CHAPTER VI

MAGNETIC PROPERTIES

Introduction

Polycrystalline ferrites are found to have wide spectrum of application due to their interesting magnetic properties [1]. It was found that the magnetic properties such as saturation magnetization, B-H loop and its shape, susceptibility Curie temperature etc, of the spinel ferrites are sensitive to the chemical composition, method of preparation, sintering rate and temperature and substitution of the foreign ions in the parent lattice [2]. Therefore many researchers show their interest in the investigation of magnetic properties. The normal spinel ferrite like ZnFe$_2$O$_4$ and CdFe$_2$O$_4$ show paramagnetic behavior at and above the room temperature, where as the inverse spinel like NiFe$_2$O$_4$ shows the ferromagnetic ordering. These properties goes on changes in definite fashion as we move from normal to inverse spinel structure [3]. A small amount of substitution of trivalent and tetravalent cation ion for Fe$^{3+}$ ions results in a significant change in the magnetic properties. The magnetic properties of Co-Zn and Cu-Zn ferrites have been studied and the results are presented along with discussion. Recently, the synthesis of magnetic materials on then a nano scale have been a field of intense study, due to the novel mesoscopic properties shown by particles of quantum dimensions located in the transition region between atoms and bulk solids [1]. Quantum size effects and the large surface area of magnetic particles dramatically change some of the magnetic properties and exhibit super paramagnetic phenomena and quantum tunneling of magnetization, because each particle can be considered as single magnetic domain. Magnetic particles of spinel ferrites are of great interest in fundamental science, especially for addressing the fundamental relationships between magnetic properties and their crystal chemistry & structure. Crystal chemistry shows how the chemical composition (chemical formula), internal structure and physical properties of minerals are linked together. Spinel ferrites have been investigated in recent years for their useful electrical & magnetic properties, applications in information storage systems, magnetic bulk cores, magnetic fluids, microwave absorbers and medical diagnostics. The synthesis and magnetic structure characterization of spinel metastable nano ferrites have been investigated with much
interest [2–4] and a lot of attention has been focused on the preparation and characterization of super paramagnetic metal oxide nano particles of spinel ferrites, MeFe$_2$O$_4$ (metal Me = Co, Mg, Mn, Zn, etc.) [5–10]. The rich crystal chemistry in spinel ferrite systems offers excellent opportunities for understanding and fine-tuning the super paramagnetic properties of polycrystalline by chemical manipulations.

6.1 Magnetization: Magnetization in the polycrystalline ferrites is due to the interaction between the two crystallographically equivalent sites, tetrahedral (A) sites and octahedral (B) sites. Hence the magnetic properties are depend upon the distribution of cations among these sites. Therefore the magnetic parameters like, saturation magnetization, coercivity etc. can be discussed by studying the hysteresis loop of the materials as shown in the figure (6.3). This magnetization against applied magnetic field which sufficiently high in the magnitude.

When magnetic material is subjected to the sufficiently large magnetic field, the spin within the material are aligned along the direction of the magnetic field and material attains the maximum value of magnetization is called the saturation magnetization (Ms), normally expressed in terms emu/gm. On reversing and decreasing the applied magnetic field the magnetization decrease. However, this decrease in the magnetization does not follow the path while increase in field but lags behind. Even at H=0 the material possesses the magnetization, which is referred to as residual magnetization (Mr) or retentivity. To reduce this magnetization to zero, the reverse magnetic field should be applied, which is called as coercive force or coercivity (Hc) expressed in terms of Oersted. The values of Ms, Mr, Hc decides the shape of the loop are the characteristics of the magnetic materials. According to value of Hc, the ferrites are classified into two categories; soft ferrites and hard ferrites. The area of the loop is a measure of the magnetic loss. The square shape loop, with large Mr and the ratio Mr/Ms=1, the prime consideration for the magnetic recording applications [4].

The magnetic induction (B) and the applied magnetic field (H) are correlated within the magnetization (M) by the relation

$$B = H + 4\pi M$$

(6.1.1)
The ratio of the magnetic induction to the applied magnetic field is called magnetic permeability ($\mu$) and that of magnetization to the magnetic field is called the magnetic susceptibility ($\chi$) that means

$$\mu = 1 + 4\pi \chi$$ \hfill (6.1.2)$$

The behavior $\mu$ and $\chi$ for the ferrites under investigation is discussed in the next section and all properties were measured by using the vibrational sample magnetometer.

