

Chapter - I

A BRIEF SURVEY OF FERRITES

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1.0 Introduction

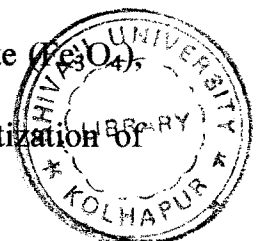
The ferrites belong to the class of magnetic oxides, containing iron oxide as the main constituent. The basic properties of the ferrites are dependent on the kinds of metal atoms, their proportions and geometric arrangement among the interstices of the closed packed cubic array of oxygen atoms in the spinel structure. They are ceramic like materials with high permeability combined with high resistivity [1]. The technical applications of ferrites depend on saturation magnetisation, Curie temperature and grain size etc [2]. Commercially important ferrites require high purity, chemical homogeneity, fine grain size and high density. High density ferrites are of importance due to their technological applications as recording heads, transformer cores, microwave devices etc.

Ferrites now are in everyday use in inductors, wide band transformers, flyback transformers, deflection coils, tunners, recording heads, memory cores, switching cores and inductance adjustment slugs in TV sets and IF transformers in radio sets etc. Ferrites with square loop characteristics of B-H curve, find extensive use in computer memory as core devices.

Today research scientists, technicians and engineers are engaged in the study, manufacture, improvement and application of ferrites.

1.1 Historical background

The first ferrimagnetic material known to man was magnetite (Fe_3O_4) the ferrous ferrite commonly called load stone. Saturation magnetization of



ferrite was firstly studied by Du-Boiss [3]. Pierre Weiss [4] revealed that the variation of magnetization and Curie temperature of ferrite is similar to that of nickel. Hilpert [5] prepared the variety of ferrites with the basic formula MFe_2O_4 , where M denotes divalent metal ion like Fe^{2+} , Ni^{2+} , Zn^{2+} , Mg^{2+} , Cu^{2+} , Cd^{2+} etc. Crystallographic and electromagnetic studies of ferrites were carried out by Kato and Takei [6]. X-ray analysis of ferrites was carried out by Barth and Posjank [7] and found that structure of ferrites to be a spinel type. Snoek [8] and his co-workers prepared number of artificial ferrites and showed that the magnetic losses increased as the function of frequency and that of high permeability was incompatible with low loss performance at high frequencies.

Verwey et al [9] have reported that the conduction in ferrites is mainly due to exchange of electrons between divalent and trivalent iron ions in ferrites. They have further concluded that ferrite with inverse spinel structure were magnetic and those with normal structure behaves as non magnetic.

The fundamental theory of ferrimagnetism was firstly introduced by Neel [10]. According to him resultant magnetic moment in ferrimagnetism is due to spin-spin interaction between the atoms in A sublattice and those in B sublattice. If the spins are equal in magnitude and antiparallel in direction, the resultant spin and magnetic moment is zero and hence sublattice is non-magnetic. However, if the spins are unequal in magnitude and antiparallel in direction they gives rise to some resultant magnetic moment and hence

substance is magnetic. Anderson [11] and Van Vleck [12] developed superexchange theory. Neel's theory fails to explain the exchange interaction between the two sublattices formed by trivalent iron ions on A site and B site. Yafet - Kittle [13] extend Neels theory of ferrimagnetism by postulating the triangular arrangement of three sublattices.

Magnetization of mixed ferrites were studied by Gorter [14] and Guillaud [15]. The dielectric dispersion is explained by Koops [16] and Moltgen [17]. The important correlation between the observed Curie temperature, magnetization and cation distribution was proposed by Gilleo [18].

Cation distribution in mixed ferrites was studied by Smart [19].

1.2 Crystal structure

On the basis of crystal structure, the ferrites are classified into four different crystal types.

1. Spinel structure
2. Garnet structure
3. Hexagonal structure
4. Pervoskite structure.

1.3 Spinel structure

The general chemical formula of spinel structure ferrite is MFe_2O_4 , where M denotes a divalent metal ion like Cu, Cd, Ni, Zn, Mg etc. Fe denotes

a trivalent iron ion. Compound of this type form a crystal of cubic symmetry similar to those of the mineral spinel $MgAl_2O_4$. The structure of mineral spinel was first determined by Bragg [20] and Nishikawa [21]. The unit cell of spinel structure is shown in Fig. 1.1. It consist of 32 oxygen, 16 trivalent iron and 8 divalent metal ions. The 32 oxygen ion forms face centered cubic lattice. There are 96 interstitial sites in the unit cell, 64 of which are tetrahedral and 32 octahedral sites. Each cation on tetrahedral site is surrounded by four oxygen ions and each cation on octahedral site is surrounded by six oxygen ions.

