



Nanostructured spinel ferrites NiFe_2O_4 and CoFe_2O_4 : influence of cation substitution on crystal structure, surface stability, and magnetic behavior

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ABSTRACT

Nanostructured spinel ferrites NiFe_2O_4 and CoFe_2O_4 were synthesized via a chemical co-precipitation route under identical conditions to enable a direct comparison of their cation-dependent structure, colloidal stability, and magnetic behavior. X-ray diffraction (XRD) confirmed the formation of single-phase cubic spinels with nanoscale crystallites. The broad peaks reflected nanoscale crystallites; however, field-emission scanning electron microscopy (FESEM) revealed agglomerated nanoparticles with an average particle size of ~ 100 nm. Dynamic light scattering (DLS) revealed hydrodynamic diameters of 185 nm for CoFe_2O_4 and 171 nm for NiFe_2O_4 , while the zeta potentials of -29 mV and -37 mV indicated moderate and higher colloidal stability, respectively. Magnetic measurements demonstrated a clear contrast between the two ferrites: CoFe_2O_4 exhibited higher saturation magnetization (75 emu g^{-1}) and coercivity (860 Oe) than the softer NiFe_2O_4 (36 emu g^{-1} , 139 Oe). The corresponding squareness ratios of 0.45 and 0.22 supported the transition from hard to soft magnetic behavior with cation substitution. These findings reveal that replacing Ni^{2+} with Co^{2+} increases magnetocrystalline anisotropy and magnetic hardness while slightly lowering colloidal stability, establishing a direct link between cation type, structural order, and magnetic performance in spinel ferrite nanostructures.

Keywords: Nanostructured spinel ferrites; NiFe_2O_4 and CoFe_2O_4 nanoparticles; Cation substitution; Chemical co-precipitation; Magnetic properties.

1. Introduction

Spinel ferrites of the general formula MFe_2O_4 have attracted wide attention due to their high chemical stability, tunable magnetic characteristics, and compatibility with diverse applications such as sensors, microwave absorbers, data storage, and biomedical systems [1,2]. The cubic Fd3m structure allows flexible occupation of tetrahedral and octahedral sites by different metal cations, providing a rich platform to tailor superexchange interactions and magnetic anisotropy [3,4]. Among them, cobalt and nickel ferrites have

gained particular interest because their distinct cationic preferences and exchange energies lead to pronounced variations in coercivity and saturation magnetization [5,6].

Various synthetic routes including sol-gel, combustion, hydrothermal, and chemical co-precipitation methods have been employed to prepare spinel ferrites [7-9]. Among these, chemical co-precipitation is considered one of the most efficient approaches owing to its simplicity, low processing temperature, and fine control over stoichiometry [10,11]. The microstructure and

resulting magnetic behavior are highly dependent on parameters such as pH, precursor chemistry, and calcination temperature [12]. In the present study, both NiFe_2O_4 and CoFe_2O_4 were synthesized using chloride precursors at pH 12 and calcined at 800 °C to ensure identical processing conditions and allow a fair comparison of cation-dependent effects.

Earlier investigations have consistently shown that CoFe_2O_4 possesses higher coercivity and magnetization than NiFe_2O_4 , reflecting its hard-magnetic character, whereas NiFe_2O_4 behaves as a soft ferrite [13,14]. These contrasting behaviors stem from the greater magnetocrystalline anisotropy of Co^{2+} and the differing degree of cation inversion between the two ferrites [15,16]. Spectroscopic studies have further revealed that shifts in metal-oxygen stretching vibrations in the Fourier-transform infrared spectra correspond to cation redistribution between tetrahedral and octahedral sites [4,17], corroborating structural adjustments at the nanoscale.

Despite the broad literature on ferrites, most previous works focused on doped compositions or employed dissimilar synthetic routes for the two ferrites, making direct comparison difficult [18,19]. Moreover, the interplay between surface stability and magnetic parameters has been rarely addressed, even though colloidal behavior is critical for aqueous and biomedical applications. Establishing a clear correlation between synthesis conditions, cation substitution, and magnetic response remains essential for designing ferrites with predictable performance.

Therefore, in this research, NiFe_2O_4 and CoFe_2O_4 nanostructures were prepared through

a controlled chemical co-precipitation process using chloride precursors at pH 12, followed by calcination at 800 °C. The aim was to systematically evaluate the influence of cation type on crystal structure, particle morphology, colloidal stability, and magnetic behavior. Structural and spectroscopic analyses using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), field-emission scanning electron microscopy (FESEM), and dynamic light scattering (DLS), combined with magnetic measurements performed by vibrating sample magnetometry (VSM), provide comprehensive insights into how cation substitution modifies lattice order, magnetic hardness, and colloidal stability in spinel ferrite nanostructures. The comparative results are expected to clarify the process-structure-property relationships between these two technologically significant ferrites and contribute to the broader understanding of cation-controlled magnetism at the nanoscale. This study is designed to provide a side-by-side comparison of CoFe_2O_4 and NiFe_2O_4 spinel ferrites synthesized under identical conditions.

2. Experimental Details

2.1. Materials

All reagents were of analytical grade and used as received without any further purification. Ferric(III) chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), nickel(II) chloride hexahydrate ($\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$), cobalt(II) chloride hexahydrate ($\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$), and sodium hydroxide (NaOH) were purchased from Sigma-Aldrich with a stated purity above 99%. Double-distilled water was used throughout the synthesis as the solvent and reaction medium.