6.2. Magnetism in materials

Materials are classified by their response to an externally applied magnetic field. Descriptions of orientations of the magnetic moments in a material help to identify different forms of magnetism observed in nature (Fig. 6.1).

**Figure: 6.1 Different types of magnetic behavior**

Five basic types of magnetism can be described: diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism and ferrimagnetism. In the presence of an externally applied magnetic field the atomic current loops created by the orbital motion of electrons respond to oppose the applied field. All materials display this type of weak repulsion to a magnetic field known as diamagnetism. However the diamagnetism is very weak and therefore any other form of magnetic behavior that appears
material may possess usually over powers the effects of the current loops. In terms of electronic configuration of materials, diamagnetism is observed in materials with filled electronic sub shells where the magnetic moments are paired and overall cancel each other. Diamagnetic materials have a negative susceptibility ($\chi < 0$) and weakly repel an applied magnetic field (e.g., quartz SiO$_2$ and calcite CaCO$_3$). The effects of these atomic current loops are overcome if the material displays a net magnetic moment or has long-range ordering of magnetic moments [11]. All other types of magnetic behavior observed in materials are at least partially attributed to unpaired electrons in atomic shells, often in the 3d or 4f shells of each atom. Materials whose atomic magnetic moments are uncoupled display paramagnetism. Thus, paramagnetic materials moments have no long-range order and there is a small positive magnetic susceptibility ($\chi \approx 0$); e.g., montmorillonite and pyrite [11].

Materials that possess ferromagnetism have aligned atomic magnetic moments of equal magnitude and their crystalline structure allows for direct coupling interactions between the moments, which may strongly enhance the flux density (e.g., Fe, Ni and Co). Furthermore, the aligned moments in ferromagnetic materials can confer a spontaneous magnetization in the absence of an applied magnetic field. Materials that retain permanent magnetization in the absence of an applied field are known as hard magnets. Materials having atomic magnetic moments of equal magnitude that arranged in an antiparallel fashion display antiferromagnetism (e.g., troilite FeS and ilmenite FeTiO$_2$). The exchange interaction couples the moments such that they are antiparallel therefore leaving a zero net magnetization [12]. Above the Neel temperature ($T_N$) thermal energy is sufficient to cause the equal and oppositely aligned atomic moments to randomly fluctuate leading to a disappearance of their long range order. In this state the material exhibits paramagnetic behavior. Ferrimagnetism is a property exhibited by materials whose atoms or ions tend to assume an ordered but non-parallel arrangement in zero applied field below a certain characteristic temperature known as the Neel temperature (e.g., Fe$_3$O$_4$ and Fe$_3$S$_4$). In the usual case, within a magnetic domain, a substantial net magnetization results from the antiparallel alignment of neighboring non-equivalent sublattices. The macroscopic behavior is similar to ferromagnetism. Above the Neel temperature, the substance becomes paramagnetic. Size reduction in magnetic materials resulting in the formation of single-domain particles also gives rise to the phenomenon of super
paramagnetism. Briefly, super paramagnetism occurs when thermal fluctuations or an applied field can easily move the magnetic moments of the nano particle away from the easy axis, the preferred crystallographic axes for the magnetic moment to point along. Each particle behaves like a paramagnetic atom, but with a giant magnetic moment, as there is still a well-defined magnetic order in each nanoparticle [13].

6.3 Single-domain particles

Domains, which are groups of spins all pointing in the same direction and acting cooperatively are separated by domain walls, which have a characteristic width and energy associated with their formation and existence. The motion of domain walls is a primary means of reversing magnetization. Experimental investigation of the dependence of coercivity on particle size showed a behavior similar to that schematically illustrated in Fig. 6.2 [14]. It was found that the coercivity $H_c$ increases with decreasing grain size $D$ down to values of about 40 nm, independent of the kind of material. The increase of $H_c$ is proportional to $1/D$.

