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Engineering Multifunctional Iron–Silver Nanostructures for Synergistic Cancer therapy

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ABSTRACT

The discovery of Nanoparticles has become a significant, unmatched opportunity to enhance the traditional cancer therapy approaches. Significant progress has been made in the treatment of cancer through the use of Nanoparticles. This review will concentrate on iron-Silver (Fe–Ag) nanocomposites, which are now being used as a multifunctional nanotechnology for cancer therapy and come in a variety of nanoshell materials. The magnetic qualities of Fe and the anticancer capabilities of Ag are combined in the Fe–Ag nanocomposites, which allow the particles to be more effectively targeted to a particular area and treated there. While Silver's well-established biological activity supports anticancer effects, iron's magnetic properties aid in medication targeting and magnetic hyperthermia. This article discusses and reviews the synthesis, characterisation, and applications of Fe–Ag nanocomposites in relation to their use in cancer therapy and the enhancement of heating efficiency through photothermal therapy and magnetic hyperthermia. The translation of nanocomposites from laboratory research to clinical applications is also covered, along with the opportunities and difficulties encountered in comprehending this process. It also highlights the need for thorough preclinical research, strong production standardization, and regulatory approval. Cancer is still one of the most difficult health issues facing the globe today, and new approaches to treatment are required. Particularly when combined with gold, Silver, and iron oxide, the Nanoparticles are showing promise as materials to alter cancer treatment. This book provides a thorough review of the state of the art in

oncological interventions based on Nanoparticles, with a focus on the remarkable advancements and therapeutic potential of iron oxide, gold, and Silver Nanoparticles. Silver Nanoparticles' well-known anti-microbial properties have made it possible for them to be used with great promise in cancer treatments by triggering apoptosis, inhibiting angiogenesis, and improving drug transport channels.

Keywords: Cancer Treatment, Oncological Interventions, Hyperthermia, Photothermal Therapy, Biocompatibility, Anti-Microbial Properties, Nanocomposites.

Introduction

A discipline of integrated science where nanotechnology brings previously unheard-of small gadgets closer to reality. They might result in an undesirable but detrimental relationship with the many biological systems in human physiology. The characteristics of Nanoparticles, such as their biological availability and solubility, aggregation, and adsorption, determine how they affect human health. When essential molecules are altered by the nanostructures effect, a bio-corona is formed. When this bio-corona comes into contact with other organelles, it causes cell death or disease. Although nanosized particulate materials are useful for managing and preventing disease, they can easily enter every bodily system and may have toxicological consequences through cytotoxicity, immunotoxicity, and genotoxicity.(Abdelghany, Elsayed, Kabary, & Salaheldin, 2025) Exploring new methods to reduce toxicity and ensure safety applications for obtaining proper health care becomes a major concern due to the likelihood of connected unfavorable negative consequences on humans. The potential for respiratory disorders, oxidative stress-related diseases, and detrimental effects on the immune system was revealed by toxicological testing of the different Nanoparticles. Furthermore, it is anticipated that nanotechnology will continue to be evaluated and expanded in the medical sciences from disease detection to disease prevention. Nanotechnology is a technology that deals with matter at the atomic or molecular level. This chapter discusses how nanotechnology can help create a more sustainable and greener future. This chapter's primary focus is on using ceramic and polymer nanotechnology to create a sustainable environment. This chapter will discuss the various ways that nanotechnology can be applied to create various renewable energy sources.(Alexeree, Abou-Seri, El-Din, Youssef, & Ramadan, 2024) It is very regrettable that the current status of the environment is unfair and would negatively impact living things. The chapter focuses on using nanotechnology to create a sustainable environment while also introducing some fundamental concepts from polymer and ceramic nanotechnology. For the manufacture of bimetallic Nanoparticles, Silver (Ag) and iron (Fe) are used because of their physicochemical, magnetic, and biological characteristics, which make them ideal for use in biomedical applications, particularly cancer treatment. Both AgNPs and FeNPs have demonstrated exceptionally excellent therapeutic potential on their own. However, if these two metals are combined to create a Silver–iron (Ag–Fe) bimetallic nanoparticle, their complementary qualities may result in synergy that enhances the catalytic performance as a whole. A powerful multifunction nanoplatform for medication administration, diagnostic imaging, and therapeutic application is created when the strong anticancer activity of Ag and the