The four oxygen ions and cation on A site form a tetrahedron as shown in Fig. 1.2a, whereas the six oxygen ions and the cation on B - site form a octahedral as shown in figure 1.2.b.

In a unit cell, only eight tetrahedral sites and sixteen octahedral sites are occupied.

Wyckoff [22] gave the atomic positions for the cubic spinel with tetrahedral anions, octahedral cations and oxygen ions as

$$\text{Anion } 32b \left[\begin{array}{l} (u, u, u); (u, \bar{u}, \bar{u}); (\bar{u}, u, \bar{u}); (\bar{u}, \bar{u}, u) \\ (1/4-u, 1/4-u, 1/4-u) (1/4-u, u+1/4, u+1/4) \\ (u+1/4, 1/4-u, u+1/4) (u+1/4, u+1/4, 1/4-u) \end{array} \right.$$

$$\text{Cation } 16 C \quad [(5/8, 5/8, 5/8); (5/8, 7/8, 7/8); (7/8, 5/8, 7/8); (7/8, 7/8, 5/8)]$$

$$\text{cation } 8 f \quad [(0,0,0) (1/4, 1/4, 1/4)]$$

With the translations, for a face centered lattice,

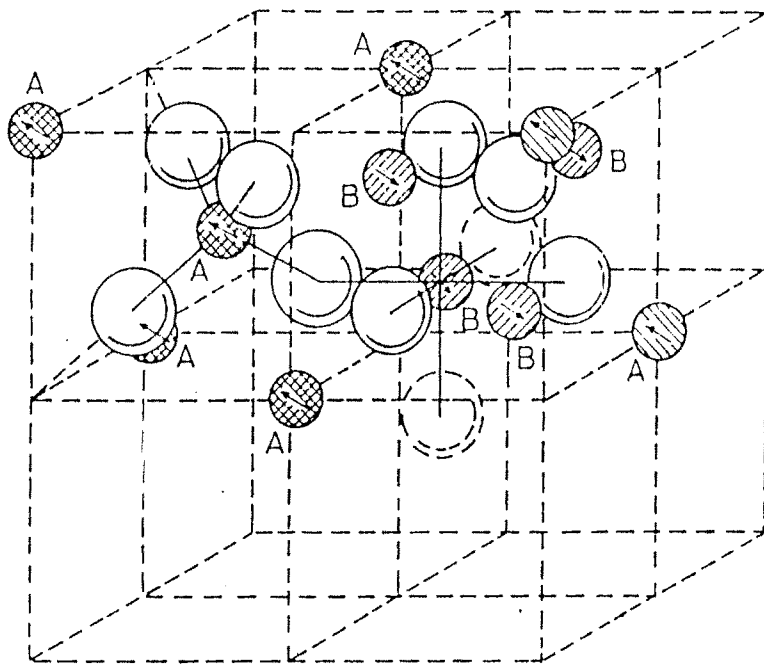


Fig. 1.1 - CRYSTAL STRUCTURE OF A SPINEL FERRITE .