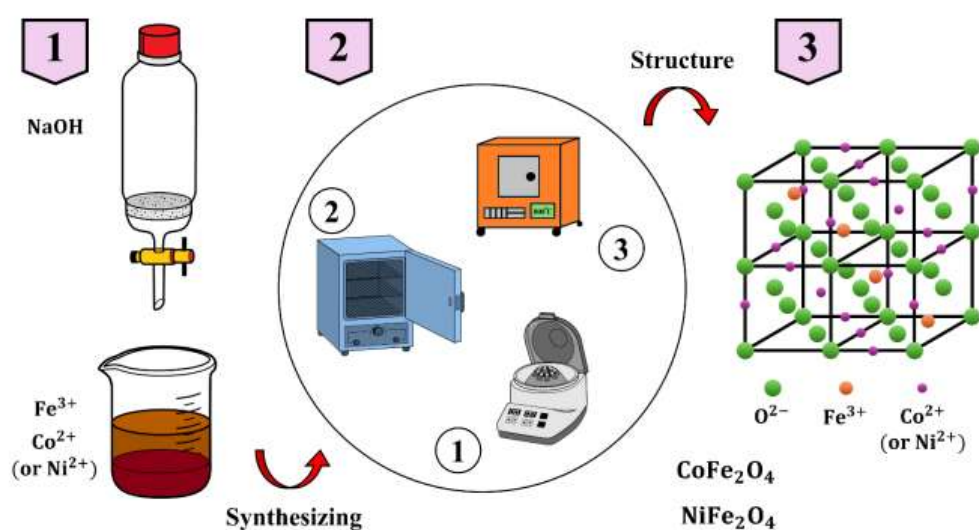


Fig. 1- Schematic illustration of the chemical co-precipitation route used for synthesizing NiFe_2O_4 and CoFe_2O_4 nanoparticles.

2.2. Synthesis method

NiFe_2O_4 and CoFe_2O_4 nanostructures were synthesized via a chemical co-precipitation route [20], as illustrated in Fig. 1. In a typical synthesis, 11.4 g of ferric(III) chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) and 5 g of either nickel(II) chloride hexahydrate ($\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$) or cobalt(II) chloride hexahydrate ($\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$) were separately dissolved in deionized (DI) water and then mixed under continuous stirring at room temperature to form a homogeneous solution. A 1 M sodium hydroxide (NaOH) solution was added dropwise until the pH of the mixture reached approximately 12, resulting in the formation of brown ferrite hydroxide precipitates. The precipitates were thoroughly washed three times with DI water and ethanol to remove residual ions and dried in an oven at 60 °C for 48 h. Finally, the dried powders were calcined in a muffle furnace at 800 °C for 2 h to obtain pure spinel NiFe_2O_4 and CoFe_2O_4 phases. This pH was selected to promote nearly complete co-precipitation of $\text{Ni}^{2+}/\text{Co}^{2+}$ and Fe^{3+} hydroxides and to suppress the formation of unwanted soluble or mixed-valence byproducts. The calcination temperature of 800 °C was chosen as a compromise, being high enough to ensure full conversion to the cubic spinel phase while limiting excessive grain growth.

2.3. Characterization

The structural, morphological, and magnetic characteristics of the synthesized NiFe_2O_4 and CoFe_2O_4 nanostructures were examined using several analytical techniques. The crystal structure was identified by XRD using an X'Pert PRO diffractometer (PANalytical, Netherlands)

operated at 40 kV and 40 mA with Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$) in the 2θ range of 5-80° and a scan step of 0.026°. The chemical bonding and functional groups were investigated through FTIR performed on a PerkinElmer Spectrum RXI spectrometer over the range 400-4000 cm^{-1} . The morphology and surface microstructure of the samples were observed using FESEM (TESCAN MIRA 3) equipped with an energy-dispersive X-ray spectroscopy (EDS) detector for elemental mapping and compositional analysis. The average particle size was further estimated from FESEM images using the ImageJ software (National Institutes of Health, USA). Particle size distribution and surface charge were determined by DLS and zeta potential measurements using a Malvern Zetasizer ZN series at room temperature. The magnetic properties were measured at room temperature using VSM (Magnetic Daneshpajoh Kashan) under an applied magnetic field of up to $\pm 15 \text{ kOe}$.

