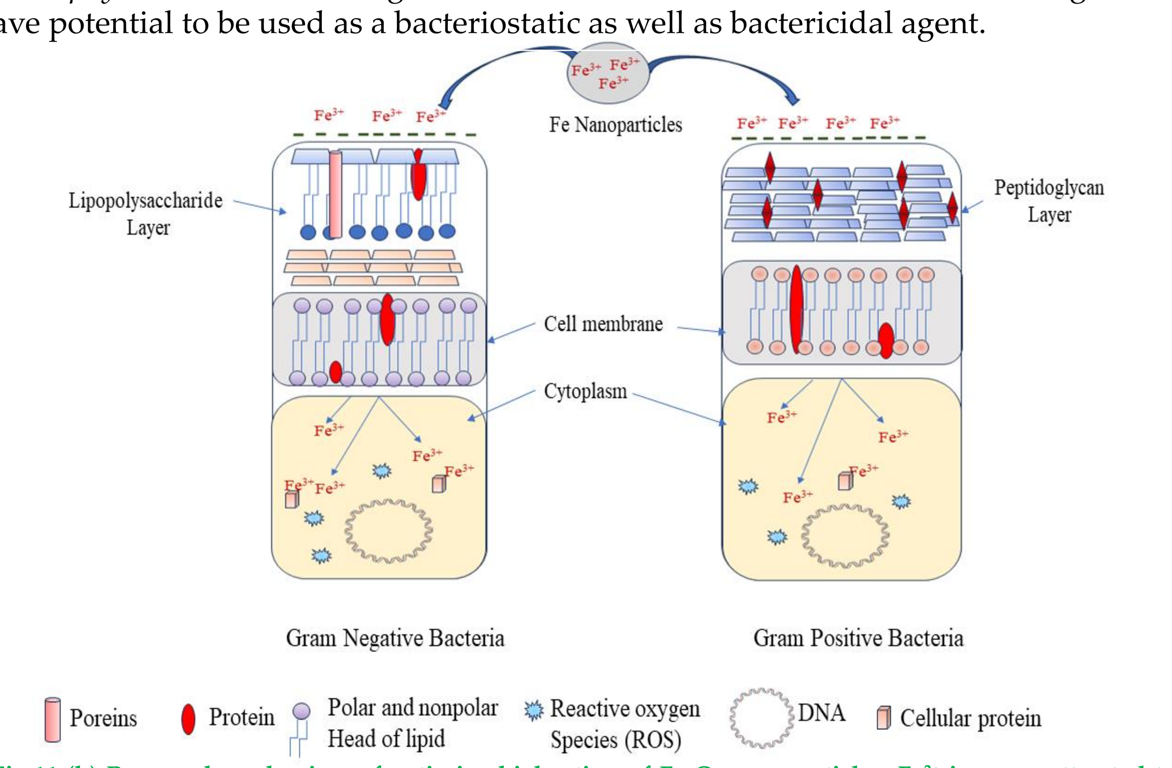

Fig.11 (b) Proposed mechanism of antimicrobial action of Fe_3O_4 nanoparticles. Fe^{3+} ions are attracted to negatively charged lipopolysaccharide layer in gram negative bacteria and peptidoglycan layer of gram-positive bacteria. After entering the cell, metal nanoparticles can disrupt cell membrane, block cellular proteins, disrupt cellular DNA and generate ROS species which can lead to death of the microorganism.

CONCLUSION

Magnetite (Fe_3O_4) nanoparticles were prepared by sol-gel method at 200°C. The Sol-gel method offers several advantages for preparation of magnetite (Fe_3O_4) nano-particles. XRD shows that Crystal structure of obtained Fe_3O_4 nanoparticles is cubic and the lattice parameter obtained is a=b=c = 8.409 A^0 and the obtained data is well match with JCPDS No: 019-0629. From UV-Visible obtained direct optical bandgap is 5.03 eV and indirect optical bandgap is 3.38 eV. The Urbach energy of magnetite (Fe_3O_4) nanoparticles is 1.36 eV. Magnetite (Fe_3O_4) nanoparticles shows antimicrobial activity.

REFERENCES

1. O. M. Lemine, et al., "Sol–gel synthesis of 8 nm magnetite (Fe_3O_4) nanoparticles and their magnetic properties," *Superlattices Microstruct.*, **(2012).**
2. H. Cui, Y. Liu & W. Ren, "and low temperature sol – gel synthesis of nearly monodispersed iron oxide nanoparticles," *Adv. Powder Technol.* **(2013)**, *24 (1)*,93–97.
3. X. L. Wang, L. Wei, G. H. Tao & M. Q. Huang, "Synthesis and characterization of magnetic and luminescent Fe_3O_4/CdTe nanocomposites using aspartic acid as linker," *Chinese Chem. Lett.* **(2011)**, *22(2)*,233–236
4. Y. Li, R. Jiang, T. Liu, H. Lv, L. Zhou, X. Zhang, One-pot synthesis of grass-like Fe_3O_4, nanostructures by a novel microemulsion-assisted solvothermal method, *Ceram. Int.* **(2014)** ,*40 (1)*,1059-1063
5. Y. Eom, M. Abbas, H.Y. Noh, C.G. Kim, Morphology-controlled synthesis of highly crystalline Fe_3O_4 and $CoFe_2O_4$ nanoparticles using a facile thermal decomposition method, *RSC Adv.* **(2016),** *6 (19)*,15861-15867.
6. H.Zhang, G. Zhu, One -step hydrothermal synthesis of magnetic Fe_3O_4 nanoparticles immobilized on polyamide fabric, *Appl. Surf. Sci.* **(2012)**, *258 (11)*,4952-4959.
7. M. bhaumik, A. Maity & V. K. Gupta, "Synthesis and characterization of Fe0 /TiO_2 nano-composites for ultrasound assisted enhanced catalytic degradation of reactive black 5 in aqueous solutions," *J. Colloid Interface Sci.* **(2017),** *506*,403–414.
8. Shaker, Sara, S. Zafarian, C. S. Chakra, and K. V. Rao. "Preparation and characterization of magnetite nanoparticles by Sol-Gel method for water treatment." *International journal of innovative research in science, engineering, and technology 2* **(2013)**, *Vol .7*,2969-2973.
9. Hassanien, Ahmed Saeed & Akl, Alaa, Effect of Se addition on optical and electrical properties of chalcogenide CdSSe thin films. Superlattices and Microstructures (2016), 89C,153-169. 10.1016/j.spmi.2015.10.044.