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magnetic property of Fe are combined.(Amendola et al., 2021) The characteristics of iron and Silver Nanoparticles were compared. Characterization of iron and Silver Nanoparticles in comparison. Both iron and Silver Nanoparticles were produced using either a conventional method or an aqueous extract of *S. fallax* moss. AgNPs and non-stabilized FeNPs were nearly spherical and up to 100 nm in size, but FeNPs stabilized by extraction had a lamellar appearance, up to 50 nm in diameter and 20 nm in thickness. FT-IR and hyperspectral imaging investigations demonstrate how biomolecules from the Sphagnum extract alter the identical extract-stabilized Nanoparticles. Both types of Silver Nanoparticles were shown to be insufficiently effective against the adherence of *E. coli* microbubbles, while FeNPs were also found to be insufficiently effective. AgNPs can be employed as antibacterial agents, whereas non-toxic FeNPs may find utility in biological research. Because they are similar to their conventional counterparts, room temperature NPs made utilizing an eco-friendly extraction approach that uses biological source extract can be employed in many of the same applications. Biological molecules are increasingly being employed as matrices, and the creation of Nanoparticles frequently involves the utilization of bacteria, fungi, plants, and plant waste.(Faderin et al., 2025)

A new class of medications known as metallo-pharmaceutics and a new class of Nanoparticles known as metallic Nanoparticles—which are said to have a broad-spectrum antibacterial effect—have been introduced in response to the demand for alternative antimicrobials. Additionally, compositions of transition metal compounds have recently been discovered to exhibit synergistic antibacterial action. Therefore, bimetallic nanoparticle synthesis and design are intriguing fields of study to imagine possible interactions between metal groups and organic complex structures of microbial targets for more effective combinatorial (synergistic) antimicrobials. These allowed us to show that the green synthesis of Ag–Fe bimetallic Nanoparticles could be achieved using an aqueous extract of *Gardenia jasminoides* leaves. According to the characterisation, the loaded structure had a spherical shape and an average diameter of 13 nm ($\pm$ 6.3 nm), with a narrow and homogenous distribution.(Gavas, Quazi, & Karpiński, 2021)

Synthesis Procedure

This "wet chemical" method is sometimes referred to as the solvent displacement technique. This comprises polymers that are not solvents in ethanol. Both natural and manufactured polymer phases are possible. The polymer instantly diffuses to the other polymer phase, which is a non-solvent polymer, when the polymer solvent comes into contact with the polymer solution, resulting in the formation of Nanoparticles. There are two processes in the interfacial tension method of producing Nanoparticles. (Khan & methods, 2025)Co-precipitation, the most popular solution technique for creating multi-component oxide ceramics, entails extracting the constituents from the solution simultaneously as a "mixed" in-form precipitate. To obtain a homogenous solution of ion clusters, inorganic salts such as nitrates, sulphates, etc. are typically dissolved in distilled water.

A 1:2 ratio of iron to Silver Nanoparticles has been produced.A 1:2 ratio of iron to Silver Nanoparticles has been produced. Two hundred milliliters of distilled water were

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collected in a sterile beaker. Using a magnetic stir bar, 10 g of iron was added to create a homogenous mixture. 8.4 g of Silver nitrate (AgNO_3) was added to the mixture while it was being agitated. To create a NaOH solution, 8 g of NaOH were dissolved in 100 mL of distilled water in a separate beaker. The reaction mixture was then mixed with NaOH solution. We measured the pH of the mixture. Until precipitation was noticed, the reaction mixture was allowed to stand.



Figure 1: Fe/ Ag nanoparticles after grinding

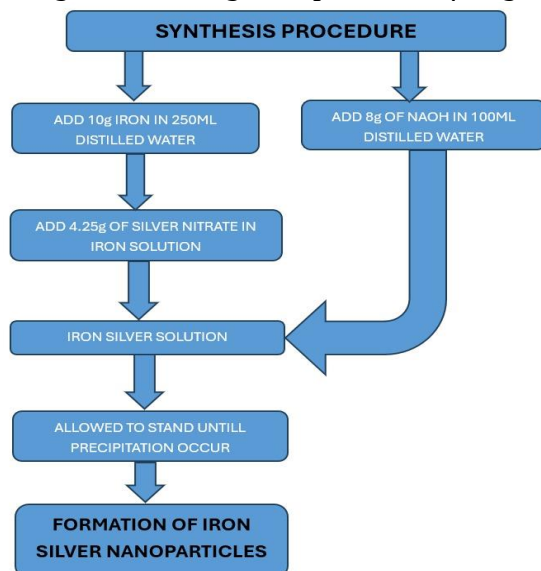


Figure 2: Flow chart for of Iron Silver Nanoparticles (1:2)