![Figure 6.2 Qualitative illustration of the behavior of the coercivity in ultrafine systems as the particle size changes, where $H$ is the magnetic field amplitude (Oe) and $D$ is the particle diameter (nm).](image)
The reason for this is that in small particles, the formation of a closed magnetic flux becomes energetically less favorable so that the magnetic domain size with a uniform magnetization becomes more and more identical with the grain size. This grain size is defined as the first critical size ($D_c$, which is characteristic of each material) where the multidomain materials change to a monodomain material. This leads to a strong increase of the coercivity (or high remanance) because a change of magnetization in this case cannot happen only by shifting the domain walls which normally requires only a weak magnetic field. As the size of magnetic element scales below 20nm, the transformation from ferromagnetic to superparamagnetic behavior occurs. In the superparamagnetic state of the material, the room temperature thermal energy overcomes the magnetostatic energy well of the domain or the particle, resulting in zero hysteresis. In other words, although the particle itself is a single-domain ferromagnet, the ability of an individual magnetic “dot” to store magnetization orientation information is lost when its dimension is below a threshold. Consequently, the magnetic moments within a particle rotate rapidly in unison, exhibiting the superparamagnetic relation phenomenon.

### 6.4 Parameters.

The most commonly measured magnetic parameters are schematically illustrated in a hysteresis loop (magnetization versus field) (Fig. 6.3). The application of a sufficiently large magnetic field causes the spins within a material to align with the field. The maximum value of the magnetization achieved in this state is called the saturation magnetization, $M_s$. As the magnitude of the magnetic field decreases, spins cease to be aligned with the field and the total magnetization decreases. In ferromagnets, a residual magnetic moment remains at zero field. The value of the magnetization at zero field is called the remanent magnetization, $M_r$. The ratio of remanent magnetization to the saturation magnetization, $M_r/M_s$, is called the remanence ratio and varies from 0 to 1. The coercive field $H_c$ is the magnitude of the field that must be applied in the negative direction to bring the magnetization of the sample back to zero.
Figure: 6.3 Hysteresis cycle of a multidomain magnetic material, where $H$ is the magnetic field amplitude (G) and $M$ is the magnetization of the material (emu/g).

Hysteresis cycle of a multi domain magnetic material, here $H$ is the magnetic field amplitude (Oe) and $M$ is the magnetization of the material (emu/g). Loop is especially of interest for magnetic recording materials, which require a large remanent magnetization, moderate coercivity and (ideally) a square hysteresis loop [15].

6.5. Magnetic properties of ferrites:

Figure: 6.4 Schematic of a partial unit cell and ferrimagnetic ordering of spinel ferrite structure.
Magnetic properties of ferrites have been explained by Neel [16-17], who postulated that the magnetic moments of ferrites are a sum of magnetic moments of individual sublattices. In the ferrospinels sublattice A consisting of cations in tetrahedral positions and sublattice B with cations in octahedral positions. Exchange interaction between electrons of ions in these sublattices has different values. Usually interaction between magnetic ions of sublattices A and B (A–B interaction) is the strongest. A–A interaction is almost ten times weaker than A–B interaction, and B–B interaction is the weakest. The dominant A–B interaction leads to a complete or partial (non-compensated) antiferromagnetism (ferrimagnetism) [17]. In the inverted ferrites one half of Fe$^{3+}$ is placed in A-sites and another half in B-sites. Their magnetic moments are mutually compensated and the resulting moment of the ferrite is due to the magnetic moments of divalent cations Me$^{2+}$ in the B-positions (Fig. 6.5a). Magnetization of MnFe$_2$O$_4$ which has inversion degree $\delta = 0.2$ is described in (Fig. 6.5b). Substitution of Mn$^{2+}$ with Zn$^{2+}$ leads to introduction of non-magnetic Zn$^{2+}$ ions into A-sites, thus increasing the saturation magnetization, $M_s$. Increasing $x$ up to 0.4 (at 0K) leads to linear increase in magnetization and is described in (Fig.6.5c) [18]. For higher Zn concentrations ($x > 0.4–0.5$) ferrite becomes normal spinel. It means that there are no more Mn$^{2+}$ in B-sites and no more Fe$^{3+}$ in A-sites. For $x > 0.4$, the A–B exchange interaction weakens and there is an increase in the role of B–B interaction. Due to this, magnetic moments of a part of Fe$^{3+}$ ions (which are now only in B-position) becomes reversibly oriented which leads to the decrease of the total magnetic moment in ferrites. Higher the temperature, greater is the relative effect of the A–B exchange weakening due to the thermal fluctuations, resulting in decreased magnetization[19].
Figure: 6.5. Cation distribution in spinel ferrites: (a) inverse ferrites, (b) manganese ferrites and (c) zinc manganese ferrites.

