



# Synthesis and Study of Structural, Magnetic and Optical Parameter of $\text{Co}_{0.5}\text{Zn}_{0.45}\text{Pr}_{0.05}\text{Fe}_2\text{O}_4$

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## Abstract :

Nanocrystalline  $\text{Co}_{0.5}\text{Zn}_{0.45}\text{Pr}_{0.05}\text{Fe}_2\text{O}_4$  ferrite was successfully synthesized via a modified auto-combustion method using citric acid as a fuel. The structural, magnetic, and optical properties of the prepared sample were systematically investigated at room temperature. X-ray diffraction analysis confirms the formation of a single-phase cubic spinel structure with space group  $Fd-3m$ , showing no evidence of secondary phases and exhibiting good agreement with JCPDS card No. 22-1086. The average crystallite size was estimated to be 5.83 nm, and the lattice parameters were determined as  $a = b = c = 8.41168 \text{ \AA}$ . Magnetic measurements reveal a soft ferromagnetic behavior at room temperature, with a saturation magnetization of 50.54 emu/g. Optical properties studied using UV-visible diffuse reflectance spectroscopy indicate a direct optical band gap of 3.49 eV. The results demonstrate that  $\text{Pr}^{3+}$ -substituted Co-Zn ferrite synthesized via the auto-combustion route exhibits promising structural stability along with tunable magnetic and optical properties, making it a potential candidate for multifunctional applications.

**Keywords:** Co-Zn ferrite; Praseodymium substitution; Auto-combustion method; Structural properties; Magnetic properties.

## I. Introduction:

Magnetism is the class of physical attributes that occur through a magnetic field, which allows objects to attract or repel each other. Because both electric currents and magnetic moments of elementary particles give rise to a magnetic field, magnetism is one of two aspects of electromagnetism. In films, television programs and radio broadcasting, women are participating and are acquiring jobs; they have become achievement oriented with the impact of globalization, advancement of technology and significance of education.

Magnetism, at its root, arises from three sources:

1. Electric current
2. Spin magnetic moments of elementary particles
3. Changing electric fields

A suitable material can then produce a strong net magnetic field. The magnetic behavior of a material depends on its structure, particularly its electron configuration, for the reasons mentioned above, and also on the temperature. At high temperatures, random thermal motion makes it more difficult for the electrons to maintain alignment.

Nuclear magnetic moments are nevertheless very important in other contexts, particularly in nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI). Ordinarily, the enormous numbers of electrons in a material are arranged such that their magnetic moments (both orbital and intrinsic) cancel out. This is due, to some extent, to electrons combining into pairs with opposite intrinsic magnetic moments as a result of the Pauli Exclusion Principle

## II. Review of Literature:

1. L. L. Ding, et.al L. L. Ding, et.al , (2016). found a non-monotonic behavior for as a function  $x$  for the Zn doped samples with a maximum at  $x = 0.4$ , while decreased monotonically with increasing  $x$  for the Mg and Al doped samples. On the basis of the O2p itinerant electron model, the magnetic moment direction of the  $Mn^{3+}$  cations is expected to be antiparallel to those of the  $Mn^{2+}$  and Fe cations in these samples. With this assumption, the curves of versus  $x$  for the three series of samples were fitted using a quantum-mechanical potential barrier model earlier proposed by our group, and the cation distributions were obtained.

2. S. Mahalakshmi, et.al; (2014) found the electrical properties of nanocrystalline nickel ferrites doped with rare earth ions having a general chemical formula  $Ni_xFe_{(3-x)}O_4$  have been studied. The AC electrical conductance has been measured as a function of frequency in the range of 0.05–900 kHz at room temperature of 296 K. The conductance was found to be dependent on concentration of nickel ions. Doping of these samples with rare earth ions has shown a change in the electrical conductance. The results are discussed in the light of a hopping model.

3. G.B. Alcantara et.al; (2013), concluded that the present study evidences that such nanocomposites display a dielectric behavior dissimilar from that exhibited by their individual counterparts much likely due to enlarged nanoparticle–polyelectrolyte interfaces.

## III. This main objectives of this paper is-

- To synthesize single-phase Pr-substituted Co–Zn ferrite nanoparticles via auto-combustion technique.
- To characterize their structural, magnetic, and optical properties at room temperature.
- To examine the effect of  $Pr^{3+}$  substitution on crystallite size, magnetic softness, and optical band gap.