3. Results and discussion

3.1. Phase and crystal structure

X-ray diffraction patterns of both NiFe_2O_4 and CoFe_2O_4 (Fig. 2 (a)) confirm a single cubic spinel phase with the Fd3m space group. The main reflections appear at approximately $2\theta \approx 18^\circ, 30^\circ, 35^\circ, 37^\circ, 43^\circ, 54^\circ, 57^\circ, 63^\circ, 71^\circ, 74^\circ, 75^\circ$, and 79° , which were indexed to the (111), (022), (131), (222), (040), (242), (151), (044), (062), (353), (262), and (444) planes, respectively [20]. The patterns match well with the ICDD reference cards for CoFe_2O_4 (96-153-3164) and NiFe_2O_4 (96-591-0065), and no additional peaks were detected, indicating phase purity. The peak positions of the two ferrites nearly overlap, consistent with their identical crystal

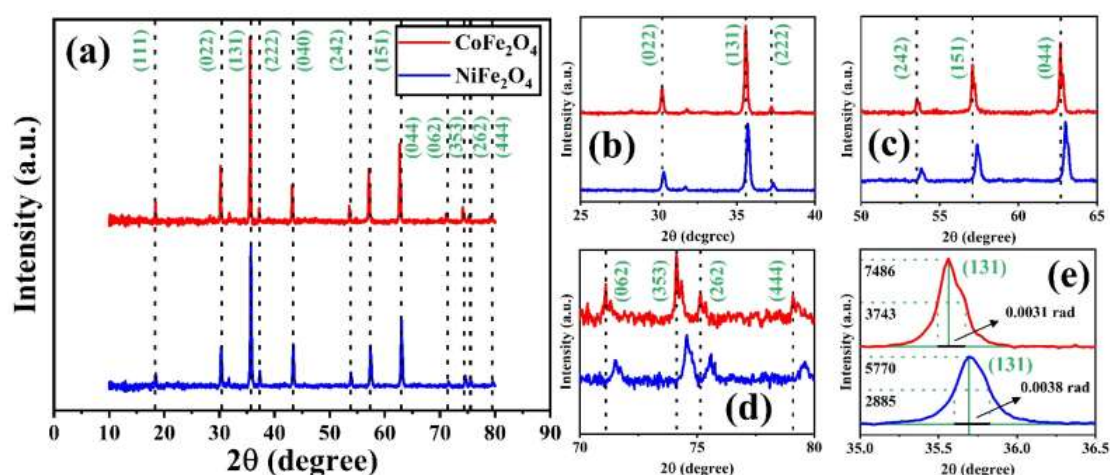


Fig. 2- . (a) XRD patterns of NiFe_2O_4 and CoFe_2O_4 confirming a single-phase cubic spinel (Fd3m); (b-d) peak shifts of NiFe_2O_4 toward higher 2θ values due to smaller Ni^{2+} ionic radius; (e) broader (131) peak for NiFe_2O_4 indicating smaller crystallite size.

symmetry and the close ionic radii of Co^{2+} and Ni^{2+} , so no noticeable 2θ shift is expected between them (Fig. 2 (b-d)). The FCC-type oxygen sublattice and the ordered spinel framework are thus verified for both compositions. Calculated d-spacings and indices agree with the reference files within experimental uncertainty.

The crystallite size was determined from the main (311) diffraction peak using the Debye-Scherrer equation (Eq. 1):

$$D = \frac{K\lambda}{\beta \cos(\theta)} \quad (1)$$

where $K = 0.9$ is the shape factor, $\lambda = 1.5406 \text{ \AA}$ is the Cu K α wavelength, β is the FWHM of the (131) peak corrected for instrumental broadening and expressed in radians, and θ is the Bragg angle. The (131) peak profile was fitted (Fig. 2 (e)), and the instrumental contribution was subtracted using a standard reference. The calculated crystallite sizes for NiFe_2O_4 and CoFe_2O_4 were 38 nm and 47 nm, respectively.

3.2. Metal-oxygen bonding and vibrational band features

The FTIR spectra in the 400-4000 cm^{-1} range exhibit the two characteristic spinel absorption bands (Fig. 3 (a)). The tetrahedral metal-oxygen stretching appears at $\approx 603 \text{ cm}^{-1}$ for NiFe_2O_4 and $\approx 590 \text{ cm}^{-1}$ for CoFe_2O_4 , while the octahedral Fe-O stretching is observed at $\approx 422 \text{ cm}^{-1}$ for NiFe_2O_4 and $\approx 405 \text{ cm}^{-1}$ for CoFe_2O_4 . The higher wavenumbers in the nickel ferrite are consistent with the smaller ionic radius of Ni^{2+} and the resulting stronger metal-oxygen bonds (Fig. 3 (b)) [21]. This shift

can be attributed to shorter Ni-O bond lengths and larger force constants in NiFe_2O_4 , which enhance the vibration frequency of the metal-oxygen lattice. In contrast, the larger ionic radius of Co^{2+} in CoFe_2O_4 leads to weaker bonding and hence lower vibrational energy. Additional features at 3435 cm^{-1} and 1611 cm^{-1} arise from O-H stretching and H-O-H bending of adsorbed water, and the band at 2355 cm^{-1} is attributed to atmospheric CO_2 . The absence of extra absorption bands supports the formation of the spinel structure in both samples without detectable secondary phases [22,23].