Result and Discussion

The material that had been calcined was used to finely grind the product. They examined the resulting materials' structural, morphological, and optical characteristics using the FTIR method. Despite being two distinct methods, they both produce significantly larger photos! The following imaging methods allow for the observation

of nanoparticles. (Mateo & Jiménez, 2022) Examples include its structure, composition, and other attributes including its electrical, magnetic, chemical, and physical qualities. The nanomaterials can be described using a variety of techniques, all of which are somewhat ambiguous. analytical method that uses measurements of absorption at different IIR wavelengths. Chemistry, biology, and materials science have all made substantial use of FTIR to learn more about the functional groups or molecular vibrations that might be present in a sample. (Kayed, Issa, & Al-Ourabi, 2024)

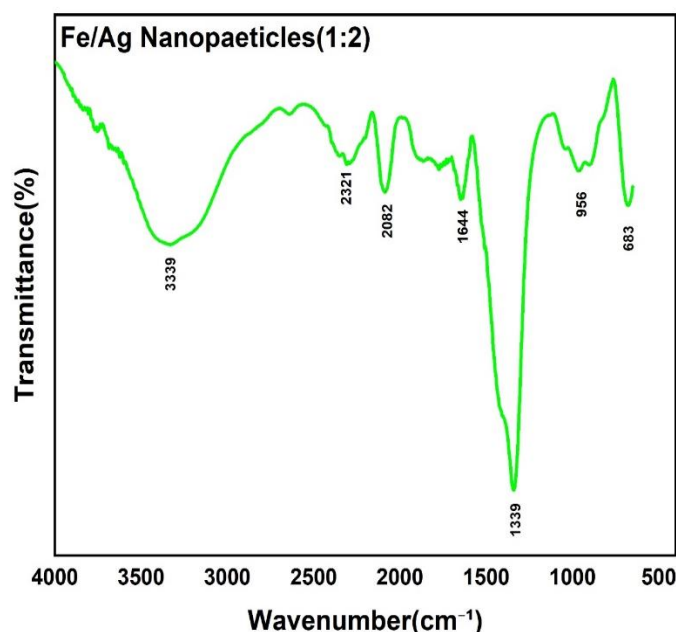


Figure 3: FTIR spectra of Silver and iron Nanoparticles(1:2)

The Fourier-transform infrared (FTIR) spectrum of the synthesised Fe/Ag nanoparticles (1:2) revealed multiple distinctive absorption bands at 3339, 2321, 2082, 1644, 1339, 956, and 683 cm^{-1} , which corresponded to various functional groups and metal oxygen interaction. The broadband absorption band at 3339 cm^{-1} is mostly caused by the O–H stretching vibrational modes of the adsorbed water molecules and/or hydroxyl groups on the NP surface. The O–H bending mode for the adsorbed water is responsible for the band at 1644 cm^{-1} , but other functional groups containing oxygen may possibly have contributed. The faint band at 2321 cm^{-1} does not seem to be a distinctive functional group of the nanoparticles and is thought to be caused by interference from atmospheric CO_2 gathered during the FTIR spectra measurement. (Liaqat, Jahan, Anwar, & Qureshi, 2022) Weak vibrations from surface-bound organic molecules or other trace elements in the nanoparticle production could be responsible for the absorption band at 2082 cm^{-1} . The presence of surface oxygen-containing species is indicated by a well-resolved band at 1339 cm^{-1} , which can be attributable to either the biomolecules or stabilizing/capping chemicals utilised in the nanoparticle synthesis. The band designated for 956 and 683 cm^{-1} is crucial for verifying interactions between the metallic components and surface species. The likelihood of the creation of iron oxide-based structures in the Fe/Ag nanoparticle system is confirmed by the correlation between the lower wavenumber area, specifically the Fe/Ag nanoparticle system band

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around 683 cm^{-1} , and metal–oxygen (M–O) vibrational interaction. In conclusion, the FTIR spectrum verifies the presence of metal-oxygen interactions and hydroxyl and oxygen-containing functional groups, indicating that these surface functional groups may have contributed to the reduction, stabilisation, and capping of the Fe/Ag nanoparticles. The successful production of a composite of connected nanoparticles Fe/Ag and the presence of surface-bound functional groups that may influence the physicochemical properties of the composite are thus demonstrated by the measured spectrum features. Good Fe/Ag (1:2) nanoparticle production was demonstrated by FTIR data, which revealed distinctive hydroxyl, oxygen-containing, and oxygen–metal vibrational bands from the surface functional groups encouraging them in the process.(Saif, Tahir, & Chen, 2016)