## IV . Methodology:

### Synthesis Method (Auto combustion method)

The synthesis of  $Co_{0.5}Zn_{0.45}Pr_{0.05}Fe_2O_4$ , we follow a modified auto combustion method, to this the precursors are, cobalt nitrate nano hydrate (98% Sigma), iron nitrate nano hydrate (98% SRL), zinc nitrate (98% Sigma), praseodymium nitrate (98% Sigma) and citric acid. With reference of stoichiometry ratio all salts are dissolved in 500ml of beaker containing 50ml of deionized water with constant rate of stirring till the homogeneous solution, then add suitable 1:1 ratio of citric acid and 3ml of ethylene glycol into the solution in same condition of stirring, once clear uniform solution obtained then apply a heat about 80 °C up to the formation of viscous gel due to evaporation process, then transfer immediately the solution into pre heated muffle furnace of 200 °C within a few seconds it ignite itself and huge nitrate gas is liberated, finally form a brown colour powder of  $Co_{0.5}Zn_{0.45}Pr_{0.05}Fe_2O_4$  nano compound. Further for removal of unwanted or impurities sinter the sample at 200 °C for 5hours in muffle furnace and cool it down at room temperature. Grind the obtained powder for achieving fine powder of  $Co_{0.5}Zn_{0.45}Pr_{0.05}Fe_2O_4$ .



### Characterization technique

The crystal structure and phase purity of this bulk polycrystalline  $Co_{0.5}Zn_{0.45}Pr_{0.05}Fe_2O_4$  sample were investigated using a Rigaku miniflex x-ray diffractometer with a  $Cu-K\alpha$  ( $\lambda = 1.5406 \text{ \AA}$ ) source at room temperature. The magnetic properties (M-H loop) of  $Co_{0.5}Zn_{0.45}Pr_{0.05}Fe_2O_4$  nano material by applying the field of -1T to +1T using vibrating sample magnetometer (VSM) at room temperature. The optical and band gap results were examined through Lab India UV DRS instrument.

**Equations and calculations**

1. Debye Scherrer formula,

$$(D) = \frac{0.89 \lambda}{\beta \sin \theta}$$

Where, D is the crystallite size,  $\lambda$  is the wavelength (1.5406 Å for Cu K $\alpha$ ),  $\beta$  is the full-width at half-maximum of main intensity peak and  $\theta$  is the diffraction angle.

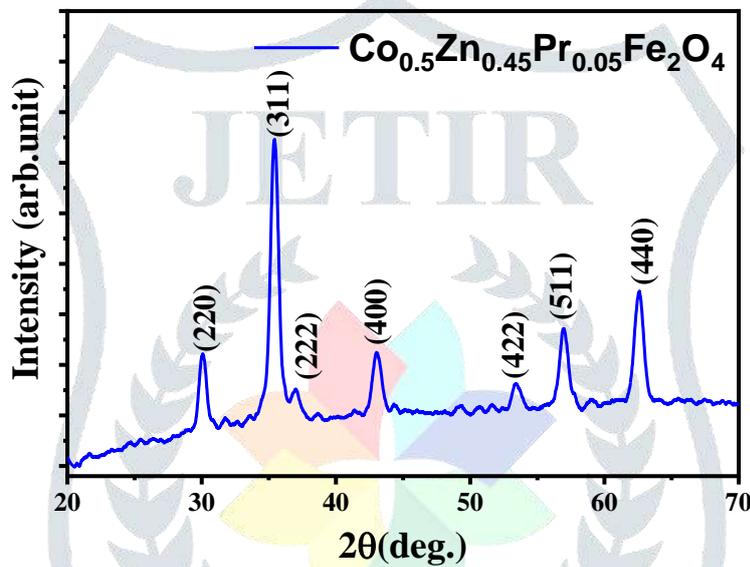
$$2. \text{ lattice constant } (a) = \frac{\lambda}{2} \left\{ \frac{\sqrt{h^2 + k^2 + l^2}}{\sin \theta} \right\}$$

$$3. \text{ Reduced remanence } (S) = \frac{\text{Remnant magnetization (Mr)}}{\text{Saturation magnetization (Ms)}}$$

$$4. \text{ Anisotropy constant } (K_c) = \frac{\text{Coercivity (Hc)} \times \text{Magnetic saturation (Ms)}}{0.64}$$

$$5. \text{ Magnetron number } (\eta_B) = \frac{\text{Molecular weight (Mw)} \times \text{Magnetic saturation (Ms)}}{N_A \times \mu_B}$$

Where, Mw in gm,  $N_A$  is the Avogadro number and  $\mu_B$  is value of one Bohr magnetron in emu.

