



Synthesis of Iron Ferrite Fe₃O₄ Nanoparticles and Investigation of Physical Properties and their Magnetism for Use in Drug Delivery

Aqeel Al-Hamaidah^{*1,2,3,6}, Ali Mohammed Bedyri Arabi²,
Bizhan Malaekheh-Nikouei^{1,4,5}, Alireza Charmforoushan²

¹ Department of Pharmaceutical Nanotechnology, School of Pharmacy, Mashhad University of Medical Sciences, Mashhad, Iran

² Department of Physics, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran

³ Department of Medical Physics, Faculty of Medicine, University of Sumer, Iraq

⁴ Department of Physics, Faculty of Science, University of Sumer, Iraq

⁵ Nanotechnology Research Center, Pharmaceutical Technology Institute, Mashhad University of Medical Sciences, Mashhad, Iran

⁶ Faculty of Dentistry, Al-Zahrawi University, Karbala, Iraq

*Corresponding Author: Aqeel Al-Hamaidah, Email (aqeel.alhamaidah@alzahu.edu.iq)

Received: March 24, 2026

Revised: April 19, 2026

Accepted: May 12, 2026

Published: June 01, 2026

ABSTRACT

Keywords: Magnetic Beads, Magnetite, Alginate, Chitosan, Sonochemistry.



Copyright: © 2026 by the authors. Submitted for open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

The technology of combining magnetic oxide nanoparticles with polymers plays an important role in physics and material science. They are used in medicine as a targeted drug delivery system. Magnetite (Fe₃O₄) is one of the most important It is the most widely used iron oxide and has various applications in nanotechnology. In this research, first, iron oxide nanoparticles were made by the sonochemical method. To characterize the prepared samples, we used the diffraction scheme, the infrared Fourier transform spectrum, and a magnetometer with an oscillating sample. In the diffraction scheme, magnetite is the phase. It is original, and the resulting powder is crystalline and has an FCC cubic spinel structure. Using Scherer's formula, the approximate average size of nanocrystals for the Miller index (133) was found to be about 37 nm. In this research, alginate magnetic beads with chitosan coatings were prepared. According to the DLS results, the average diameter size of the nanoparticle with two different methods is about 3 nm and 13 nm. is confirmed in this nanocomposite. For (Fe₃O₄) magnetic beads, absorption bands were observed at 73.3061, 13.3130, 61.61, and 3611 cm⁻¹. Residual rings (H-M) of magnetite nanoparticles magnetic beads were measured at room temperature by a magnetometer with an oscillating sample, and the results of the measurements show a behavior similar to paramagnetic clouds in the produced nanostructures. The saturation magnetization values of magnetite nanoparticles were obtained (131.03 and 1117.30 g/emu, respectively). Considering that the magnetic beads are made of 13 nm, they have more drug-loading capability. Due to the similar behaviors of the paramagnetic cloud phase, the produced magnetic beads are most likely to have favorable performance in the targeted drug delivery system and heat therapy.

1. INTRODUCTION

The 21st century, the century of nanotechnology, is considered the most important era in industry. On the nanoscale, the physical, chemical, and biological properties are different from the bulk properties of matter. Nanoscale particles have unique characteristics that lead to new achievements in medical, engineering, military, and health sciences [1]. In nanotechnology, we deal with natural and

synthetic materials in the size range of 1 to 100 nanometers. Some physical properties of materials will change when their dimensions approach nanometer dimensions. At the nanometer scale, classical Newtonian mechanics or thermodynamics cannot explain the observed properties of materials. Therefore, to express the properties of matter, we will usually refer to quantum mechanics and solid-state physics. In the natural world around us, there are many examples of structures with dimensions of one or more