3.3. Microstructure and elemental homogeneity

The microstructural morphology of the synthesized NiFe_2O_4 and CoFe_2O_4 samples is shown in Fig. 4(a, b). Both ferrites exhibit closely packed nanoparticles with irregular polyhedral shapes, typical of spinel ferrites prepared via co-precipitation [24]. The grains form dense agglomerates with intergranular voids, suggesting partial coalescence during calcination at 800°C . No secondary or impurity phase is observed, indicating that the calcination process preserved single-phase integrity. The particle size distribution obtained from ImageJ analysis (Fig. 4(c)) reveals an average size of approximately 89 nm for NiFe_2O_4 and 114 nm for CoFe_2O_4 , confirming nanoscale morphology consistent with the crystallite dimensions estimated from XRD. Because FESEM was conducted on dried and heat-treated powders, some degree of aggregation is expected; accordingly, FESEM mainly provides particle/grain-level morphology. Consistent with this, the FESEM-observed particle/grain sizes (~ 89 -114

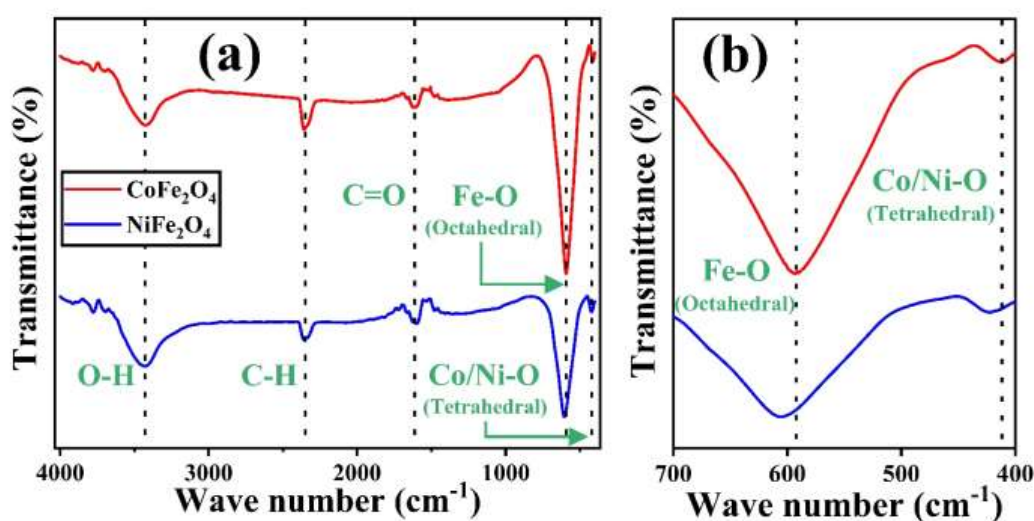


Fig. 3- FTIR spectra of NiFe_2O_4 and CoFe_2O_4 showing the spinel metal-oxygen vibrations.

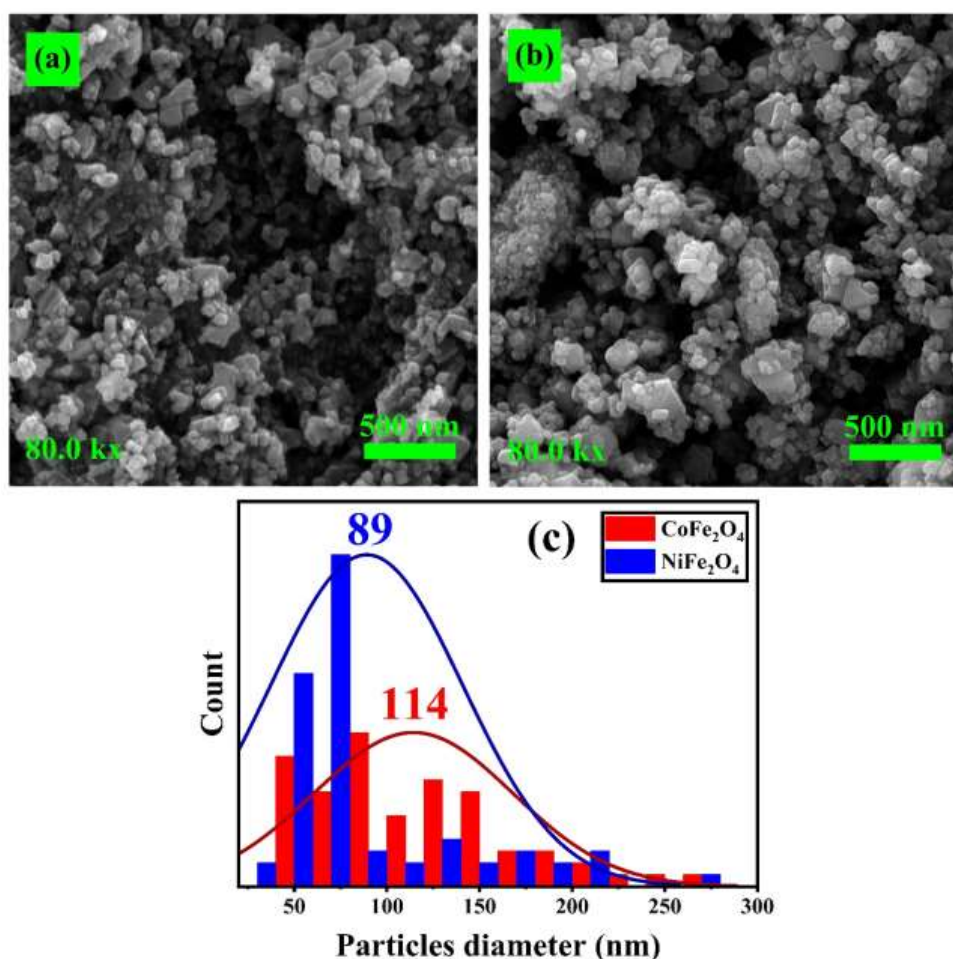


Fig. 4- FESEM images of (a) NiFe₂O₄ and (b) CoFe₂O₄ nanoparticles recorded at a magnification of 80.0 kx, showing densely agglomerated polyhedral grains with nanoscale morphology and (c) particle size distribution histograms obtained from Image.

nm) are larger than the XRD crystallite sizes (~38-47 nm), indicating that the imaged particles likely comprise multiple crystallites and/or experienced partial coalescence during calcination, while the primary crystallite size is more appropriately inferred from XRD.

