CHAPTER - 1

INTRODUCTION

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The pioneering work done by Hilpert[1] and Snoek[2] has led to the development of magnetic ceramics. Most of this magnetic ceramic is called a Ferrite. Ferrites are generally known as spinel ferrites, orthoferrites, magnetoplumbite etc.

To cater to the quantitative and qualitative demands of the consumer electronics as well as in computer technology, a substantial effort has been made by various laboratories to prepare ferrite materials since last forty years. The magnetic ceramics are used for a great variety of different applications and they are designed and tailored specifically for each purpose[3]. The numerous applications are permanent magnets, core for high and low frequency applications, T.V. deflection yokes etc. The Table 1 gives the spectrum of applications of ferrites.

The present chapter deals with fundamental properties of ferrites along with theories. Orientation of present work is also included at the end.

1.1. HISTORICAL

The nature prepared herself the ferrite in the form of magnetite $FeOFe_2O_3$ which aroused the scientific curiosity of human beings. The ancient people living in 600 B.C. believed the statement of Thale's[4] that load stone(magnetite) possesses an inherent living force which accounts for the observed attraction between magnetite and iron. Gilbert(1540-1603) applied the scientific methods to a systematic study of magnetic phenomenon.

The human interest developed in synthesizing magnets to reduce

eddy current losses for microwave applications, as studied by Hilpert at Bell Telephone Laboratories. In thirties Forsteir[5], Kato and Takai[6] and Barth and Posjnak[7] have studied ferrites from various different angles and their work remained as background knowledge for the Snoek, who laid the strong foundation for improved ferrites. He and his co-workers at the Philips Research Laboratories in the Netherlands developed the first soft ferrites for commercial applications and since then number of investigators developed new ferrites for the various technical applications. Electronic conductivity in ferrite is due to the exchange of electrons between trivalent and divalent Fe ions, was established by Verwey[8]. He also showed inverse spinel structure ferrites are ferrimagnetic and normal spinel structure ferrites are nonmagnetic.

Neel[9,10] published the first explanatory theories on the origin of magnetism in ferrites by introducing the concept of sublattices to explain the spin-spin interaction in 1948 and modified the same in 1952. Anderson[11] and Vanvleck[12] developed the super-exchange theory of interactions. Yafet and C.Kittle[13] suggested the modifications in the Neel's theory, by postulating a triangular arrangement of spins in a sublattice so that, net spin of the sublattice is opposite in direction to the spin on the other sublattice of ferrite.

Further investigation on the technology of ferrites was made by Gorter[14] and Guillaud[15] and his co-workers. Gorter measured the magnetizations of Mn, Fe, Co, Ni, Cu and Mg ferrites mixed with zinc and gave the direct experimental proof of Neel's theory. Guillaud and his co-workers studied the variation of magnetisation with temperature for mixed ferrites in ferrimagnetic region. The Sh-

ull and Strauser[16], with the help of Neutron diffraction studies of ferrites, confirmed the Neel's theory for magnetite and zinc ferrite. The correlation of curie temperature with magnetization and cation distribution was carried out by Gilleo[17]. Koops[18] studied high conductivity associated with high dielectric constant and obtained the formula giving a phenomenological theory to explain the conduction behaviour.

Technological developments in electronics and telecommunication have increased the demand of ferrite materials in quantity as well as in quality of the materials. In ICF-3(1980) Professor Takeshi Takei[19] made a small reference to the new technology that would soon explode. Hirayam[20] presented a paper on the use of ferrite material as power ferrite. During the period between ICF-3(1980) and ICF-4(1984) the switched mode power supply market grew rapidly and also the literature on power ferrites. Mochizuki et al,[21] Stijntjes et al[22], Kamada and Suzuki[23] and Goldman[24] reported that power ferrites had an edge for cost and performance. Since then use of power ferrites has been multiplied many more times. Power supplies operating at 1MHz and above are commercially available. The need for small compact power supplies for computers, micro-processors and VCR's have triggered a great demand for power ferrites. Correspondingly, the equal number of papers were presented in the ICF-5 (1989).

1.2. STRUCTURE OF FERRITES

Ferrites are classified according to their different crystal structures. There are different types of crystal structures like Spinel, Garnet, Hexagonal etc. The details of the spinel structure are given below.

The spinel structure derives its name from the nonmagnetic mineral spinel $MgAl_2O_4$ and is a complex cubic structure. The divalent Mg^{2+} can be replaced by Fe^{2+}, Mn^{2+}, Cu^{2+}, Co^{2+}, Zn^{2+} or more often by combinations of these and trivalent Al may be replaced by Fe^{3+} or by Fe^{3+} in combination with other trivalent - ions. The magnetic spinels have the general formula $MeOFe_2O_3$ or $MeFe_2O_4$, where Me is a divalent metal ion like Cu, Co, Zn, Mn and Mg. The oxygen ions form a f.c.c. lattice with eight molecules of the formula in the unit cell of edge length nearly equal to $8A^o$. The space group is $Fd3m-o_h^7$. The metal ions in the unit cell occupy the interstitial positions with four fold and six fold oxygen co-ordinations. The metal ion surrounded by four oxygen ions is called A site(tetrahedral) and that surrounded by six oxygen ions at the vertices of octahedron is called B site(octahedral). There are in all 96 interstitial positions with 64 A site and 32 B sites. However, 8 cations occupy A sites and 16 cations occupy B sites in spinel structure. The co-ordinates of the ionic positions are as follows:

8A sites at 8f positions (0,0,0; 1/4, 1/4, 1/4)face centered

16B sites at 16d positions(5/8, 5/8, 5/8; 5/8, 7/8, 7/8; 7/8, 5/8, 7/8; 7/8, 7/8, 5/8) face centered.