6.6. Classification and applications

Magnetic materials are grouped into two types, soft and hard. This classification based on their ability to magnetized and demagnetize and not their ability to withstand penetration or abrasion. Soft materials are easy to magnetize and demagnetize, so are used for electromagnets, while hard materials are used for permanent magnets. They can also be classified based on their coercive field strength into soft and hard materials. With soft magnetic materials the hysteresis loop is small (low coercive field strength, independent of magnetic field amplitude); with permanent magnets however it is large (high coercive field strength). Table 6.1 gives a comparative account of both types.

\[ H_c < 10 \text{ A/cm}: \text{soft magnetic} \]
\[ H_c > 300 \text{ A/cm}: \text{hard magnetic} \]
Some Properties of microwave ferrites

Hard ferrite magnets are made in two different magnetic forms—-isotropic and oriented. Isotropic magnets are formed to desired shapes, sintered and then magnetized. These exhibit modest magnetic field and find applications in cycle dynamos.

<table>
<thead>
<tr>
<th>Soft magnets</th>
<th>Hard magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>High saturation magnetization (1–2 T)</td>
<td>High saturation magnetization (0.3–1.6 T)</td>
</tr>
<tr>
<td>Low coercivity ($H_c$)</td>
<td>High coercivity</td>
</tr>
<tr>
<td>High permeability</td>
<td>Not important, but low</td>
</tr>
<tr>
<td>Low anisotropy</td>
<td>High anisotropy</td>
</tr>
<tr>
<td>Low magnetostriction</td>
<td>Not important</td>
</tr>
<tr>
<td>High Curie temperature ($T_C$)</td>
<td>High $T_C$</td>
</tr>
<tr>
<td>Low losses</td>
<td>High-energy product</td>
</tr>
<tr>
<td>High electrical resistivity</td>
<td>Not important</td>
</tr>
</tbody>
</table>

Oriented magnets are formed to shape under a strong magnetic field and then sintered. These exhibit a very strong magnetic field and find applications in loudspeakers, magnets in two wheelers like scooters, etc. [20].

6.6.2. Soft ferrites

Soft ferrites are ceramic electromagnetic materials, dark gray or black in appearance and very hard and brittle. The magnetic properties of soft ferrites arise from the interactions between metallic ions occupying particular positions relative to the oxygen ions in its spinel crystalline structure. The magnetic domain theory suggests that these interactions create magnetic domains, which are microscopically magnetized regions within the material. When no magnetizing force is present, these magnetic domains are random and the net flux contribution is zero even though local domains are fully magnetized. When a magnetizing force is present the magnetic domains align in the direction of the magnetizing force resulting in a large net flux contribution. Soft ferrites are also semiconductors. In inductor cores, transformer cores and other applications, electromagnetic materials are required to operate at high frequencies. The advantages, soft ferrites over other electromagnetic materials include their inherent high resistivity which results in low eddy current losses over wide frequency ranges and high permeability and stability over a wide temperature range.
range. These advantages make soft ferrites paramount overall other magnetic materials [21]. The general properties and applications of hard and soft magnetic materials are given in Table 6.2.

6.7. Advantage over other magnetic materials

Most other technologically useful magnetic materials such as iron and metallic alloys have low electrical resistivity. This makes them useless for applications at high frequencies, for example, as inductor cores in TV circuits. The problem is that their low electrical resistivity allows induced currents (called eddy currents) to flow within the materials themselves, thereby producing heat. This is wasted energy and the heat is often a serious problem. Thus, the materials become inefficient as they waste energy, the more so as the frequency gets higher. However, ferrites can perform much better at high frequencies because they have high electrical resistivity. High permeability and time/temperature stability are important additional characteristics, which have widened the use of ferrites into high frequency and wide-band transformers, quality filter circuits, adjustable inductors, delay lines and other high-frequency electronic circuitry. At high frequencies the use of ferrites is relatively more routine as compared to that of other circuit components whose performance needs improvement. An important factor in choosing ferrites is that they are generally cheaper than magnetic metals and alloys. Ferrites are the best core material choice for frequencies from 10 kHz to a few hundred MHz when one requires the combination of low cost, high $Q$ (inductor quality), high stability and low volume. Furthermore, no other magnetic material has magnetic and mechanical parameters as flexible as those of ferrites.