The corresponding EDS spectra and elemental mapping images (Fig. 5) confirm the presence of Fe, O, and the respective divalent cations (Ni or Co) with no detectable extraneous elements. The homogeneous distribution of all constituent atoms across the scanned regions verifies complete cation incorporation into the spinel lattice and the absence of compositional segregation at the nanoscale.

3.4. Dispersion and colloidal stability in aqueous media

The particle size distribution of the synthesized ferrite nanoparticles was evaluated using dynamic light scattering (Fig. 6). Both NiFe₂O₄ and CoFe₂O₄ exhibit single, narrow peaks, indicating a uniform particle dispersion. The hydrodynamic diameters were determined to be 171 nm for NiFe₂O₄ and 185 nm for CoFe₂O₄. The slightly larger hydrodynamic diameters compared with the sizes estimated from XRD and FESEM are expected, since DLS measures solvated (hydrated) entities in the liquid phase rather than the dry particle/grain size. Differences between DLS- and microscopy-

derived sizes, as well as their interpretation, have been discussed in comparative particle-size characterization studies using SEM and DLS [25].

The schematic illustration in Fig. 7(a) depicts the electrical double-layer model that defines the zeta potential (ζ), showing the Stern layer, slipping plane, and potential decay as a function of distance from the particle surface. This conceptual diagram clarifies the physical meaning of ζ potential, representing the electrostatic potential at the slipping plane between stationary and mobile ions. The experimental values presented in Fig. 7(b) reveal zeta potentials of -37 mV for NiFe_2O_4 and -29 mV for CoFe_2O_4 . The negative values and their magnitudes above 25 mV indicate sufficient electrostatic repulsion for colloidal stability [26].

The higher absolute ζ potential of NiFe_2O_4 implies stronger surface charge and enhanced suspension stability compared with CoFe_2O_4 . In aqueous dispersions, such a difference in ζ potential is reasonable because replacing Ni^{2+} with Co^{2+} modifies the local coordination environment and surface chemistry of the spinel ferrite. This change can alter the density and protonation state of surface hydroxyl groups and other adsorption sites, which directly govern the electrostatic potential at the slipping plane and thus the measured ζ values. More broadly, ferrite-based magnetic nanomaterials are known to exhibit a strong link between crystal chemistry, surface physicochemical properties, and colloidal stability, as highlighted in recent studies on ferrite photocatalysts [42].