32 positions at 32c $(u,u,u;\ u,\bar{u},\bar{u};\ \bar{u},u,\bar{u};\ \bar{u},\bar{u},u;\ \frac{1}{4}-u,\ \frac{1}{4}-u,\ \frac{1}{4}-u;\ \frac{1}{4}-u,\ \frac{1}{4}+u,\ \frac{1}{4}+u;\ \frac{1}{4}+u,\ \frac{1}{4}-u,\ \frac{1}{4}+u;\ \frac{1}{4}+u,\ \frac{1}{4}+u,\ \frac{1}{4}-u)$ face centered.

For u = 0.375, the oxygen ions form a perfect close-packed cube. However, in general 'u' value is slightly greater than the value mentioned above and deviations indicate increase in size of 8 tetrahedral interstices and decrease in size of 16 octahedral interstices.

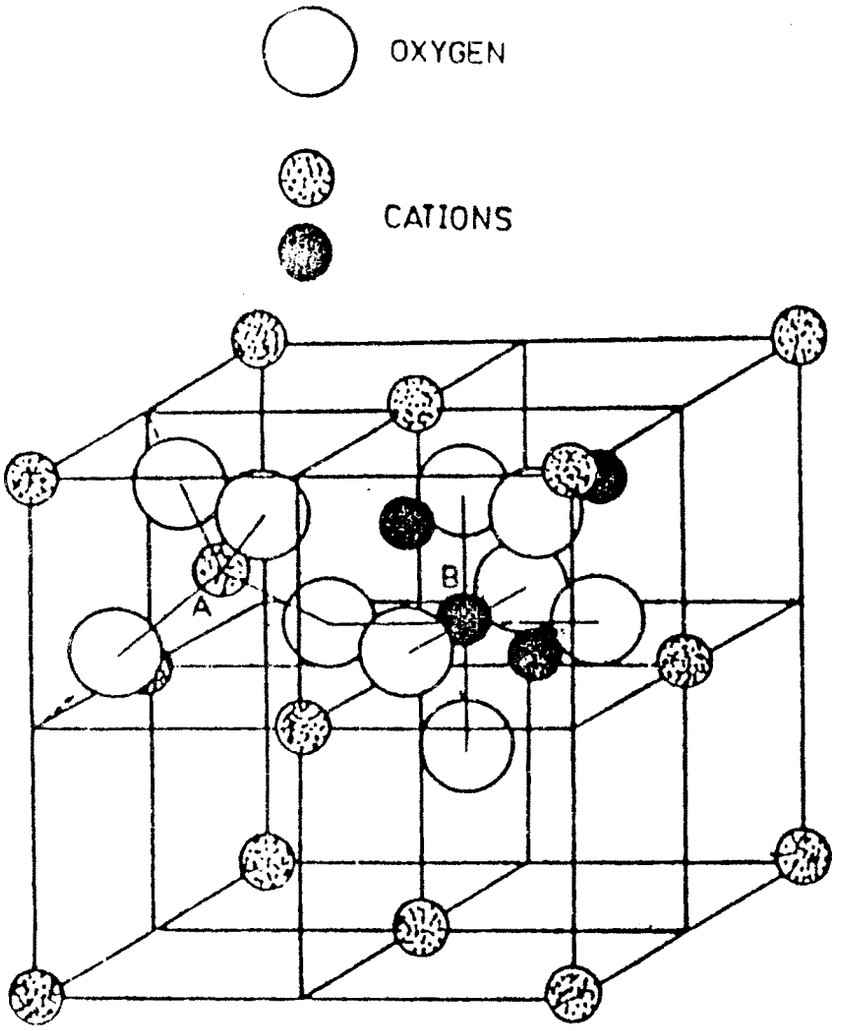
The distribution of cations in spinel ferrite can take place in the following ways.

i) When the 8A sites are occupied by the 8 Me^{2+} ions and 16B sites are occupied by 16 Fe^{3+} ions, the normal spinel structure results, and structural formula is $Me^{2+}(Fe_2^{3+})O_4^{2-}$ where the ions in the bracket sit on the B-sites. The zinc and-- cadmium ferrites are having normal spinel structure. These are non-magnetic in nature.

ii) When the 16B-sites are occupied by 8 Me^{2+} and 8 Fe^{3+} ions and 8A-sites are occupied by the remaining 8 Fe^{3+} ions, the Inverse-structure of spinel results. The structural formula is $Fe^{3+}(Me^{2+}\ Fe^{3+})O_4^{2-}$ where the ions in the bracket are on B-sites. The manganese, copper, cobalt and nickel - ferrites are having completely inverse structure. The inverse spinel ferrites are magnetic in nature.

iii) There is a possibility of intermediate case in which divalent metal ions and trivalent metal ions are randomly distributed over A and B sites. $Me_{1-x}^{2+}Fe_x^{3+}(Me_x^{2+}Fe_{2-x}^{3+})O_4^{2-}$. where x takes the values from 0.1 to 1.0. Such ferrites are known as Partial inverse spinels. The spinel structure, Asite and B-site interstitial positions are shown schematically in the figures 1.1, 1.2(a) and 1.2(b).

iv) By replacing the divalent and trivalent metal ions with -- other magnetic or non-magnetic ions in spinel ferrites, -- substitutional ferrites can be obtained. If partial replacement of divalent metal ion is done by divalent metal -- ion of the other metal, substitutional ferrite of one type results. e.g. $Co_{1-x}Mn_xFe_2O_4$. Secondly, trivalent iron ions



THE SPINEL STRUCTURE (SCHEMATIC)