Properties and applications of hard and soft magnetic materials are listed in table 6.2.
Some Properties of microwave ferrites

Table: 6.2

<table>
<thead>
<tr>
<th>Properties and applications of hard and soft magnetic materials</th>
<th>General properties and applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hard magnetic materials</strong></td>
<td></td>
</tr>
<tr>
<td>Aluminium oxide- nickel alloy (ALNCO) with copper and titanium</td>
<td>Magnets can be cast into complex shapes and perform well at high temperatures</td>
</tr>
<tr>
<td>Rare-earth alloys</td>
<td>High magnetic strength</td>
</tr>
<tr>
<td>Neodymium-iron-boron alloys</td>
<td>Very low magnetic strength</td>
</tr>
<tr>
<td>Hard ferrite-iron-aluimium oxide</td>
<td>Low cost</td>
</tr>
<tr>
<td><strong>Soft magnetic materials</strong></td>
<td></td>
</tr>
<tr>
<td>Iron with 3-8% silicon</td>
<td>Magnetic, generators and transformers</td>
</tr>
<tr>
<td>Metallic glass combinations of Fe, Co, Ni, B and Si</td>
<td>Low energy loss</td>
</tr>
<tr>
<td>Nickel-silicon alloys</td>
<td>Low permeability applications</td>
</tr>
<tr>
<td>Hard ferrite-iron, nickel and cobalt ferrite</td>
<td>Low electrical conductivity reduces eddy current losses</td>
</tr>
</tbody>
</table>

6.8 Review of the literature

The polycrystalline ferrites of general formula $\text{MF}_{2}\text{O}_{4}$ show the dependence of saturation magnetization on the cations. The zinc and cadmium ferrites are paramagnetic at room temperature. However the substitution zinc or cadmium in the Mg, Cu, or Ni containing ferrites results in increasing the saturation magnetization. The magnetic properties of zinc substituted Co, Fe, Mn, Li, Cu; ferrites have been studied for different concentration by Gorter [22]. He explained his results on the basis of Neel theory [23]. Fallot and Aroni pointed out the limitations of the Neel’s theory to account the temperature dependence of magnetization at Curie temperature [24]. $\text{Ms}$ increases with the increase in the Cd concentration, and decrease thereafter. In order to explain this behavior of magnetization ($\text{Ms}$), Yaftet-Kittle (1952) have proposed the three sub lattice model by introducing the theory of triangular spin arrangement [25]. On the basis of this three sub lattice model based on the canting angle on B-sites, the magnetic properties of Cu-Zn-Mg [26], Ni-Zn [27], Fe-Zn [28], Cd-Co [29] etc., have been successfully explained. Kulkarni et.al, suggested that...

The effect of magnesium substitution on Co-Cr ferrites have been studied by Shukla et.al showing decrease in the saturation magnetization and curie temperature with increase in Mg concentration [31]. Chen et.al (1999) have prepared the Nano particle size magnesium ferrites by co precipitation method and reported the composition have super magnetic characteristic [32]. In Zn Fe₂O₄ the Fe³⁺ ions are in the octahedral (B) sites and gives rise to cluster glass formation due to the weak A-O-B interaction [33,34]. Magnetic phase diagram was studied by Bakker et.al for Zn and Mg substituted ferrites and reported that the compositions for Zn>0.80 are paramagnetic at and above room temperature [35]. Many researchers have investigated the effect of Cr³⁺ substitution on spinel ferrites [36-38]. ZnFe₂O₄ is the normal ferrites showing the antiferromagnetism below 10K [39,40]. The magnetic properties of Ni substituted Zn-Mg ferrites have been studied by using the neutron diffraction technique by Yunas et al, reporting the cation distribution for the system [41]. Magnetic studies of Zn substituted MgFeCrO₄ system was carried out by Upadaya, suggesting that the existence of two sub lattice model up to x=0.40 and three sub lattice model after x=0.50 [42]. The super exchange interaction per unit linkage Fe (A)-O-Fe (B) depends on the crystal structure, Fe–O bond distance and number of cations other than Fe³⁺ ions [43].