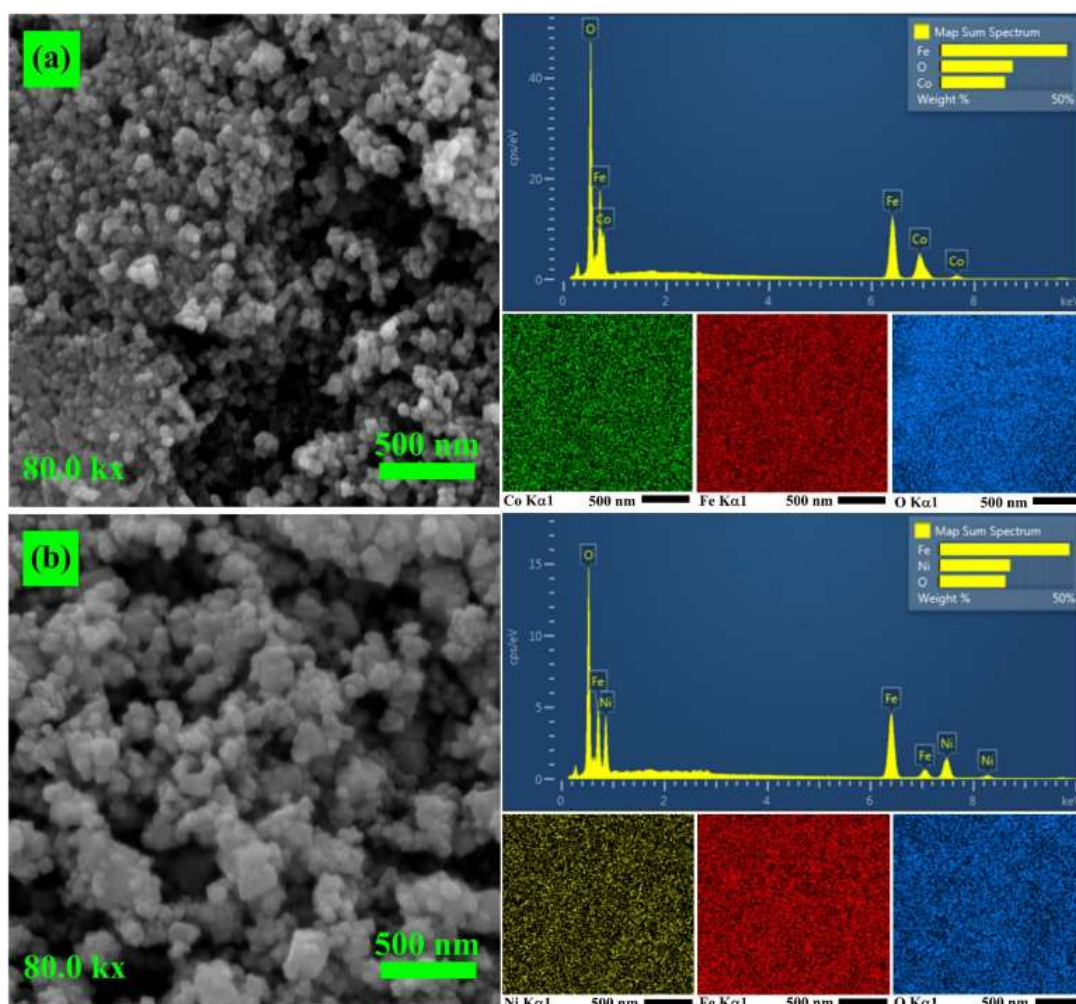


Fig. 5- EDS spectra and elemental maps of (a) CoFe_2O_4 and (b) NiFe_2O_4 confirming the presence and homogeneous distribution of Co/Ni element, Fe and O.

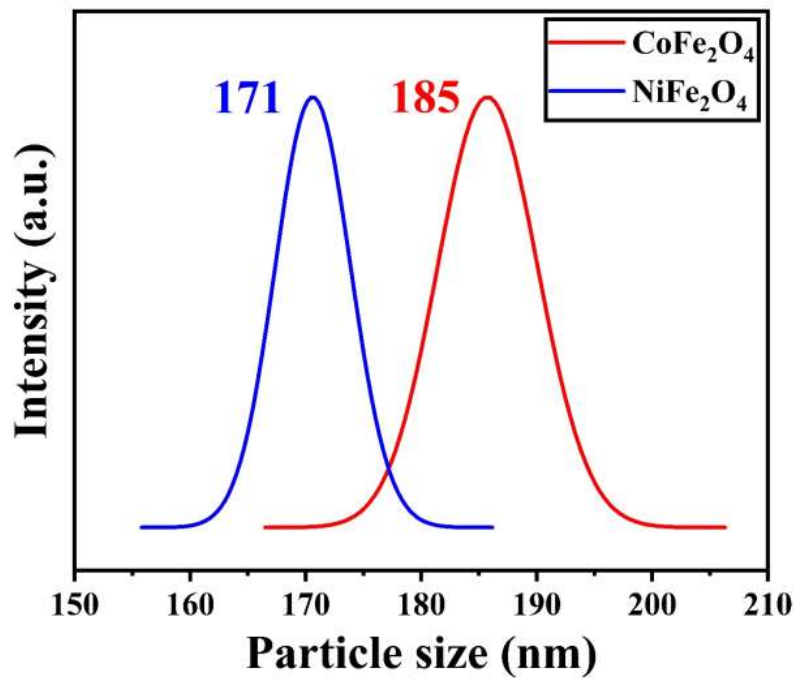


Fig. 6- Particle size distribution of NiFe_2O_4 and CoFe_2O_4 nanoparticles obtained from DLS analysis.

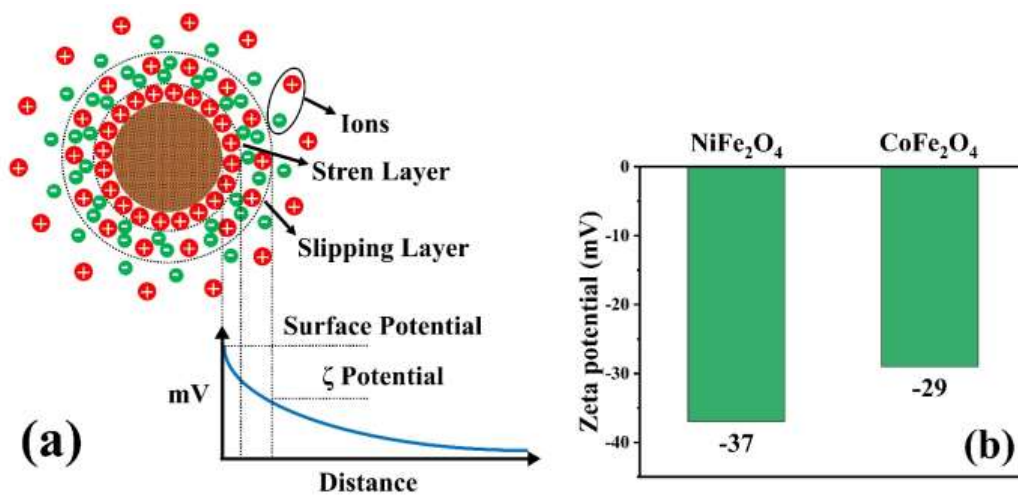


Fig. 7- (a) Schematic illustration of the electric double layer defining the zeta potential (ζ) (schematic redrawn by the authors based on Ref. [27]). (b) Measured zeta potentials of NiFe_2O_4 and CoFe_2O_4 .