Fig. 1-1

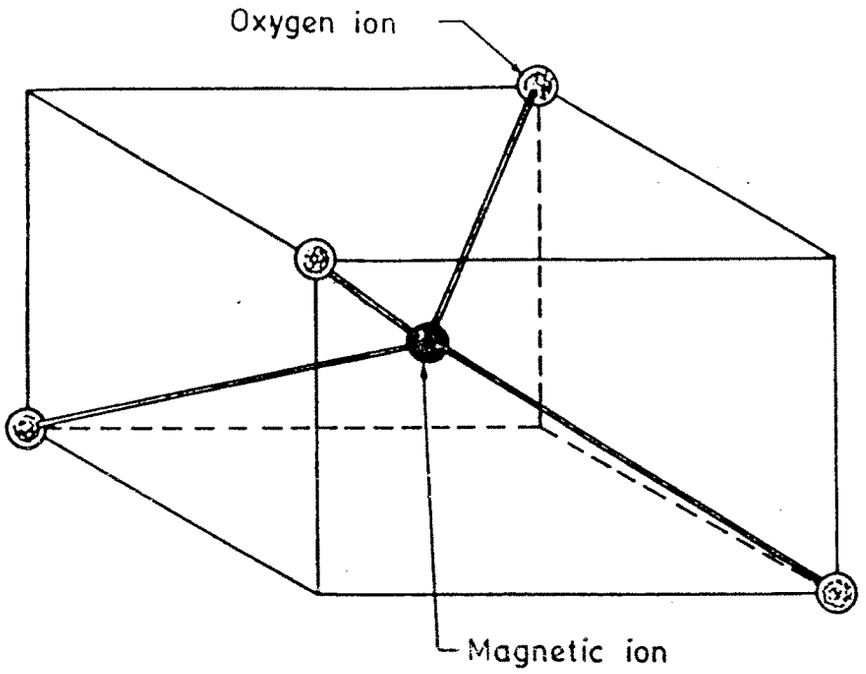


Fig.1·2(a): THE MAGNETIC ION OCCUPIES A "TETRAHEDRAL LATTICE SITE" WHERE IT IS SURROUNDED BY FOUR NEAR-NEIGHBOUR OXYGEN IONS.

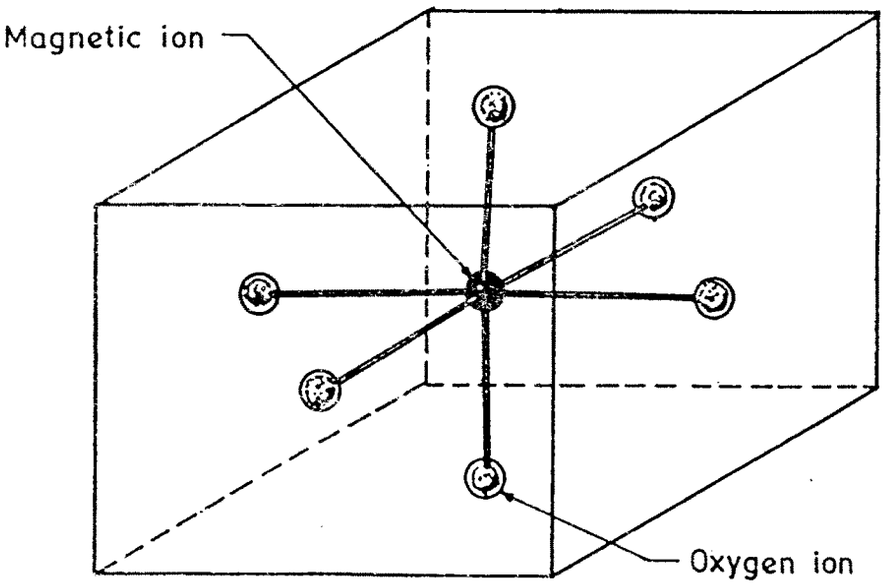


Fig.1·2(b): THE MAGNETIC ION IS SAID TO OCCUPY AN "OCTAHEDRAL LATTICE SITE" WHERE IT IS SURROUNDED BY SIX NEAR-NEIGHBOUR OXYGEN IONS.

can be replaced by other trivalent metal ions, which need not be magnetic in character and this gives rise to substitutional ferrite of other type. e.g. $NiFe_{2-x}Cr_xO_4$ nickel chromium ferrite.

1.3. FERRITE-A MAGNETIC MATERIAL

In a magnetic material, magnetic phenomena originate in the unpaired electronic spins of atoms. For example the Fe atom has a net paramagnetic moment or polarization due to four unpaired but parallel spins, whereas Fe^{3+} ion has magnetic moment due to five unpaired spins as shown in the Fig.1.3.

The large scale magnetic effects occur in only few metallic - elements Fe, Co, Ni and some of the rare earths. In certain materials containing these elements, the atomic spin effect is great - which is due to the co-operative phenomenon of interaction of large number of these spins. In the region of co-operative interaction, all spins are essentially aligned parallel and these materials are called Ferromagnetic. The regions of the materials in which co-operative phenomenon exists, are called domains, as shown by Weiss[25]. He postulated the existance of molecular field that produced the interaction of aligning spins of neighbouring atoms parallel. - Heisenberg[26] explained the molecular field on the basis of exchange forces. The boundaries between neighbouring domains are called - domain walls.[27]

In ferromagnets, the positive exchange force aligns spins of neighbouring atoms parallel. In oxides, the interaction of unpaired spins of two neighbouring metal ions is through an intermediate - oxygen ion, leading to an indirect exchange called super exchange[28] or double exchange.[29] However, this leads to a negative exchange force producing a phenomenon called antiferromagnetism, which - orients spins of neighbouring metal ions antiparallel.