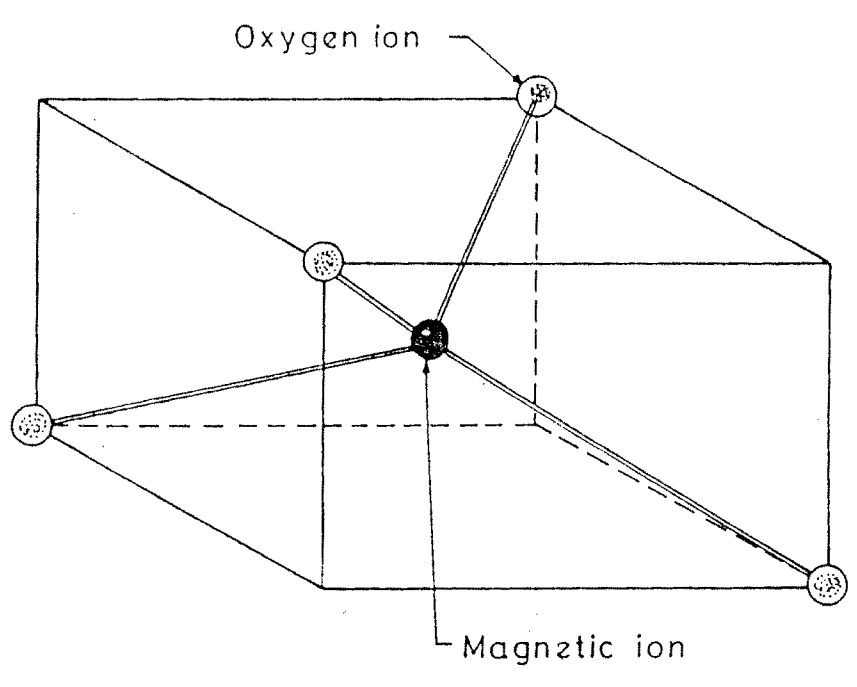


Fig.1-2(a) - THE MAGNETIC ION OCCUPIES A "TETRAHEDRAL LATTICE SITE" WHERE IT IS SURROUNDED BY FOUR NEAR NEIGHBOUR OXYGEN IONS.

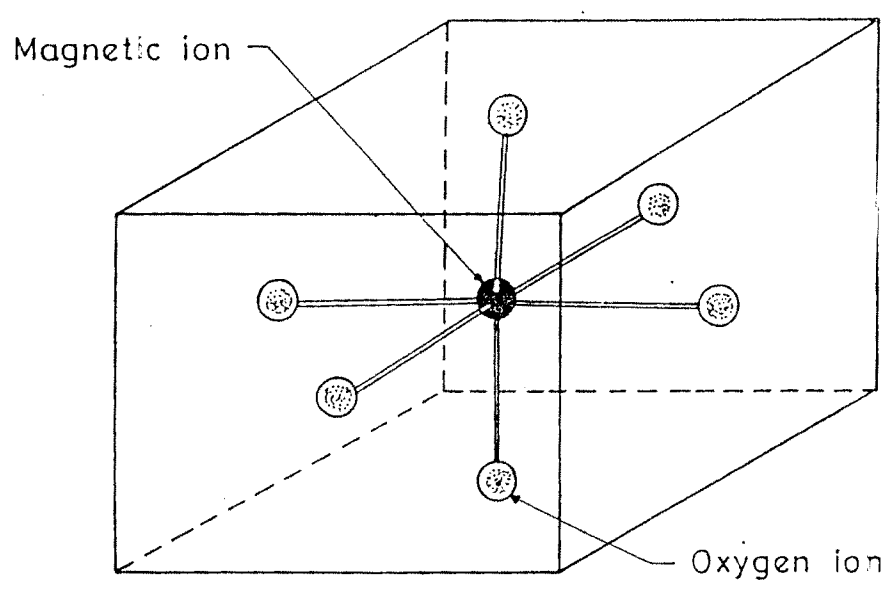


Fig.1-2(b) - THE MAGNETIC ION IS SAID TO OCCUPY AN "OCTAHEDRAL LATTICE SITE" WHERE IT IS SURROUNDED BY SIX NEAR NEIGHBOUR OXYGEN IONS.

(0,0,0) (0, 1/2, 1/2) (1/2, 0, 1/2) (1/2, 1/2, 0)

When oxygen parameter $u = 3/8$, packing of the ions within the lattice is perfect and cation positions listed above refer to this ideal spinel arrangement. Crystallographic data for some spinel ferrites [23] shows that the values of u do not differ markedly from the ideal value of u .

1.4 Classification of spinel ferrites

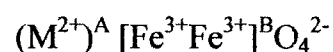
The distribution of cations on A site and B sites is dominated by relative site preference energies of the respective metal ions present in the ferrites. Goodenough and Loab [24] pointed out the significance of site preference energies. According to which, the spinel ferrites are classified into three groups as

- a) Normal spinel ferrites
- b) Inverse spinel ferrites
- c) Random spinel ferrites

a) Normal spinel ferrites

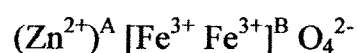
In normal spinel ferrites, all the divalent metal ions occupy the tetrahedral (A) sites and all the trivalent iron ions occupy octahedral (B) sites.

The cation distribution of normal ferrites is represented as,



e.g. Zinc ferrite and Cadmium ferrite

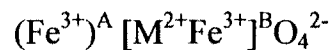
The cation distribution of zinc ferrite is



b) Inverse spinel ferrites

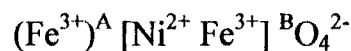
In inverse spinel ferrites, all the divalent metal ions occupy octahedral sites and trivalent iron ions are equally distributed among the tetrahedral and octahedral sites.