3.5. Magnetic response and cation-dependent hardness/softness

Magnetic hysteresis loops of the NiFe_2O_4 and CoFe_2O_4 nanoparticles were measured at room temperature under an applied magnetic field of ± 15 kOe (Fig. 8). Both samples exhibit clear ferromagnetic behavior, yet their magnetic parameters show distinct variations. The extracted values of saturation magnetization (M_s), remanent magnetization (M_r), coercivity (H_c), and squareness ratio ($R_s = M_r/M_s$) are summarized in Table 1.

For CoFe_2O_4 , the obtained M_s , M_r , H_c , and R_s values were 75 emu g^{-1} , 34 emu g^{-1} , 860 Oe , and 0.45 , respectively, whereas NiFe_2O_4 showed lower values of 36 emu g^{-1} , 8 emu g^{-1} , 139 Oe , and 0.22 . The higher M_s of CoFe_2O_4 originates from the intrinsically larger magnetic moment of Co^{2+} ($3 \mu\text{B}$) compared with Ni^{2+} ($2 \mu\text{B}$), as well as its stronger magnetocrystalline anisotropy, which promotes spin alignment at the octahedral (B) sites. In CoFe_2O_4 , Co^{2+} ions predominantly occupy B sites, strengthening the $\text{Fe}^{3+}\text{-O}^{2-}\text{-Co}^{2+}$ superexchange interactions and yielding a larger net moment ($M_B - M_A$) according to Néel's two-sublattice model [28-30]. In contrast, partial occupancy of Ni^{2+} ions at the tetrahedral (A) sites in NiFe_2O_4 reduces the overall magnetic moment.

The coercivity of CoFe_2O_4 (860 Oe) is roughly

six times higher than that of NiFe_2O_4 (139 Oe), reflecting its stronger magnetic anisotropy and “semi-hard” magnetic character. This arises from the electronic configuration of Co^{2+} ($3d^7$, 4T_g) that preserves significant orbital angular momentum and produces a higher crystal-field anisotropy [31]. Conversely, the lower H_c of NiFe_2O_4 is associated with its smaller particle size and weaker anisotropy, facilitating domain-wall motion and classifying it as a “soft ferrite” [31].

The remanence ratio (M_r/M_s) also supports this distinction: CoFe_2O_4 exhibits a value of 0.45 , characteristic of single-domain-like particles with considerable magnetic retention, while NiFe_2O_4 shows a smaller ratio of 0.22 , indicative of multidomain behavior and lower remanence. At the nanoscale, the overall magnetic performance of these ferrites results from the interplay of crystal anisotropy, cation inversion, and surface spin disorder.

In summary, CoFe_2O_4 exhibits semi-hard magnetic behavior with higher M_s and H_c than NiFe_2O_4 , whereas NiFe_2O_4 shows a typical soft-magnetic response with lower coercivity under identical synthesis conditions. For further context, Table 2 compares the M_s , M_r , and H_c values of the present CoFe_2O_4 and NiFe_2O_4 samples with representative literature reports for similar spinel ferrites prepared by comparable synthesis routes.

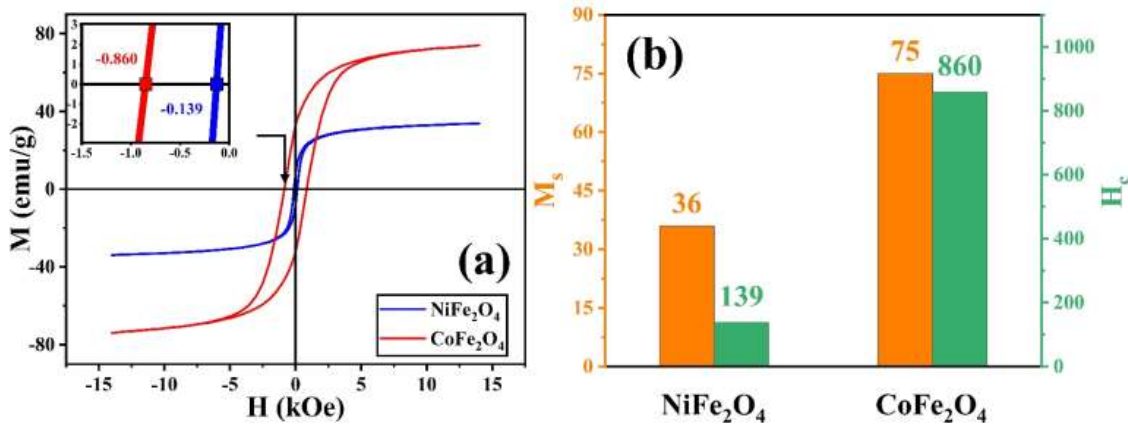


Fig. 8- (a) Magnetic hysteresis loops of NiFe_2O_4 and CoFe_2O_4 nanoparticles measured at room temperature, and (b) comparison of M_s and H_c values showing higher magnetization and coercivity for CoFe_2O_4 .