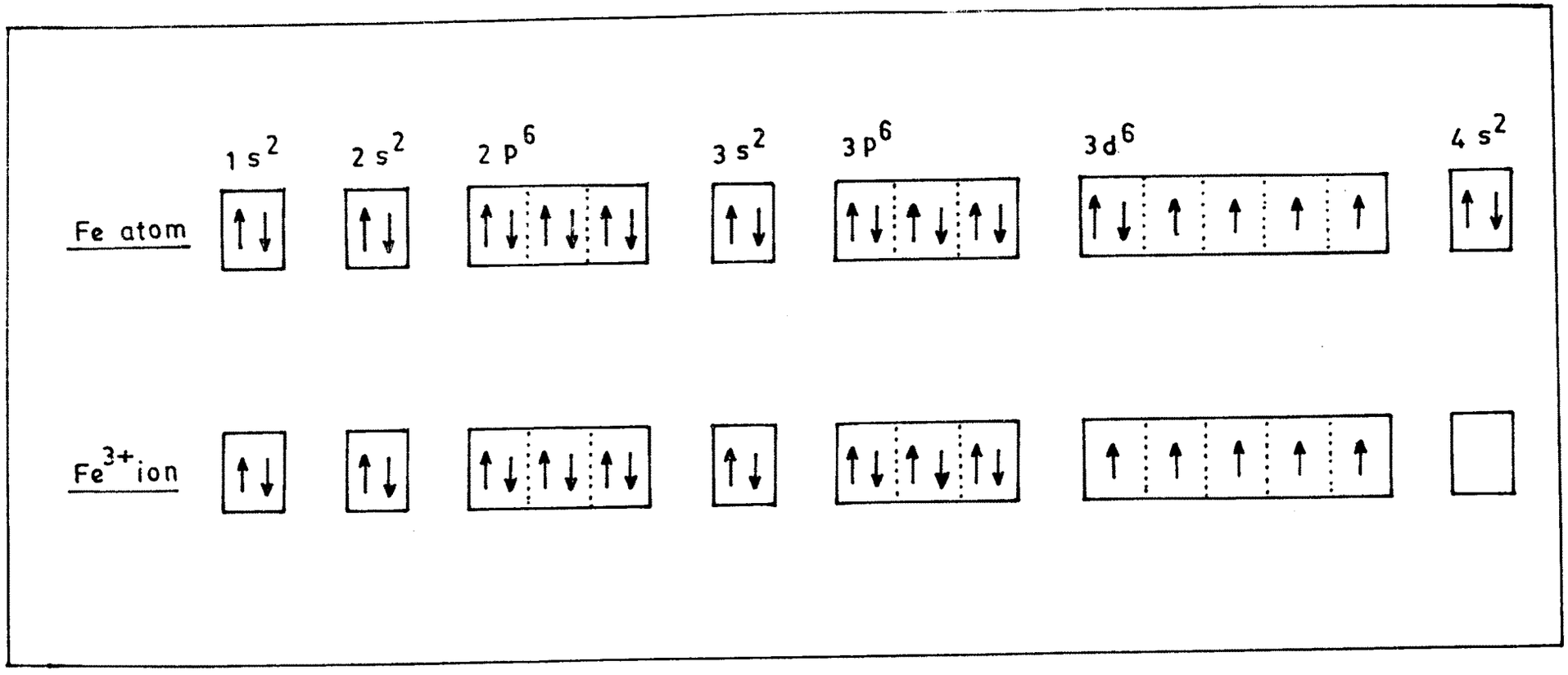


FIG. 1·3 — ELECTRONIC CONFIGURATION OF Fe ATOM AND Fe^{3+} ION.

In antiferromagnetics, negative interaction occurs between equal numbers of magnetic metal ions on two different lattice sites and thus complete cancellation of ionic spin moments is accomplished. However, if there are unequal numbers of magnetic ions on the two lattice sites, antiparallel alignment still occurs, but with a net moment, due to uncompensated spins on the excess ions. This is ferrimagnetism and hence, net moments due to ferrimagnetism can be treated as ferromagnetic moments and form magnetic domains in the similar way. Hence, ferromagnetic properties are exhibited by ferrites.

The saturation magnetization, anisotropy, magnetostriction and curie temperature are intrinsic properties while permeability, hysteresis and other losses, resistivity and dielectric constant are structural properties, which depend on grain size, porosity, impurities etc.

a) Magnetization in Ferrites

The magnetization of solid material as a whole, is the vector sum of magnetizations of each of the domains, the contribution of each being weighed by its fraction of total volume. Thus the net magnetization of the solid ranges from zero, if the weighed vector sum is zero, the net magnetization is maximum, if the solid is a single domain with all the atomic moments aligned in a given direction.

The two sublattice model applied to spinel structure to explain the magnetization of ferrites is successful to a large extent. The inverse spinel magnetization can be deduced as follows. The inverse spinel structure is given by $(Fe^{3+})_A(Fe^{3+}M^{2+})_BO_4^{2-}$. The Fe^{3+}

ions on A-site are coupled with their spins antiparallel to those of Fe^{3+} ions on B-sites. Therefore, the net moment is only due to M^{2+} divalent metal ions. In case of Fe_3O_4, M^{2+} is Fe^{2+}. Hence net moment is 4 Bohr magnetons, as 4 electron spins are unpaired.

For M, a transition element with n electrons in d shell, the magnetic moment per unit formula is n Bohr magnetons or (10-n)Bohr-magnetons depending on d shell which is filled less than half or more than half respectively. The degree of inversion is a fraction x of the divalent metal ions that are on B-site. The arrangement of moments could be written as $[(1-x)M\uparrow xFe\uparrow]_A$ $[(1-x)Fe_B\downarrow xM\downarrow]_B$ and net magnetic moment is given by difference between moments on A and B sites.

b) <u>Anisotropy</u>

The spins apart from the exchange interaction between neighbouring atoms, have interaction with lattice atoms. The spin-lattice interaction is seen if all the spins are completely aligned and direction of alignment is rotated relative to the crystal axis. Preferred directions of magnetic moments are then observed.

The excess work done in magnetizing to saturation a specimen or ferrite in a direction, compared with the easy direction, is called crystal anisotropy energy and it plays an important role in determining the properties like permeability, hysteresis and magnetostriction.[30]

For cubic material, anisotropy energy is given by

$$E_A = K_1(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2) + K_2(\alpha_1^2\alpha_2^2\alpha_3^2)$$

where K_1, K_2 = constants depending on material and temperature.