The cation distribution of inverse spinel ferrite is represented as



e.g. Nickel ferrite and Ferrous ferrite

The cation distribution of nickel ferrite is



c) Random spinel ferrites

In random spinel ferrites, all the divalent metal ions and trivalent iron ions are randomly distributed over the tetrahedral and octahedral sites depending on their physico-chemical conditions of preparations.

The general formula for cation distribution of random spinel ferrites is represented as



where x = coefficient of normality

$1-x$ - coefficient of inversion

e.g. copper ferrite and Magnesium ferrite

The cation distribution of copper ferrite is



when $x=0$, we get CuFe_2O_4 as inverse ferrite

$x=1$, we get normal spinel ferrite

$0 < x < 1$, we get random spinel ferrite

1.5 Theories of ferrimagnetism

a. Neel's theory of ferrimagnetism

Neel [25] assumed that,

i) ferrimagnetic crystal lattice could be divided into two sublattices such as tetrahedral (A) site and octahedral (B) sites

ii) Existence of only one type of magnetic ion, of which fraction ' λ ' appeared on A site and fraction u on B site so that

$$\lambda + u = 1. \quad \dots 1.1$$

iii) The A-B and B-A interactions are identical and predominate over A-A and B-B interactions.

According to Weiss molecular field theory, the total magnetic field acting on an ion is given by

$$H = H_0 + H_m \quad \dots 1.2$$

where H_0 - is the external applied field and H_m - is the internal field due to interaction with the other ions within in the material.

For ferrimagnetic material above equation can be written as

$$H_A = H_{AA} + H_{AB} \quad \dots 1.3$$

$$H_B = H_{BB} + H_{BA} \quad \dots 1.4$$

where H_A - molecular field acting on A ion

H_{AA} - molecular field acting on A ion due to neighbouring A ions.

H_{AB} - molecular field acting on A ion due to neighbouring B ions.

Similar definitions hold for the molecular field H_B acting on a B ion. The molecular field components may be written as

$$H_{AA} = \gamma_{AA}M_A \quad H_{AB} = \gamma_{AB}M_B \quad \dots 1.5$$

$$H_{BB} = \gamma_{AB}M_B \quad H_{BA} = \gamma_{BA}M_A \quad \dots 1.6$$

where γ_{AA} , γ_{AB} , γ_{BB} and γ_{BA} are the molecular field coefficients. M_A and M_B be the magnetic moment on A and B sites respectively.

It may be shown that

$$\gamma_{AB} = \gamma_{BA} \quad \text{but } \gamma_{AA} \neq \gamma_{BB}$$

Neel showed that $\gamma_{AB} < 0$, favouring antiparallel arrangement of M_A and M_B giving rise to ferrimagnetism. In the presence of an external field H_0 , the total magnetic fields on each site may be written as

$$\begin{aligned} H_a &= H_0 + H_A \\ &= H_0 + \gamma_{AA}M_A + \gamma_{AB}M_B \quad \dots 1.7 \end{aligned}$$

$$\begin{aligned} H_b &= H_0 + H_B \\ &= H_0 + \gamma_{BB}M_B + \gamma_{BA}M_A \quad \dots 1.8 \end{aligned}$$

Paramagnetic region

Ferrimagnetic substances at high temperature behaves like paramagnetic substances

In paramagnetic region, the magnetization is given by

$$M = NgJ\mu_B B_j(x)$$



where $B_J(x)$ is the Brillouin function and is given by

$$B_J(x) = \frac{2J+1}{2J} \coth h \left[\frac{(2J+1)x}{2J} - \frac{1}{2J} \coth(x/2J) \right]$$

where $x = (gJ\mu_B H) / KT$

K - Boltzmann constant

T - Absolute temperature

when $x \ll 1$, $B_J(x) = (J+1 / 3J) x$ 1.10

Thus the magnetization is given by

$$M = \frac{Ng^2\mu_B^2 J(J+1) H}{3KT} \quad \dots 1.11$$

From this, the susceptibility χ will be

$$\chi = M/H$$

$$\chi = \frac{Ng^2\mu_B^2 J(J+1)}{3KT} \quad \dots 1.12$$

$$\chi = C/T, \text{ the Curie law}$$

If the magnetic field in the Curie law is taken to be $H+H_m$. Then we have

$$\frac{M}{H+H_m} = \frac{M}{H + vM} = \frac{C}{T}$$

which leads to the Curie Weiss law

$$\chi = C / (T - T_C)$$

Neel applied similar method to each sublattice of the ferrimagnetic material.