nanometers, but the possibility of making nanomaterials artificially goes back several decades. Researchers in this period of time to Significant progress has been made in the construction and detailed study of the properties of nanostructures. The thickness of the magnetic walls in a ferromagnetic material is about 100 nm. Therefore, when the dimensions of the particles are in this order, such as nanoparticles, the magnetic domain disappears and the particles become single domains. They say [2]. The magnetization vector in these particles, in the absence of field 13, is in the easy direction of the crystal. With the application of the field, since we do not have a magnetic field, only the rotation of the dipole moment becomes important in the hysteresis curve. In the rotation of the dipole moment, the crossing of the crystal hard direction is also done, and therefore a de-hysteresis field will be created. The smaller the size of the particles, the smaller the anti-residual field. As the dimensions of the particles become smaller, we reach a point where the anti-resonant field is zero, and as a result, there is no resistance against the rotation of the spins in the particle. In this case, we have reached the behavior of superparamagnetic, and this value is the size of superparamagnetic [3]. It should be noted that the size of superparamagnetic materials strongly depends on parameters such as temperature, crystal anisotropy, and Shape anisotropy. In the nonchemical method, the chemical reaction is performed by applying ultrasonic waves. As a result of the process, Cavitation and bubbles are formed in the reaction environment, and the size of the particles depends on the concentration of the reactants. In this method, holes are created by passing sound waves with a constant frequency through the solution. By increasing or decreasing the power of the applied wave, the bubbles are formed and finally disintegrated, leading to the formation of nanoparticles [4]. The advantages of this method are simplicity, the ability to perform at ambient temperature, the possibility of synthesizing amorphous nanoparticles, the ability to introduce high-purity nanoparticles into porous materials, the ability to settle nanoparticles on the surface of ceramics, and the product's surface being free from contamination. Among its disadvantages are particles sticking to each other, a very low concentration of prepared nanoparticles, carrying out the process in a protective environment, and the toxicity of the consumables [1]. The authors. [5] in an article made magnesium ferrite-based nano ferrites by the hydrothermal method. They added small amounts of Mn and in to 4O2MgFe ferrite and investigated its magnetic and microwave properties together. The nanoparticles obtained in this research are superparamagnetic, and the saturation magnetization and coercive field in the sample without any contamination are about gr/emu10 and Oe37, respectively. The dimensions of the synthesized nanoparticles are about 4 nm and have a good distribution. XRD characterization of these nanoparticles shows very broad peaks with low intensity, which indicates the formation of very small particles of the nanometer order. This feature is in very good agreement with TEM analysis.[2,6,7]

Magnetic polymer beads can be prepared directly by depositing iron salts in the polymer matrix. In this method, the polymer matrix limits the growth of magnetic particles. The size of nanoparticles produced in the presence of a

polymer matrix is smaller than that of particles produced in the absence of a polymer [4]. salts, so far, with the coprecipitation method of iron sites, magnetic beads based on many polymers such as polystyrene (PS) [4] polyacrylamide, dextran [1], alginate [3], PVA [1], copolymers [8,9] Alginate magnetic gels have been prepared through an in-situ synthesis process of iron oxide 1. Nisho was examined as a mixture of alginate in a hydrophilic iron salt solution. Also, the authors [1] synthesized iron oxide nanoparticles in alginate polymer for use in drug delivery by stimulation with an external magnetic field, in which the iron oxide particles were between 1-3 nm and showed superparamagnetic properties. In this research, the magnetic nanoparticles of iron oxide have a size of approximately 22 nanometers, the distribution of the powder is very good, and no accumulation was found. This is very good for using in medical applications, and because of the magnetic properties of the magnetic structure (70), coercivity ($H_c = 12$), and size of this sample, it can be used in various medical applications such as drug delivery, MRI, and hyperthermia.

2. SYNTHESIS MAGNETITE NANOPARTICLES Fe3O4

In this research, a sonochemical method was used to make magnetite nanoparticles. Iron chloride ($O2H3.6FeCl$) (with a purity of 33%; Merck company) and iron chloride ($O2H2.4FeCl$) (with a purity of 99%; RECTAPUR company) were used as sources of iron 1 and iron 1, respectively. The combination of sodium hydroxide (NaOH) (with a purity of 37%, Floba Company) and deionized water was used as a solvent and to control the pH. In the following steps, magnetite nanoparticles are added. 6/Preparation of the solution: First, the value of g is 0.1233 iron chloride 6a, along with 0.4324 g of iron 6a chloride in powder form, which was poured inside the beaker. To prevent iron oxidation, after placing the cap and closing the pores completely, the beaker was placed under a nitrogen atmosphere. Metal salts were subjected to a nitrogen atmosphere, and 166 ml of deionized water with a temperature of 0 °C was added through a decanter. To obtain a uniform and homogeneous solution, the solution for 50 minutes.[10,11]

STRUCTURAL CHARACTERIZATION

To determine the crystal structure and also to calculate the average size of nanocrystals, we used the X-ray diffraction pattern (XRD). The magnetite sample's X-ray diffraction pattern was made with a copper tube and KCu radiation with a wavelength of 1.54. It was prepared in the central laboratory of Ferdowsi University of Mashhad in the angular range of 10 to 90 degrees and at a rate of 0.01 degrees per second.[12–14]