$\alpha_1, \alpha_2, \alpha_3$ = direction cosines.

It is found that the electronic structure also contributes to the anisotropy constants.[31]

c) Magnetostriction

Ferrites change their length when they are magnetized. This small change in length is called longitudinal magnetostriction which plays an important role in domain geometry and in practical use of transformer materials.

The incremental change may be positive or negative for different materials at saturation. Most of the ferrites exhibit negative incremental change except for few cases like Fe_3O_4.

d) Hysteresis

The characteristic feature of hysteresis is that the demagnetization process lags behind the decreasing magnetic field, and it shows that energy introduced into the solid during magnetization is not completely recovered during the demagnetization so that some energy is lost. The magnitude of energy loss in a complete cycle is proportional to the area enclosed by the loops of hysteresis.

The irreversibility and hysteresis in ferromagnetic material are due to the impedements to the motion of domain walls. These impedements are the inclusions, grain boundaries, dislocations and heterogeneties due to other phases. The magnetization increases slowly by reversible wall motion at low fields and above critical field by irreversible wall motion and at very high field by irreversible rotation. The rotation of domains has been observed by Barkhahusen[32]. The wall energy is maximum at very high fields, leading to irreversible increase in magneto-elastic and magnetost-

atic energies under the action of external magnetic field. When the magnetic field is reduced to zero, the residual magnetisation remains and opposite field is required for the reversal of domains to its original state of zero magnetisation. This opposite field is coercive field. The coercive force can range from 0.1 oersted to 0.3 oersteds. Ferrites with low coercive force are called soft ferrites and with high coercive force are called hard ferrites. The permeability, saturation magnetisation and coercive force and remanant magnetisation help to decide the nature of application of ferrites.

e) Permeability

Permeability depends on the microstructural conditions. This is primarily true during excitation by alternating currents, and becomes extremely important at very high frequencies. Since a.c. excitations produce rapid movement of the magnetic domain walls, and since permeability is related to the ease of movement of these walls, the presence of any imperfections in the ceramic structure will reduce the permeability.

The fewer the grain boundaries, the larger the grains will be, and higher the permeability, as the grain boundaries act as impedements to domain wall motion. Tebble and Craik[33] pointed out that in very high permeability metallic materials, domain walls appear to move across grain boundaries easily. In ferrites the grain boundary is thicker and the same unhindered movement does not occur. Lack of purification, presence of pores and inclusions prevent the attainment of very high permeabilities, which extend upto 100,000 in metals.

When the a.c. field is H and B is induced field, then $\mu = B/H$. For $H = H_o \exp(i\,wt)$, $B = B_o \exp(i\,wt+\delta)$, $\mu = [B_o/H_o](\cos\delta + i\sin\delta) = \mu' + \mu''$ Where μ' gives component of the flux which is in phase and μ'' is 90° out of phase with the applied field.

Energy loss per cycle can be given as $\tan\delta = \mu''/\mu'$. At low fields the hysteresis and eddy current losses are low for ferrites.

f) Electrical Conductivity

By nature, ferrites are semiconductors and at room temperature, resistivity of ferrites ranges from 5×10^{-3} Ohm-cm in case of magnetite to markedly the order of 10^{11} Ohm-cm in case of certain nickel ferrites[34]. The temperature dependence of resistivity obeys the law $\rho = \rho_o \exp(E_g/KT)$

where E_g = activation energy

K = Boltzmann constant

T = absolute temperature.

In linear relationship of $\log\rho$ versus $1/T$, the break occurs at a temperature which corresponds to the observed ferrimagnetic curie temperature and the slope helps in the determination of activation energy[35]. The values range between 0.1 ev and 0.5 ev. The high activation energy[36] is associated with high resistivity at room temperature. To achieve high resistivity, it is common practice to avoid an excess of Fe_2O_3 and oxidising atmosphere during sintering.

g) Dielectric Behaviour

Ferrites show abnormally high dielectric constants and dispersion of dielectric constant in the frequency range from few Hertz to few MHz. Koops[18] investigated the dielectric constant

and resistivity of nickel-zinc ferrites. Moltgen[37] studied the copper-zinc ferrite and Kamiyoshi[38] worked on nickel-cobalt ferrite.

The dispersion in dielectric constant is due to inhomogeneous dielectric structure and the inhomogeneity may be due to picking up of the oxygen by ferrite grain from the atmosphere while cooling. This causes an insulating layer on the grains, while within the grains, small amounts of Fe^{2+} ions continue to be present, rendering the inner regions as conducting grains, separated by layers of lower conductivity.

The high dielectric constant may arise at low frequencies due to oxygen ions having 3B-sites and 1A-site neighbour. The maximum polarizability of oxygen justifies it.

1.4 THEORIES OF FERRIMAGNETISM: Neel's Theory

The knowledge of crystal structure and sign of magnetic interaction in it help us to account for the saturation magnetic moment and magnetic structure of a compound.

Neel[10,39] assumed the ferrimagnetic crystal to be divided into two sublattices, such as tetrahedral A-site and octahedral B-site in spinel structure, with only one type of magnetic ion. The fractions of magnetic ion appeared on A and B sites, so that $\lambda + \mu = 1$. (1) where λ = fraction of magnetic ion on A-site.

μ = fraction of magnetic ion on B-site.

The negative interaction or exchange force between the moments on A and B sites exists, according to him, tending to promote an antiparallel alignment of A and B ions. The magnitude of interaction depends on the distances between these ions and

oxygen ion that links them and also on the angle between the three ions. The interaction is greatest for an angle of 180° and also when the interatomic distances are shortest. The interaction between moments on A and B sites is greatest, the BB interaction is very much stable and most unfavourable occurs in AA interactions.