$$M_A = (\lambda_C/T) H_a \quad \text{and} \quad M_B = (\mu_C/T) H_b \quad \dots 1.13$$

where λ_c and μ_c be the volumes occupied by the magnetic ions in each sublattice

$$\text{Writing } \chi = M/H_o \text{ and } M = M_A + M_B$$

After necessary simplification, Neel rewrites the equation of susceptibility such as

$$\frac{1}{\chi} = \frac{T^2 - C v_{AB} (\lambda_\alpha + \mu_\beta) T + c^2 \lambda \mu v_{AB}^2 (\alpha\beta - 1)}{C [T - \lambda \mu_c v_{AB} (2 + \alpha + \beta)]} \quad \dots 1.14$$

Rewrite above equation as

$$\frac{1}{\chi} = \frac{T}{C} + \frac{1}{\chi_o} - \frac{\xi}{T - \theta} \quad \dots 1.15$$

where $1/\chi_o = v_{AB} [2\lambda\mu - \lambda^2\alpha - \mu^2\beta]$

$$\theta = v_{AB} \lambda \mu C [2 + \alpha + \beta]$$

$$\xi = v_{AB}^2 \lambda \mu C [\lambda(1 + \alpha) - \mu(1 + \beta)]^2$$

The graphical representation of equation (1.15) is a hyperbola as shown in Fig.1.3, which cuts the temperature axis at C/χ_o .

Its asymptote ($T \rightarrow \infty$) is given by

$$1/\chi = T/C + 1/\chi_o \quad \dots 1.16$$

The paramagnetic Curie point T_p is found by equating $1/\chi$ to zero. This yields,

$$T_p = (v_{AB}/2) C \{(\lambda\alpha + \mu\beta) + [(\lambda\alpha + \mu\beta)^2 + 4\lambda\mu]^{1/2}\} \quad \dots 1.17$$