DYNAMIC LIGHT SCATTERING (DLS)

is a physical method to determine the distribution of particles in solutions and suspensions. In this method, the light scattered by the particles in the suspension solution changes, which depends on the particle diameter. The particle size of magnetite, alginate, alginate with chitosan, and magnetite samples It was determined by alginate and chitosan coating with a 3VASCO Cordua/LPSA device located in the central laboratory of Ferdowsi University of Mashhad. The magnetic behavior of magnetite samples with magnetite nanoparticles was investigated by a magnetometer device with an oscillating sample (VSM). [15–17]. This device works based on Farad's law, so that by changing the magnetic flux, the electric motive power is induced according to the magnetization of the sample. When the magnetic material is placed in a uniform magnetic field H , a magnetic moment M is induced in the sample. In the VSM device, the sample is placed between the sensitive coils and is subjected to oscillating motion electromechanically. With changes in magnetic flux, a proportional current the magnetic field of the sample is induced in the coils, which can be used to check the magnetic behavior of the material. H-M residual loop of the samples, at room temperature, by a magnetometer with an oscillating sample located in the laboratory. Renewable energies, magnetism, and nanotechnology were measured at Ferdowsi University of Mashhad, Faculty of Science. the X-ray diffraction pattern of the sample.[18–20]

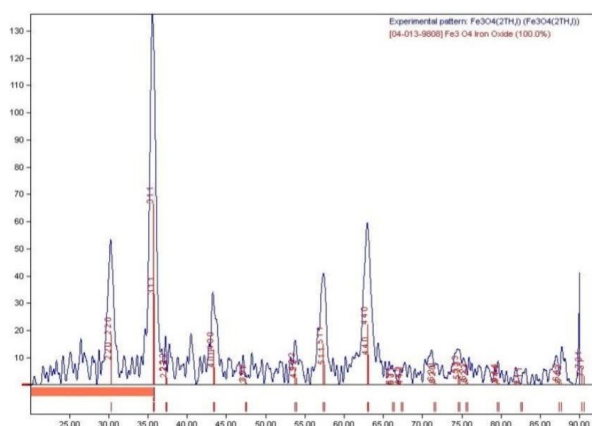


Figure 1: The diffraction pattern of magnetite nanoparticles Fe_3O_4 .

To confirm the crystal structure and calculate the approximate size of nanocrystals, the X-ray diffraction spectrum of magnetite nanoparticles was taken. Figure 1 shows the X-ray diffraction pattern of the sample. In the XRD spectrum, magnetite is the main phase. The powders are crystalline, and according to the standard card number 61-631-3060, they have an FCC cubic spinel structure with a lattice constant of $0.16 = a$ and the space group is $m\text{-}3\text{Fd}$ [3]. Using the position of the peak and the half width of the peaks, the approximate size of the nanocrystals can be determined with the help of Scherer's relation. Using this relationship, the approximate average size of nanocrystals for the Miller index (111), which is the preferred peak of the diffraction pattern, was determined to be 17 nm. FTIR spectrum of fabricated samples.[21–23]

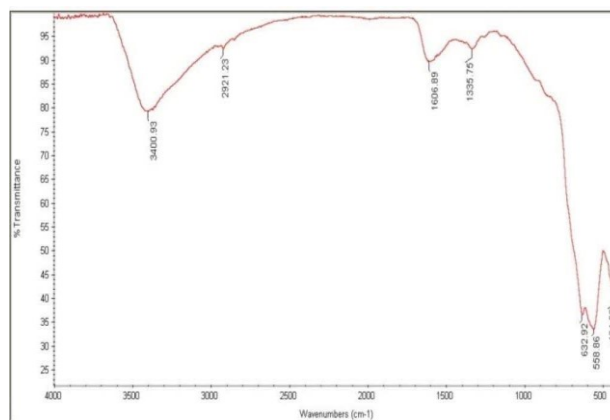


Figure 2: FTIR spectrum of magnetite.

(FTIR) spectrum of the sample was investigated. Figure 2 shows the FTIR spectrum of magnetite, which includes two main bands in the 559/cm range [4]. Tape around 425/cm. They are one of the main characteristics of the spinel structure. 113 /cm Cubic unit cell oscillations can be created in tetrahedral sites (A) and octahedral sites (B). 3 and 1 absorption bands due to stretching fluctuations of the metal-oxygen bond corresponding to the tetrahedral sites, respectively Fe-O, and they become octahedral. Changing the position of the bands due to the difference in link length Fe ion in positions A and B.[24–26]