Assuming the molecular field due to Weiss[25], he gave the molecular fields for ferrite magnetic material by the equations,

$$H_A = H_{AA} + H_{AB} \quad \text{and} \quad H_B = H_{BB} + H_{BA} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

where H_A = Molecular field acting on ions of A-site.

H_{AA} = Molecular field acting on ions of A-sites due to presence of neighbouring A ions.

H_{AB} = Molecular field acting on A due to presence of neighbouring B-sites.

Similarly H_B, H_{BB} and H_{BA} can be defined. The molecular field components may be written as

$$H_{AA} = \gamma_{AA} M_A \qquad H_{BB} = \gamma_{BB} M_B$$

$$H_{AB} = \gamma_{AB} M_B \qquad H_{BA} = \gamma_{BA} M_A \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

where γ's are the appropriate Molecular field co.efficients and - M_A and M_B are magnetic moments of A and B sublattices. $\gamma_{AB} = \gamma_{BA}$ but $\gamma_{AA} \neq \gamma_{BB}$ unless two sublattices are identical. Neel showed that γ_{AB} is less than zero, favouring antiparallel alignments of M_A and M_B for ferrimagnetism.

In the presence of an applied field H_o, the total magnetic - fields acting on each sublattice may be written as

$$H_a = H_o + H_A = H_o + \gamma_{AA} M_A + \gamma_{AB} M_B \qquad \ldots\ldots\ldots\ldots\ldots(4)$$

$$H_b = H_o + H_B = H_o + \gamma_{BB} M_B + \gamma_{BA} M_A \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

using these, he obtained the susceptibility for paramagnetic region above curie temperature and expression for spontaneous magnetisation.

a) Paramagnetic Susceptibility

The paramagnetic susceptibility is given by the equation

$$1/X = T/C + 1/X_o - \xi/T-\theta \qquad \text{.....(6)}$$

where $X = (M_A+M_B)/H_o$ .....(7)

$$1/X_o = \gamma_{AB}\ (2\lambda\mu - \lambda^2\alpha - \mu^2\beta) \qquad \text{.....(8)}$$

$$\theta = \gamma_{AB}\lambda\mu C\ (2+\alpha+\beta) \qquad \text{.....(9)}$$

$$\xi = \gamma_{AB}^2\lambda\mu C\left[\lambda(1+\alpha) - \mu(1+\beta)\right]^2 \qquad \text{.....(10)}$$

$$\alpha = \gamma_{AA}/\gamma_{AB} \qquad \beta = \gamma_{BB}/\gamma_{AB} \qquad \text{.....(11)}$$

The first two terms of equation(6) give the Curie-Weiss form of temperature dependence of 1/X above curie point. The graph of $1/X \rightarrow T$ of equation(6) represents a hyperbola which indicates that above curie point, ferrimagnetic interactions play a little part. The paramagnetic curie point is given by

$$T_p = \gamma_{AB}C/2\left[\lambda\alpha + \mu\beta + \left\{(\lambda\alpha-\mu\beta)^2+4\lambda\mu\right\}^{1/2}\right] \qquad \text{.....(12)}$$

b) Spontaneous Magnetization

Below curie temperature, $M = M_A + M_B$ is measured where M_A and M_B are oppositely directed and spontaneous magnetisation can be written as,

$$M_{Asp} = \lambda Ng\mu_B\ B_J\ (\mu_b gJ\mu_b H_A/KT) \qquad \text{.....(13)}$$

$$M_{Bsp} = \mu Ng\mu_B\ B_J\ (\mu_b gJ\mu_b H_B/KT) \text{ where} \qquad \text{.....(14)}$$

μ_b = Bohr Magneton, B_J = Brillouin Function, g = Lande's factor

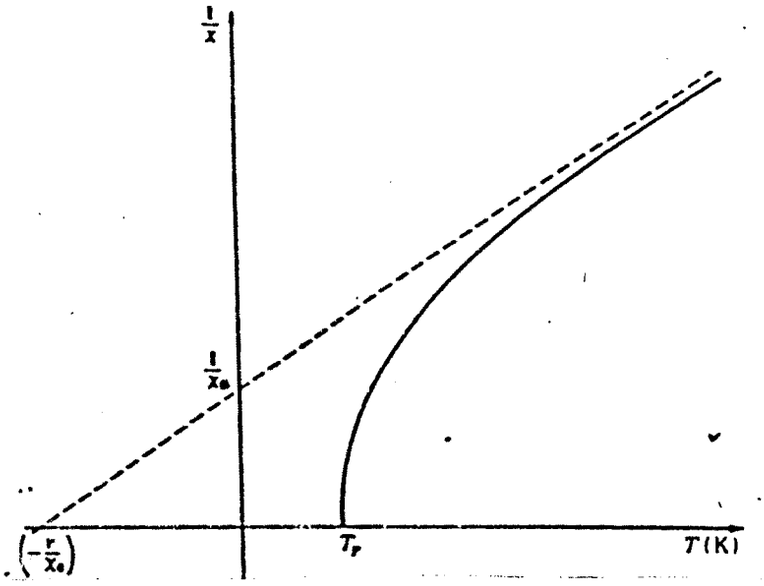


Fig 1.4 a: Predicted susceptibility curve of a ferrimagneto material above the curie point.