6.9 Experimental: The measurement of saturation magnetization and magnetic moments of the powder samples of Cu-Zn and Co-Zn ferrites at different compositions at room temperature was carried out using Lakeshore VSM model 7400 series, with magnetic field strength of 10KG. The powder samples were placed between the two electromagnets of known air, the reading was recorded for 200 steps until it reach the saturation. The magnetic moment in terms of Bohr magneton was calculated using the relation

\[ \mu_B = M_s \times M/W/55856 \]  
(6.9.1)

Where M/W is the molecular weight of the compositions. The values of 4πMs are then calculated by using the relation

\[ 4\pi M_s = 4\pi (1-p) M_s \times D_x \]  
(6.9.2)
Where \( p \) is the porosity and \( dx \) is the x-ray density of the sample.

Figure: 6.6 (C) Saturation magnetization Coercive field and remanence field for Co-Zn (Y-series) and Cu-Zn ferrites (X-series).
Figure: 6.6 (D) X-Y series magnetic moment as function of Zn Concentration

Table: 6.3 Bohr magnetron numbers $n_B$, $M_s$, $M_r$ of Cu-Zn ferrites

<table>
<thead>
<tr>
<th>Sample No</th>
<th>$n_B$ (µB)</th>
<th>Mr</th>
<th>He Gauss</th>
<th>Saturation magnetization emu/gm</th>
<th>Y-K angle ($\alpha_{YK}$) (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu-Zn Ferrites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>0.00014</td>
<td>-</td>
<td>-</td>
<td>0.0058</td>
<td>33°33'</td>
</tr>
<tr>
<td>S2</td>
<td>0.47</td>
<td>0.85</td>
<td>120.28</td>
<td>11</td>
<td>43°51'</td>
</tr>
<tr>
<td>S3</td>
<td>0.53</td>
<td>1.83</td>
<td>27.75</td>
<td>12.5</td>
<td>56°31'</td>
</tr>
<tr>
<td>S4</td>
<td>0.75</td>
<td>1.25</td>
<td>83.27</td>
<td>17.5</td>
<td>65°22'</td>
</tr>
<tr>
<td>S5</td>
<td>0.49</td>
<td>-</td>
<td>-</td>
<td>11.5</td>
<td>77°20'</td>
</tr>
<tr>
<td>S6</td>
<td>0.00023</td>
<td>6.71</td>
<td>27.75</td>
<td>0.0054</td>
<td>89°59'</td>
</tr>
</tbody>
</table>

Table 6.4 Bohr magnetron numbers $n_B$, $M_s$, $M_r$ of Co-Zn ferrites

<table>
<thead>
<tr>
<th>Sample No</th>
<th>$n_B$ (µB)</th>
<th>Mr</th>
<th>He Gauss</th>
<th>Saturation magnetization emu/gm</th>
<th>Y-K angle ($\alpha_{YK}$) (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-Zn Ferrites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y1</td>
<td>0.37</td>
<td>-</td>
<td>-</td>
<td>8.9</td>
<td>26°29'</td>
</tr>
<tr>
<td>Y2</td>
<td>0.22</td>
<td>1.39</td>
<td>18.51</td>
<td>0.54</td>
<td>47°6'</td>
</tr>
<tr>
<td>Y3</td>
<td>0.23</td>
<td>0.074</td>
<td>27.75</td>
<td>0.56</td>
<td>59°37'</td>
</tr>
<tr>
<td>Y4</td>
<td>0.35</td>
<td>0.051</td>
<td>74.77</td>
<td>0.82</td>
<td>69°8'</td>
</tr>
<tr>
<td>Y6</td>
<td>0.38</td>
<td>0.139</td>
<td>407.40</td>
<td>0.88</td>
<td>86°53'</td>
</tr>
</tbody>
</table>
7.0 Results and Discussion:

In the cubic system of ferrimagnetic spinels, the magnetic order is mainly due to the super exchange interaction mechanism occurring between the metal ions in the A and B sublattices. The substitution of nonmagnetic ions such as Zn, which has preferential A site occupancy results in the reduction of exchange interaction between A and B sites. Hence varying the degree of zinc substitution, it is possible to vary magnetic property of the fine particle. Figure (6.6A) and (6.6B) shows the room temperature hysteresis loop of powder samples of various zinc substitution.