**V. Results:****Phase and structural study:**

**Fig 1. XRD patterns of CoNi<sub>0.5</sub>Nb<sub>1.5</sub>O<sub>6</sub> sample**

Fig.1 shows the XRD patterns of Co<sub>0.5</sub>Zn<sub>0.45</sub>Pr<sub>0.05</sub>Fe<sub>2</sub>O<sub>4</sub> nano particles and confirms the formation of cubic structure with Fd-3m space group. There are no secondary phases or Fe related impurities in all the samples and it is well matched with JCPDS no: 22-1086. In addition obtained lattice parameter, unit cell volume and tabulated in Table 1. The crystallite size of the Co<sub>0.5</sub>Zn<sub>0.45</sub>Pr<sub>0.05</sub>Fe<sub>2</sub>O<sub>4</sub> sample is estimated by Debye Scherrer formula (Eq. 1) and the values are listed in the Table1.

Table 1: Lattice parameter, cell volume and crystallite size data

Lattice Parameter (Å)	Cell Volume (Å <sup>3</sup> )	Crystallite Size (nm)
8.41168	595.17	5.83

Magnetic parameters study

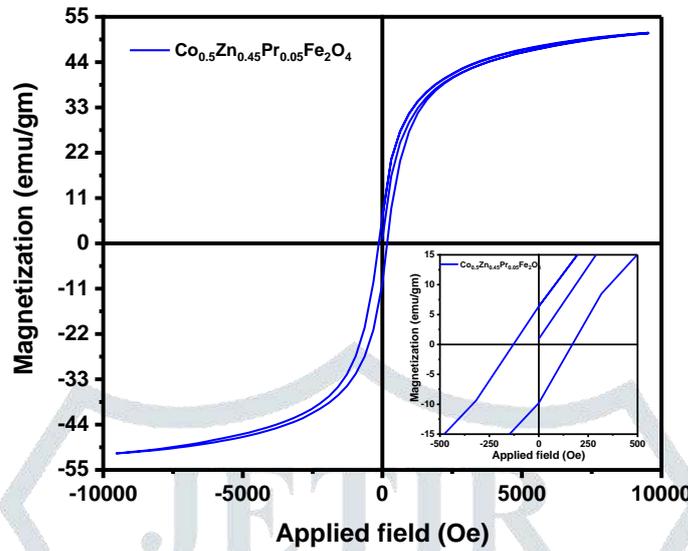


Fig 2. M-H loop of Co<sub>0.5</sub>Zn<sub>0.45</sub>Pr<sub>0.05</sub>Fe<sub>2</sub>O<sub>4</sub> sample

The investigation of effect of Pr dopant in magnetic properties were observed by applying the field of +1T to -1T using vibrating sample magnetometer at room temperature, displayed in Fig. 2. It reveals that ferromagnetic nature with magnetic saturation is 50.54 (emu/gm) this is due the ionic radii of Pr is more than Zn<sup>+2</sup>, this confirms the weak exchange interactions in octahedral site and leads net magnetization in ferrite material. The detailed magnetic saturation (Ms), remnant magnetization (Mr), coercivity (Hc), squareness ratio (S), anisotropic constant (kc) and Bohr magnetron number (η<sub>B</sub>) are calculated using the equations (3), (4) and (5) and are summarized in Table 2.