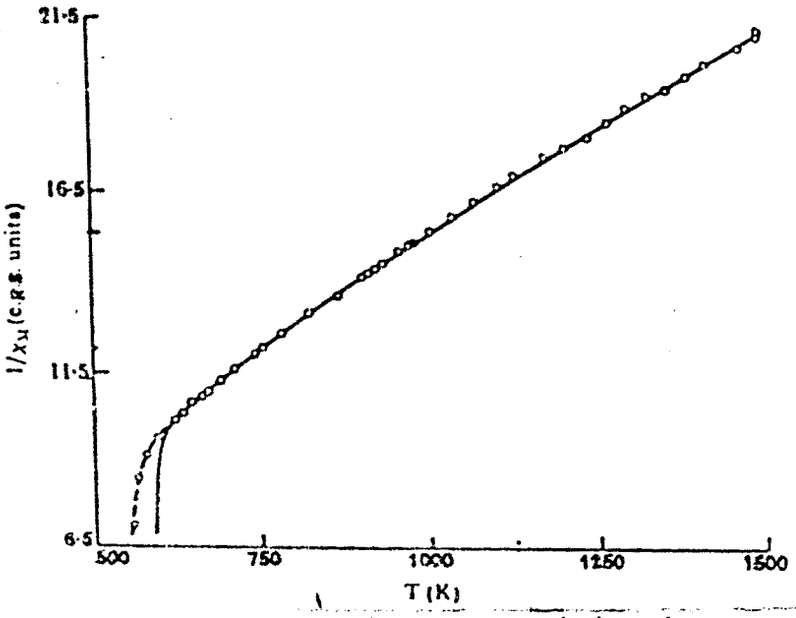
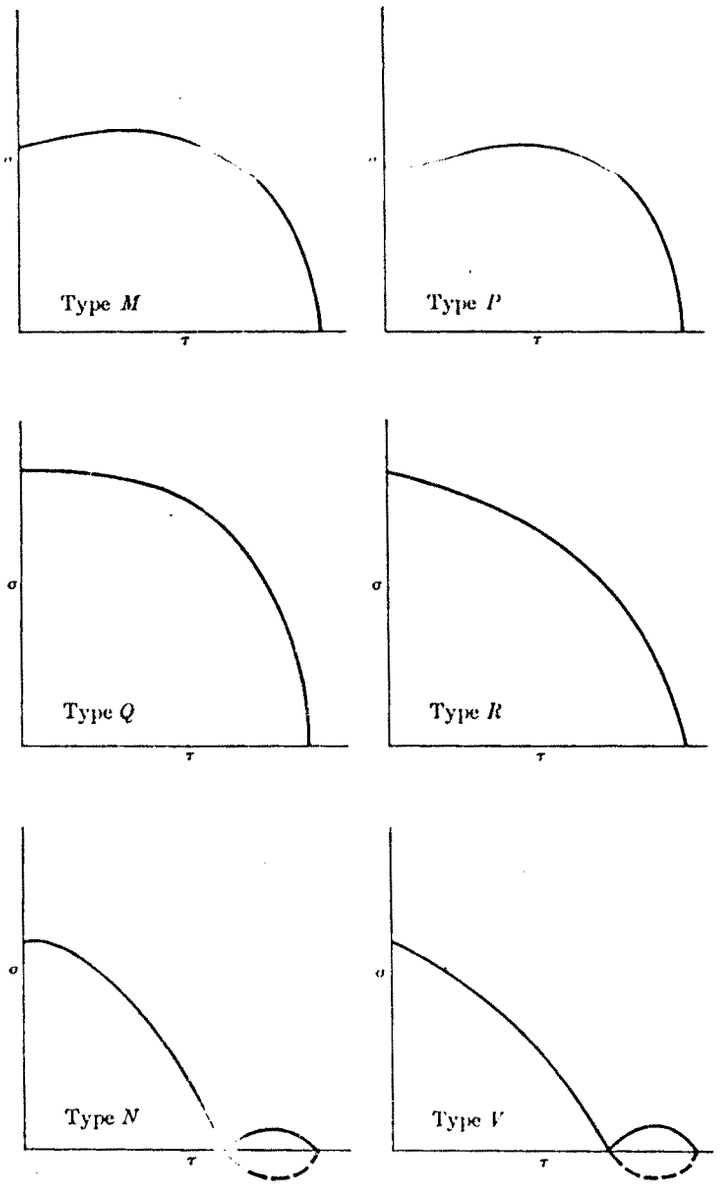


Fig.1.4b: Experimental susceptibility/ temperature curve for gadolinium-iron



Magnetic corresponding states (σ/τ) curves predicted by Néel's theory.

Fig. 1.5

and $M_{sp} = M_{Bsp} - M_{Asp}$ is the total observed spontaneous magnetisation.

The solution of M_{sp} with variation of temperature cannot be solved analytically and graphical methods are to be used.

$\sigma = M_{sp}/M_{sat}$, $\tau = T/T_p$. The (σ, τ) curves are P type, M type, Q type, R type, N type and V type as shown in the figure(1.5)

1.5 YAFET-KITTLE THEORY

For the spinels containing chief metal ions other than Fe, the observed magnetisation is smaller than Neel's model values and to remove the thermodynamic difficulties near 0°k, of third law, Yafet and Kittle proposed triangular arrangement of moment, due to the subdivision of a sublattice as shown in the figure(1.6)

The sub-structures B_1 and B_2 are spontaneously magnetised,with angle ϕ other than 180°, but the resultant B is antiparallel to A. This arrangement results in values of reduced magnetisation of the order of Neel, but free from the thermodynamic difficulties. They also proved that Neel structure is stable if the total number of - sublattices is restricted to six, with a condition on ratio of exchange energies.

1.6 KAPLAN'S SPIRAL STRUCTURE

Kaplan[40] proposed spin configuration of spiral type which he observed in some compounds by neutron-diffraction. This structure-lowers the exchange energy for the compounds he studied. Further Lotgering[41] developed the theory of spiral configurations and applied it to experimental results.