From the table 6.3 and 6.4 it can be seen that the variation of specific saturation magnetization as a function of Zn content shows increases for small substitution and reaches to the maximum value and then the decrease. The variation of remanence and coercivity, which decrease with the increase in zinc substitution. The changes in these parameter are due to the influence of the cationic stoichiometry and their occupancy in the specific sites. In addition to that the formation of dead layer on the surface, existence of random canting of particle surface spins[56], non saturation effects due to random distribution of particle size, deviation from the normal cation distribution, presence of adsorbed water, etc.[57] might be cause for the reduction of the magnetic properties of ferrites.
Figure: 6.6 (A) Hysteresis of Co-Zn ferrites of different concentration
Some Properties of microwave ferrites

Department of Physics Kuvempu University Shankarghatta
Some Properties of microwave Jerrites

The spinel structure of the ferrites consists of two interpenetrating sub lattices, forming two types of sites where the metal ions are located at the tetrahedral (A) and Octahedral (B) sites. In the crystal structure of Co-Zn ferrite Zn$^{2+}$ occupy tetrahedral sites(A), Co$^{2+}$ ions have a tendency to enter in to B-sites, Fe$^{2+}$ occupies octahedral sites (B) sites and Fe$^{3+}$ occupies either tetrahedral or octahedral sites randomly [44,45]. For the small dopant concentration, Ms increases with increasing in the Zn content. This result is expected if most Zn$^{2+}$ ions enter the lattice a interstitial sites instead of occupying Fe site ions in the lattice. Because the magnetic Zn$^{2+}$ ions are dissolved in the spinel lattice, the net value of magnetic moment and also Ms may be increased by increased number of magnetic ions in the spinel lattice.

Further increase in the dopant concentration, Ms decreases. A possible explanation of this decrease may be that Zn$^{2+}$ entering the B-sites, maybe that some Fe$^{3+}$ ions prevent to occupy this position, pushing the Fe$^{3+}$ ions from B to A sites with further increasing dopant concentration as discussed by [46,47]. The net magnetization is the result of difference in the sub lattice moments of the two sites, which depends upon the cation occupancy [45]. When Fe$^{3+}$ ions at B-sites are replaced by magnetic Zn$^{2+}$, because of the difference between the magnetic moments of Fe$^{3+}$ and Zn$^{2+}$, the magnetic moments of the A-sites sub lattice (M$_A$) will increases and the moment of

![Figure 6.6 (B) Hysteresis of Cu-Zn ferrites of different concentrations](image)
the B-site sub lattice ($M_B$) will decreases. Therefore, the value of the net moment $M$ being equal to $M_B - M_A$ will decreases which Explains the observed decrease.

Similarly in case of Cu-Zn ferrites the Zn occupy tetrahedral A site and Cu$^{2+}$ ions are distributed over the tetrahedral A and octahedral B sites. Due to non magnetic substitution of Zn$^{2+}$ ions at tetrahedral A sites magnetic moment decreases [48,49]. Similarly due to the substitution of Cu$^{2+}$ ions at tetrahedral A and octahedral B sites in place of Fe$^{3+}$, the magnetic moment of octahedral B-site also decreases. However, A-site magnetic moment is less than B-site for all composition. Hence net magnetic moment increases initially up 0.6 and then decreases with further increase of zinc content due to Yafet and Kittle spin arrangement [50].