Table 2: The values of Ms, Mr, Hc, S, Kc and η<sub>B</sub> of Co<sub>0.5</sub>Zn<sub>0.45</sub>Pr<sub>0.05</sub>Fe<sub>2</sub>O<sub>4</sub> nano particles

Ms (emu/gm)	Mr (emu/gm)	Hc (Oe)	S (Mr/Ms)	Kc (erg/Oe)	η <sub>B</sub> (μ <sub>B</sub> )
50.54	6.51	130.66	0.128	10318.0	1.4656

UV DRS

The absorption spectrum of ferrite Co<sub>0.5</sub>Zn<sub>0.45</sub>Pr<sub>0.05</sub>Fe<sub>2</sub>O<sub>4</sub> nano particles were captured through UV-Vis (DRS) spectroscopy, as illustrated in Fig. 12. To determine the band gap, Tauc's relationship was applied to the absorption data.

$$ahv = A(hv - Eg)^n \tag{6}$$

In the context of Tauc's relationship, the absorption coefficient (a) is expressed as a function of photon energy (hv), absorption coefficient at reference energy (a<sub>0</sub>), constants A and h, and the optical band gap of the material (Eg). The parameter 'n' is associated with the type of electronic transition and takes on values such as 1/2, 3/2, 2, and 3, with the specific value depending on the nature of the electronic transition. For instance, n equals 1/2 for direct band gap semiconductors. The optical band gap (Eg) value is determined by extrapolating the linear region of the plot of (ahv)<sup>2</sup> versus hv, as illustrated in Fig. 13. The optical band gap value is found around 3.49 eV.

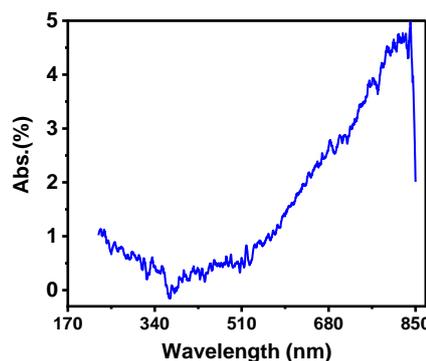


Fig 3. UV-Vis (DRS) absorption spectra of Co<sub>0.5</sub>Zn<sub>0.45</sub>Pr<sub>0.05</sub>Fe<sub>2</sub>O<sub>4</sub>sample

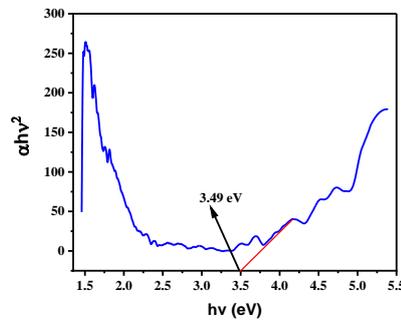


Fig. 4. Optical band gap determination curve of  $\text{Co}_{0.5}\text{Zn}_{0.45}\text{Pr}_{0.05}\text{Fe}_2\text{O}_4$  sample

## VI. Conclusion:

We successfully synthesized the  $\text{Co}_{0.5}\text{Zn}_{0.45}\text{Pr}_{0.05}\text{Fe}_2\text{O}_4$  sample via modified auto combustion method with citric acid as a fuel, and investigate the room temperature structural, magnetic and optical properties were systematically studied. The XRD pattern reveals the no formation of second phase and well fit with JCPDS No 22-1086, confirms the cubic structure with space group  $Fd-3m$  with the crystallite size 5.83 nm. The estimated lattice parameters are  $a = b = c = 8.41168 \text{ \AA}$ . Room temperature M-H loop of  $\text{Co}_{0.5}\text{Zn}_{0.45}\text{Pr}_{0.05}\text{Fe}_2\text{O}_4$  sample displays a ferromagnetic type of soft magnetic nature with magnetic saturation 50.54 emu/gm. RT UV-DRS explores the optical band gap values is 3.49 eV.

## VIII. Applications:

- Ferrite cores are used in electronic inductors, transformers, and electromagnets where the high electrical resistance of the ferrite leads to very low eddy current losses.
- Ferrites are also found as a lump in a computer cable, called a ferrite bead, which helps to prevent high frequency electrical noise (radio frequency interference) from exiting or entering the equipment; these types of ferrites are made with lossy materials to not just block (reflect), but also absorb and dissipate as heat, the unwanted higher-frequency energy.
- Early computer memories stored data in the residual magnetic fields of hard ferrite cores, which were assembled into arrays of core memory. Ferrite powders are used in the coatings of magnetic recording tapes.

Ferrite particles are also used as a component of radar-absorbing materials or coatings used in stealth aircraft and in the absorption tiles lining the rooms used for electromagnetic compatibility measurements.

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