Aghil#Fe3O4

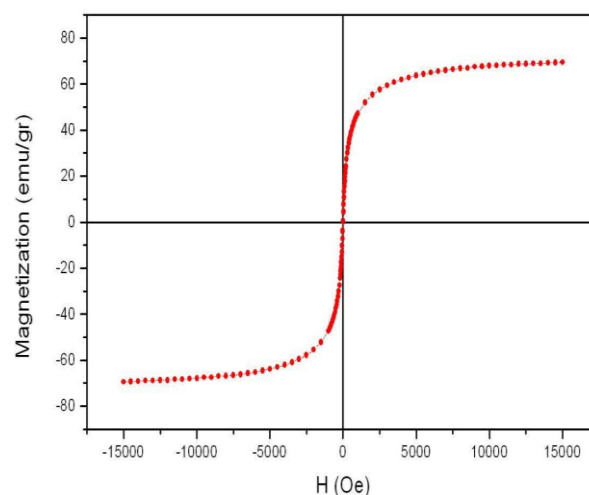


Figure 3: FTIR Spectrum of Fe_3O_4 Magnetite Nanoparticles Showing Characteristic Fe–O Vibrational Bands

Figure 4 shows the hysteresis loop (H-M) of the of the Fe_3O_4 , which shows the very small area of the hysteresis loop. The behavior is superparamagnetic the magnetic properties of the magnetic structure (70), coercivity ($H_c = 12$), and size of this sample, it can be used in various medical applications such as drug delivery, MRI, and hyperthermia [27]

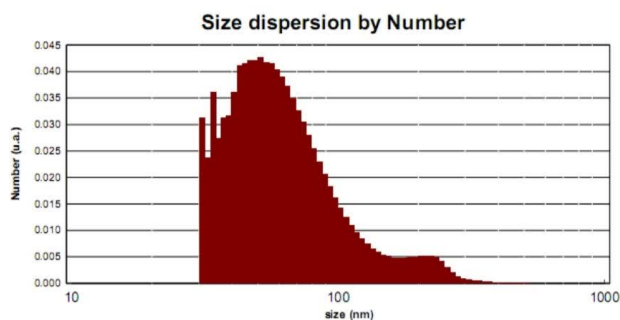


Figure 4: Size distribution diagram of magnetite nanoparticles.

Dynamic light scattering was also used to determine the size of magnetite nanoparticles. In average form in Fig. 4, the size of the hydrodynamic diameter of magnetite nanoparticles was reported to be about 33 nm.[28–30]

3. SUMMARY AND CONCLUSION

This study used the Sashimi method to create iron oxide nanoparticles. According to the DLS results, the size the average diameter of nanoparticles made by the two Sashimi methods is about 31 and 22 nm, respectively. Magnetite nanoparticles made by the nonchemical method have a cubic spinel structure, and the average size of their nanocrystals was estimated to be around 27 nm. According to the results of the FTIR spectrum, magnetic nanoparticles are formed. The saturation magnetization value of magnetite nanoparticles was measured at 70 g/emu, and according to the shape of the residual rings, at room temperature, the samples have the same behavior as the paramagnetic cloud phase. From the results, it has been shown that if these nanoparticles are coated, they can be used in biological, medical, and drug delivery applications. Considering that the nanomagnets made are between 13 and 22 nm, they have the ability to load more drugs. Due to the similar behavior of the paramagnetic super phase, the produced magnetic nanoparticles are most likely to have favorable performance in the targeted drug delivery system and heat therapy.

AUTHORS' DECLARATION

We confirm that all the Figures and Tables in the manuscript belong to the current study.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this study.

REFERENCES

[1] Ramanathan S, Gopinath SCB, Arshad MKM, Poopalan P, Perumal V. Nanoparticle synthetic methods: strength and limitations. *Nanoparticles in*

analytical and medical devices, Elsevier; 2021, p. 31–43.

[2] Buschow KHJ, Boer FR, others. *Physics of magnetism and magnetic materials*. vol. 7. Springer; 2003.

[3] Fermon C. *Introduction to Magnetic Nanoparticles. Nanomagnetism: Applications and Perspectives: Applications and Perspectives* 2017:127–36.

[4] Subramani K, Elhissi A, Subbiah U, Ahmed W. *Introduction to nanotechnology. Nanobiomaterials in clinical dentistry*, Elsevier; 2019, p. 3–18.

[5] Sugawara E, Nikaido H. Properties of AdeABC and AdeIJK efflux systems of *Acinetobacter baumannii* compared with those of the AcrAB-TolC system of *Escherichia coli*. *Antimicrob Agents Chemother* 2014; 58:7250–7.

[6] Abdellahi M, Tajally M, Mirzaee O. The effect of the particle size on the heating and drug release potential of the magnetic nanoparticles in a novel point of view. *J Magn Magn Mater* 2021; 530:167938.

[7] Curiale J, Granada M, Troiani HE, Sánchez RD, Leyva AG, Levy P, et al. Magnetic dead layer in ferromagnetic manganite nanoparticles. *Appl Phys Lett* 2009;95.