Discussion

The nature of the chemical interactions and surface functional groups of the produced nanocomposite can be inferred from the FTIR spectra of the Fe/Ag nanoparticles made at the 1:2 ratios. The spectra revealed bands at 3339, 2321, 2082, 1644, 1339, 956, and 683 cm^{-1} that corresponded to hydroxyl, oxygen-containing, and metal-associated bands. This suggests that metal, hydroxyl, and oxygen-containing functional groups might be involved in the process of nanoparticle creation–H stretching vibrations, which may originate from hydroxyl groups in the nanoparticles or from moisture molecules that are superficially adsorbed, are primarily responsible for the broad band at 3339 cm^{-1} . (Pugazhenthiran et al., 2023)The existence of this band suggested that the hydroxyl-containing substances may have stabilised the nanoparticle by reacting with its surface. The O–H bending vibrations of the water molecules adsorbed on the surface are primarily responsible for the band at 1644 cm^{-1} , but the existence of functional groups containing oxygen is not entirely ruled out.An environmental-background CO_2 adjustment is typically included in Fourier Transform Infrared (FTIR) analysis because a faint band at 2321 cm^{-1} is a common characteristic of CO_2 in the atmosphere.(Saber, Mirtajani, Karimzadeh, & Technology, 2018) The band that was detected at 2082 cm^{-1} might be connected to the surface-associated species' weak vibrations that originate and persist during the synthesis process. The prominent absorption band at 1339 cm^{-1} in the fingerprint region indicates the presence of biomolecules and/or interactions between biomolecules and other stabilising species to the NP surface. In terms of the synthesised product's structure, two of these bands 956 and 683 cm^{-1} are particularly interesting. However, the vibrational characteristics in the lower wavenumber range may be related to interactions between metal and oxygen, such as those created by iron oxides. In the Fe-containing component of the nanocomposite formation, the band at 683 cm^{-1} thus suggests that a Fe–O bond may occur. These bands imply that surface functional groups participated in the creation and stabilisation of Fe/Ag nanoparticles, along with other FTIR characteristics.(Padilla-Cruz et al., 2021) The FTIR results often show that Fe/Ag (1:2) nanoparticles have several surface active functional groups and metal–oxygen interactions. The stability, surface chemistry, and interactions of nanoparticles with their surroundings can all be significantly influenced by their functional groups. Thus, the observed spectrum profile verifies that the Fe/Ag nanocomposite was successfully synthesised and demonstrates that the chemical groups present during the synthesis

process were on the nanoparticles' surface.

Future Perspective and Conclusions

Future research should focus on further refining the process of producing Fe–Ag nanoparticles under regulated parameters of size, shape, and surface characteristics with controlled stability of the Fe–Ag product. To understand their anticancer cytotoxic effect and any selectivity for cancer cells, comprehensive investigations on their anticancer activity on different cancer cell lines are crucial. Additionally, research on ROS production, apoptosis, cellular absorption, and molecular pathways may provide useful information regarding their therapeutic mechanism. Iron and silver nanoparticles may work in concert to improve cancer prevention and treatment efficacy while reducing adverse effects on healthy cells. Furthermore, to prove safety and therapeutic potential, in vivo research is essential in addition to thorough biocompatibility and toxicity evaluation. In the future, tailored drug delivery strategies and surface functionalisation may be investigated to further enhance the selective accumulation of Fe–Ag nanoparticles at the tumour location. The findings of these studies may help create Fe–Ag nanostructures as a possible tool for cancer diagnosis and treatment in the future. Fe/Ag nanoparticles (1:2) with a variety of functional groups and distinctive metal–oxygen interactions have been confirmed by FTIR analysis. O–H stretching vibrations are most likely responsible for the broad band at 3339 cm^{-1} , which may be read as hydroxyl groups that have been adsorbed onto the nanoparticle surface or as water of adsorption on the surface. O–H bending vibrations have a band at 1644 cm^{-1} . It is possible to attribute the bands seen at 2321 and 2082 cm^{-1} to air or surface-adsorbed species. Surface-related vibrations are represented by the absorption band at 1339 cm^{-1} , whereas metal oxygen bond vibrations are represented by the band at 683 cm^{-1} (Justify the structure of Fe/Ag nanoparticles). These functional groups and surface characteristics may be essential for the stability of the nanoparticles and how they interact with the surface, which may make them useful for medicinal uses like cancer treatment. However, additional in-vitro and in-vivo biological research is required to assess the therapeutic potential of the synthesized Fe/Ag nanoparticles against cancer.

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