Table 1- Magnetic parameters of NiFe_2O_4 and CoFe_2O_4 nanoparticles obtained from VSM measurements at room temperature

Spinel ferrite	M_s (emu g^{-1})	M_r (emu g^{-1})	R_s	H_c (Oe)
CoFe_2O_4	75	34	0.45	860
NiFe_2O_4	36	8	0.22	139

3.6. Correlation between structure and magnetism

The combined structural and magnetic results indicate that the magnetic contrast between CoFe_2O_4 and NiFe_2O_4 is mainly governed by cation distribution/inversion, magnetocrystalline anisotropy, and nanoscale size effects in spinel ferrites [6,15,16,30]. Although both samples crystallize in a single-phase cubic spinel (Fd3m), the divalent cation can modify the local metal-oxygen bonding environment, consistent with the observed shifts of the metal-oxygen stretching bands [21]. The higher M_s and H_c of CoFe_2O_4 can be rationalized by the stronger magnetocrystalline anisotropy of Co^{2+} and its preferential occupancy of octahedral (B) sites, which strengthens A-B superexchange interactions and increases the net sublattice moment ($M_B - M_A$) within Néel's two-sublattice framework [15,16,30]. In contrast, NiFe_2O_4 typically exhibits lower anisotropy and partial cation inversion, which reduces ($M_B - M_A$) and facilitates domain-wall motion, consistent with a softer magnetic response [15,16,30,31]. Moreover, the smaller crystallite/particle size of NiFe_2O_4 can enhance surface spin disorder, which may further decrease the apparent magnetization [29,30]. Therefore, under identical processing conditions, tuning the divalent cation provides an effective route to control the magnetic hardness/softness of spinel ferrite nanostructures [6,30].

4. Conclusion

NiFe_2O_4 and CoFe_2O_4 nanoparticles were successfully synthesized via a chemical co-precipitation route at pH 12 followed by calcination at 800 °C. The XRD results confirmed the formation of a single-phase cubic spinel structure with an Fd3m space group for both samples. FTIR spectra exhibited characteristic metal-oxygen stretching vibrations near 600 cm^{-1} and 420 cm^{-1} , corresponding to tetrahedral and octahedral sites, respectively. FESEM images revealed agglomerated nanosized grains with uniform elemental distribution verified by EDS mapping. DLS measurements showed hydrodynamic diameters of 185 nm for CoFe_2O_4 and 171 nm for NiFe_2O_4 , while zeta potential analysis indicated higher colloidal stability for NiFe_2O_4 (-37 mV) compared with CoFe_2O_4 (-29 mV).

Magnetic characterization demonstrated a clear difference in their magnetic responses. CoFe_2O_4 exhibited higher saturation magnetization ($M_s = 75 \text{ emu g}^{-1}$) and coercivity ($H_c = 860 \text{ Oe}$) than NiFe_2O_4 ($M_s = 36 \text{ emu g}^{-1}$, $H_c = 139 \text{ Oe}$), attributed to the stronger magnetocrystalline anisotropy and exchange interactions of Co^{2+} ions. The smaller particle size and partial cation inversion in NiFe_2O_4 led to reduced magnetic moments and softer ferromagnetic behavior. These findings confirm that the magnetic performance of spinel ferrites can be effectively tailored by modifying the type of divalent cation while maintaining identical synthesis conditions.

Table. 2- Comparison of composition, synthesis method, and M_s , M_r , and H_c values for selected spinel ferrites analogous to the present work

Composition	Synthesis method	$M_s(\text{emu g}^{-1})$	$M_r(\text{emu g}^{-1})$	$H_c(\text{Oe})$	Ref.
CoFe_2O_4	Sol-gel	73.7	29.1	973.5	[32]
NiFe_2O_4		62.7	14.5	257.0	[33]
$\text{Cu}_{0.25}\text{Mn}_{0.75}\text{Fe}_2\text{O}_4$	Sol-gel auto-combustion	32.4	18.9	0.3	[34]
$\text{Cu}_{0.25}\text{Mg}_{0.75}\text{Fe}_2\text{O}_4$		40.1	21.3	0.4	
$\text{Cu}_{0.25}\text{Ni}_{0.75}\text{Fe}_2\text{O}_4$		47.1	24.8	1.6	
$\text{Cu}_{0.25}\text{Co}_{0.75}\text{Fe}_2\text{O}_4$		59.0	34.4	3.1	
NiFe_2O_4	Self-combustion	6.7	1.0	159.0	[35]
NiFe_2O_4		37.7	6.9	114.0	
NiFe_2O_4	Co-precipitation /thermal decomposition	29.1	-	58.3	[36]
NiFe_2O_4	Co-precipitation	33.7	6.3	81.0	[37]
CoFe_2O_4		61.2	15.7	275.0	
CoFe_2O_4		69.0	30.1	302.9	[38]
NiFe_2O_4		47.6	13.6	500.1	[39]
NiFe_2O_4		30.5	6.0	134.0	[40]
$\text{Mn}_{0.05}\text{Ni}_{0.95}\text{Fe}_2\text{O}_4$		31.8	6.6	112.0	
$\text{Zn}_{0.05}\text{Ni}_{0.95}\text{Fe}_2\text{O}_4$		36.3	7.1	133.0	
$\text{Co}_{0.5}\text{Mn}_{0.5}\text{Fe}_2\text{O}_4$		85.3	15.6	229.0	[41]
CoFe_2O_4	Co-precipitation	75.0	34.0	860.0	This work
NiFe_2O_4		36.0	8.0	139.0	

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