[8] Yang G, Park S-J. Conventional and microwave hydrothermal synthesis and application of functional materials: A review. *Materials* 2019; 12:1177.

[9] Sarkar A, Saha N, Majumdar G. *Fabrication and characterization of flexible semi-conducting nanocomposite polymer* 2022.

[10] Coey JMD. *Magnetism and magnetic materials*. Cambridge university press; 2010.

[11] Cullity BD, Graham CD. *Introduction to magnetic materials*. John Wiley & Sons; 2011.

[12] Maity D, Kandasamy G, Sudame A. Superparamagnetic iron oxide nanoparticles for cancer theranostic applications. *Nanotheranostics: Applications and limitations*, Springer; 2019, p. 245–76.

[13] Mohapatra J, Liu JP. Rare-earth-free permanent magnets: the past and future. *Handbook of Magnetic Materials* 2018; 27:1–57.

[14] Tsay C-Y, Chiu Y-C, Lei C-M. Hydrothermally synthesized Mg-based spinel nanoferrites: phase formation and study on magnetic features and microwave characteristics. *Materials* 2018; 11:2274.

[15] Dodrill B, Lindemuth JR. *Vibrating sample magnetometry. Magnetic measurement techniques for materials characterization*, Springer; 2021, p. 15–37.

[16] Lim J, Yeap SP, Che HX, Low SC. Characterization of magnetic nanoparticle by dynamic light scattering. *Nanoscale Res Lett* 2013; 8:381.

[17] Szymczak H. *Magnetic materials and applications* 2005.

[18] Cao C, Xia A, Liu S, Tong L. Synthesis and magnetic properties of hydrothermal magnesium–

- zinc spinel ferrite powders. *Journal of Materials Science: Materials in Electronics* 2013; 24:4901–5.
- [19] Tsay C-Y, Chiu Y-C, Tseng Y-K. Investigation on structural, magnetic, and FMR properties for hydrothermally-synthesized magnesium-zinc ferrite nanoparticles. *Physica B Condens Matter* 2019; 570:29–34.
- [20] Pervaiz E, Gul IH, Anwar H. Hydrothermal synthesis and characterization of CoFe₂O₄ nanoparticles and nanorods. *J Supercond Nov Magn* 2013; 26:415–24.
- [21] Zhao D, Wu X, Guan H, Han E. Study on supercritical hydrothermal synthesis of CoFe₂O₄ nanoparticles. *J Supercrit Fluids* 2007; 42:226–33.
- [22] Melo RS, Banerjee P, Franco Jr A. Hydrothermal synthesis of nickel doped cobalt ferrite nanoparticles: optical and magnetic properties. *Journal of Materials Science: Materials in Electronics* 2018; 29:14657–67.
- [23] Baykal A, Kasapoğlu N, Köseoğlu Y, Toprak MS, Bayrakdar H. CTAB-assisted hydrothermal synthesis of NiFe₂O₄ and its magnetic characterization. *J Alloys Compd* 2008; 464:514–8.
- [24] Suryanarayana C, Norton MG. Practical aspects of X-ray diffraction. *X-ray diffraction: A practical approach*, Springer; 1998, p. 63–94.
- [25] Jabir SA-A, Harbbi KH. A comparative study of Williamson-Hall method and size-strain method through X-ray diffraction pattern of cadmium oxide nanoparticle. *AIP Conf. Proc.*, vol. 2307, 2020, p. 20015.
- [26] Mayeen A, Shaji LK, Nair AK, Kalarikkal N. Morphological characterization of nanomaterials. *Characterization of nanomaterials*, Elsevier; 2018, p. 335–64.
- [27] Boldoo T, Ham J, Kim E, Cho H. Review of the photothermal energy conversion performance of nanofluids, their applications, and recent advances. *Energies (Basel)* 2020; 13:5748.
- [28] Amirthavalli C, Thomas JM, Nagaraj K, Prince AAM. Facile room temperature CTAB-assisted synthesis of mesoporous nano-cobalt ferrites for enhanced magnetic behaviour. *Mater Res Bull* 2018; 100:289–94.
- [29] Feng C, Liu X, Or SW, Ho SL. Exchange coupling and microwave absorption in core/shell-structured hard/soft ferrite-based CoFe₂O₄/NiFe₂O₄ nanocapsules. *AIP Adv* 2017;7.
- [30] Sattar AA, El-Sayed HM, ALSuqia I. Structural and magnetic properties of CoFe₂O₄/NiFe₂O₄ core/shell nanocomposite prepared by the hydrothermal method. *J Magn Magn Mater* 2015; 395:89–96.