1.7 THE ORIENTATION OF PRESENT WORK

The applications of ferrites in telecommunication and other microwave devices are widely known. The properties of ferrites for

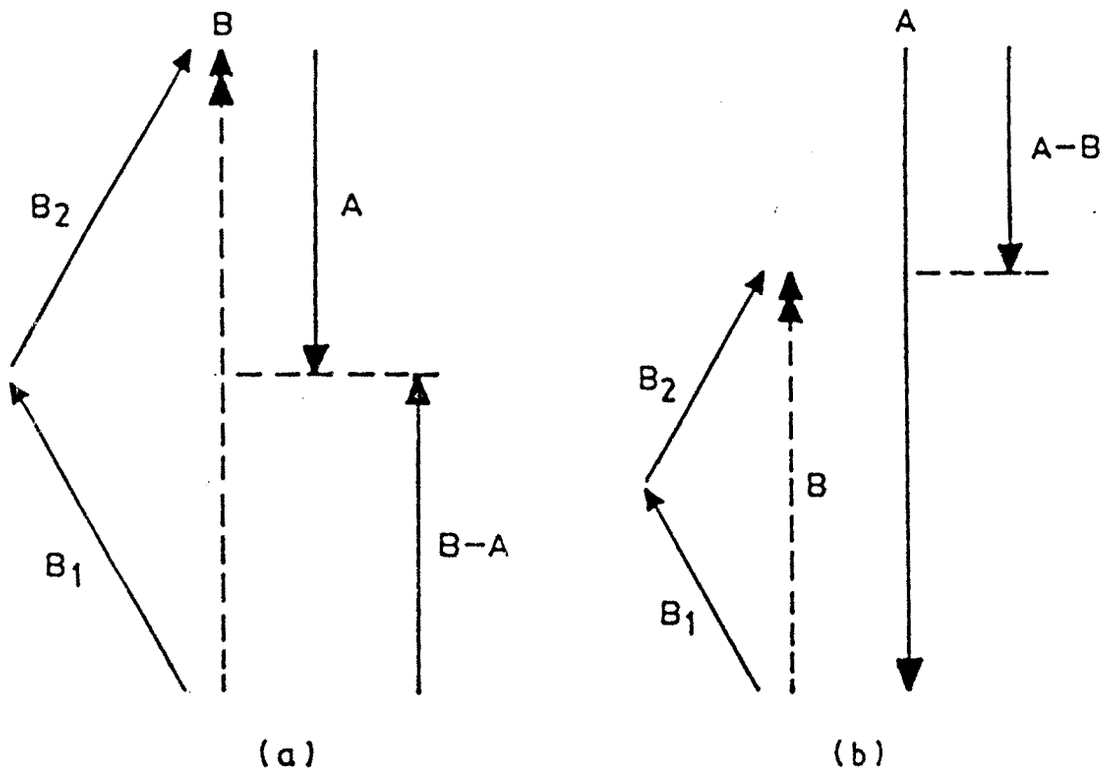


Fig 1.6: TRIANGULAR SPIN CONFIGURATION .

technical applications depend on the combination of intrinsic properties such as saturation magnetization, curie temperature etc. - and the microstructure of ferrites such as porosity, grain size etc. Commercially important ferrites require high purity, chemical homogeneity, fine grain size and high density. However, it is not possible to prepare a ferrite with best combination of properties, and compromises are to be made and process parameters are to be arrived at, to prepare a ferrite, suitable for a particular application.

During the early days of soft ferrites applications were primarily in the communication. When television arrived, they were - used as fly back transformers or as deflection yokes. In ICF(3)1980, Professor Takei in his opening remark pointed out the need of power ferrite materials which can be operated at much higher flux levels than those encountered in telecommunication. The characteristics of power ferrites are(1) They had to possess high saturations B_s(2)They require relatively low core losses at higher flux densities(near the position of maximum permeability) and at fairly high frequencies.To achieve the high saturation, new compositions had to be formulated. For the low losses under the conditions of operations, the microstructure also had to be optimized.

Magnesium-Zinc and Nickel-Zinc ferrites are considered to be the most versatile ferrite families. The amount of these materials used is much larger than the other materials. Recently it has been observed that the tetravalent ion substitution increases resistivity. Titanium, Tin and Germanium substituted in nickel-zinc and other -- mixed ferrites were studied by many investigators[42]. They have stated that these substituents also modulate the microstructure.

Considering the above facts, we have undertaken to synthesize

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nickel-zinc ferrite with tetravalent manganese. This substitution is selected as it is magnetic in nature, in contrast to the non-magnetic tetravalent substitutions. It has been observed however that manganese prevents the formation of Fe^{2+} ions during sintering. In order to understand the role of manganese the following studies have been undertaken.

1) Preparation of $Zn_{.3}Ni_{.7+x}Mn_xFe_{2-2x}O_4$ ferrite series by ceramic method where x varies from 0 to 0.4.

2) X-ray and I.R. studies to confirm the formation of solid solution, to determine the lattice parameter, bond length and impurity phases.

3) Magnetization and permeability to understand the behaviour of manganese in modulating the cation distribution.

4) Scanning electron microscopy to observe the developed microstructure due to substitution and sintering.

5) D.C. and A.C. electric conductivity, to understand the conduction phenomenon.

TABLE-1

CLASSIFICATION OF FERRITES AND THEIR APPLICATIONS

Class of ferrite		Composition	Applications
Crystal structure	Magnetic property		
1. Spinels (Cubic)	Soft ferrites	$M^{2+}Fe_2^{3+}O_4$ where M= Mg, Zn, Mn, Fe, Co, Ni.	Transformer core recording head. antenna rod, loading coil, memory, microwave devices.
	Square loop ferrites	Mg-Mn-Zn-Fe-Li-Ni-Fe.	Computer memory, logic devices.
2. Hexagonal ferrites	Hard ferrites	$M^{2+}Fe_{12}^{3+}O_{19}$	Permanent magnet, relays, loud speaker, small motor generators.
3. Garnets (Cubic)	Microwave ferrites	$R_3Fe_5^{3+}O_{12}$ R= yttrium or rare earth element.	Phase shifter, switches, isolators, bubble memory and tunable devices.
4. Ortho ferrites	Microwave ferrites	$RFe^{3+}O_3$ R = yttrium or rare earth element	Bubble memory.

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