The values of $M_s$ are shown in Fig.6.6A and 6.6B whereas that of (nB) are shown in Fig.6.9. For both series of samples, it an the increase up to $x = 0.6$ and then decrease with the increase in Zn concentration. Similar reports about saturation magnetization have been quoted by others [51–53]. The increasing trend suggests that the variation in magnetic properties can be explained on the basis of Neel two sub-lattice model [54]. The decreasing trend is due to the non-zero Y–K angles in the samples that cannot be explained on the basis of the Neel’s two sub-lattice model. It is due to the fact that for all the samples ($x > 0.2$) the Y–K angles are non-zero. This suggests that there are triangular type spin arrangements on B sites which weaken A–B interaction. So it results in a reduction of the resultant saturation magnetization, as $x$ exceeds 0.2 [55]. Satyamurthy et al. and Yafet and Kittel have also observed the similar kind of weakening A–B interaction in two sub-lattices due to Zn substitution in mixed ferrites. The Yafet–Kittel (Y–K) angles have been calculated using the formula [54]:

$$nB = (6 + x) \cos \alpha Y-K - 5(1-x)$$ (7.1)

it observed from the table that Y–K angles are low for samples of $x=0.0$ of Cu-Zn ferrites and $x=0.0$ of Co-Zn ferrites which indicates that the magnetization results can be explained on the basis of Neel's two sub lattice model. The increase in YK angle with further increase in Zn content beyond $x=0.0$ suggest that the magnetization in these ferrites can be explained on the basis of canted spin model. The increase of Y-K angle with Zn content for $x>0.0$ indicates the fact that
triangular spin arrangement is suitable on the B-site leading to the reduction in A-B interaction. Many workers are reported the similar results [58, 59-61].

From the above discussions the results obtained can be summarized as follows.

7.1 Conclusion: The cumulative magnetic property can be explained on the basis of exchange energy, magneto crystalline anisotropy and spin canting. The variation of saturation magnetization and magnetic moment, it explains a lowering of A-B exchange arising from mixed spinel formation and the presence of the spin canting suggest that the prepared material favours Yafet-Kittle arrangement rather than Neels model. For the prepared samples it shows super paramagnetic behaviour, which was documented by the hysteresis loop, measured at room temperature. From the hysteresis it shows that it is not hard materials since hysteresis loop is very small and it known that ZnFe$_2$O$_4$ is a soft magnetic material. These soft magnetic materials have very interesting application, in magnetic coatings and in the preparation of ferrofluids.
Some Properties of microwave ferrites

References:


Some Properties of microwave ferrites


1. List of Publications:

1. Microcrystalline parameter of Cu-Zn ferrites using X-ray line profile analysis.
   Ashok.R.Lamani, H.S.Jayanna, P/Parameswar,R.Somashekar

2. Dielectric properties of polycrystalline Cu–Zn ferrites at microwave frequencies.
   Ashok R. Lamani, H.S. Jayanna, P. Parameswara, R. Somashekar, Ramachander,
   Ramchandra Rao, G.D. Prasanna,

3. Electrical conductivity and microcrystalline parameter in Co-Zn ferrites.
   Ashok.R.Lamani, H.S.Jayanna, R.Somashekar, P.PARAMESWAR.

4. Polyaniline/CoFe2O4 nanocomposites: A novel synthesis, characterization and magnetic properties.
   G.D. Prasanna, H.S. Jayanna, A.R. Lamani, S. Dash

5. Low-Frequency Dependence of Conductivity and Dielectric Properties of Polyaniline/ZnFe2O4 Nanocomposites.
   G. D. Prasanna, H. S. Jayanna, Ashok R Lamani, M. L. Dinesha, C. S. Naveen,
   G. J. Shankaramurthy


   Title: Dielectric properties of polycrystalline Cu-Zn ferrites at Microwave frequency

2) Participated and presented a paper at 53rd DAE solid state symposium, BARC Mumbai -2008 Dec 16-20.
   Title: Microcrystalline parameters of Cu-Zn ferrites using line profile analysis.

3) Participated and presented a paper in the international conference on nanotechnology and medical science at D.Y Patil university Kolhapur oct-21-23-2010.
   Title: Electrical Conductivity and microcrystalline parameters in Co-Zn ferrites
4) Participated and presented a paper at center for converging technologies university of Rajasthan Jaipur from 6-8-2011

Title: Characterization and measurement of some properties of metal Phthalocyanine complexes.

5) Participated in the third international Nano at Cochin and presented the paper on 14-17-2011.

Title: Some properties of polyaniline doped with ZnFe$_2$O$_4$

6) Attended and presented the paper in 56$^{th}$ DAE symposium held at SRM University Chennia-2012 from 19-23 April 2011.

Title: Line profile analysis and low temperature AC susceptibility of Cu-Zn ferrites.