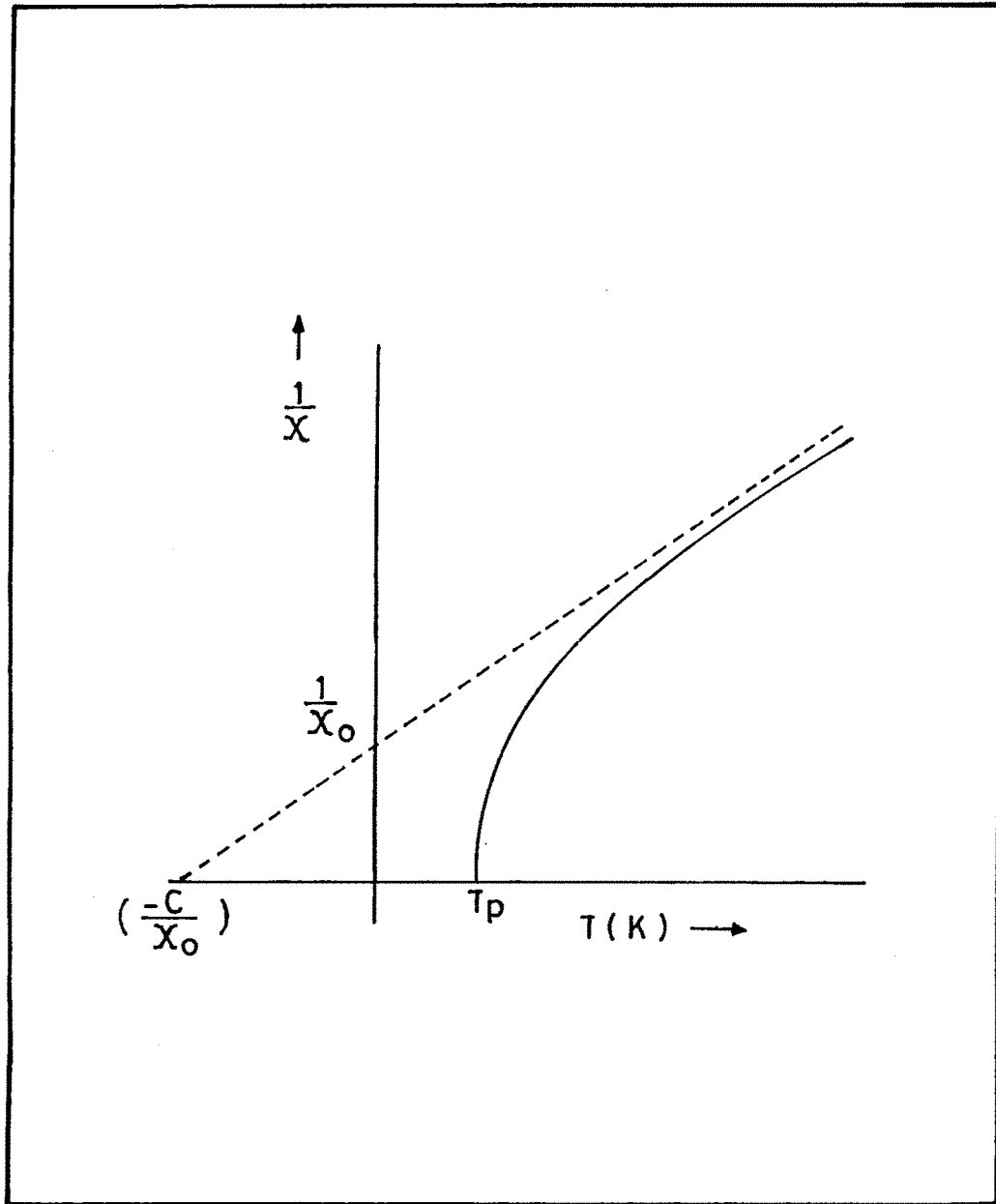


FIG. 1-3- PREDICTED SUSCEPTIBILITY CURVE OF A FERRIMAGNETIC MATERIAL ABOVE CURIE POINT.

Another form of temperature is also obtained namely,

$$T'_p = (v_{AB}/2)C \{(\lambda\alpha + \mu\beta) - [(\lambda\alpha - \mu\beta)^2 + 4\lambda\mu]^{1/2}\} \quad \dots 1.18$$

Where T_p is the Curie temperature of assembly when M_A and M_B antiparallel and T'_p is the Curie temperature of assembly when M_A and M_B are parallel.

Spontaneous magnetization

The spontaneous magnetization in a ferrimagnetic material is given by

$$M_{sp} = NJg\mu_B B_s(x) \quad \dots 1.19$$

where $x = (Jg\mu_B/KT) H_A$

With the use of form of equation (1.19), the spontaneous magnetization in the case of ferrimagnetic material below the Curie temperature for both A and B sublattices can be written as

$$M_{ASP} = \lambda NgJBs(gJ\mu_B H_A) /KT \quad \dots 1.20$$

$$M_{BSP} = \mu NgJ\mu_B Bs(gJ\mu_B H_B) /KT \quad \dots 1.21$$

or

$$M_{ASP} / M_{Asat} = Bs(gJ\mu_B H_A) /KT \quad \dots 1.22$$

$$M_{SP} = M_{bsat} = Bs(gJ\mu_B H_B) /KT \quad \dots 1.23$$

where $M_{Asat} = \lambda NgJ\mu_B$ - saturation magnetization of sublattice A

$$M_{Bsat} = \mu NgJ\mu_B \quad \text{- saturation magnetization of sublattice B}$$

The observed spontaneous magnetization is given by

$$M_{sp} = M_{BSP} - M_{ASP} \quad \dots 1.24$$

The graph of M_{sp} versus T are of different vertices as shown in Fig. 1.4. They provide information about spontaneous magnetization and exchange energy at different temperatures. The above theory is supported by experimental curves of Neel [25], Gorter [26] and Smart [27].

1.6.B Yafet-Kittel theory

The Neel theory fails to explain the reduction in magnetization with antiparallel spin arrangement as well as to explain the behaviour of mixed ferrites.

Yafet and Kittel [13] suggests modification in Neels theory as it is observed that for the spinels containing metal ions other than iron, the observed magnetization value is smaller than that calculated by Neel's model for spin arrangement. They showed that for certain ratios of exchange interaction in spinels, there can exists three sublattices with triangular spin arrangement and has lower energy than the two sublattice model. In such a case, there exists a possibility of negative interaction within the sublattice itself giving rise to B_1 and B_2 sub lattices, which are neither exactly antiparallel to each other nor to sublattice A. Instead, they align at some angle other than at 180° . Thus there is a resultant magnetization of A lattice as shown in figure 1.5. These triangular arrangements within the lattice results in values of reduced magnetization of the same order and magnitude as those stated by Neel's model.

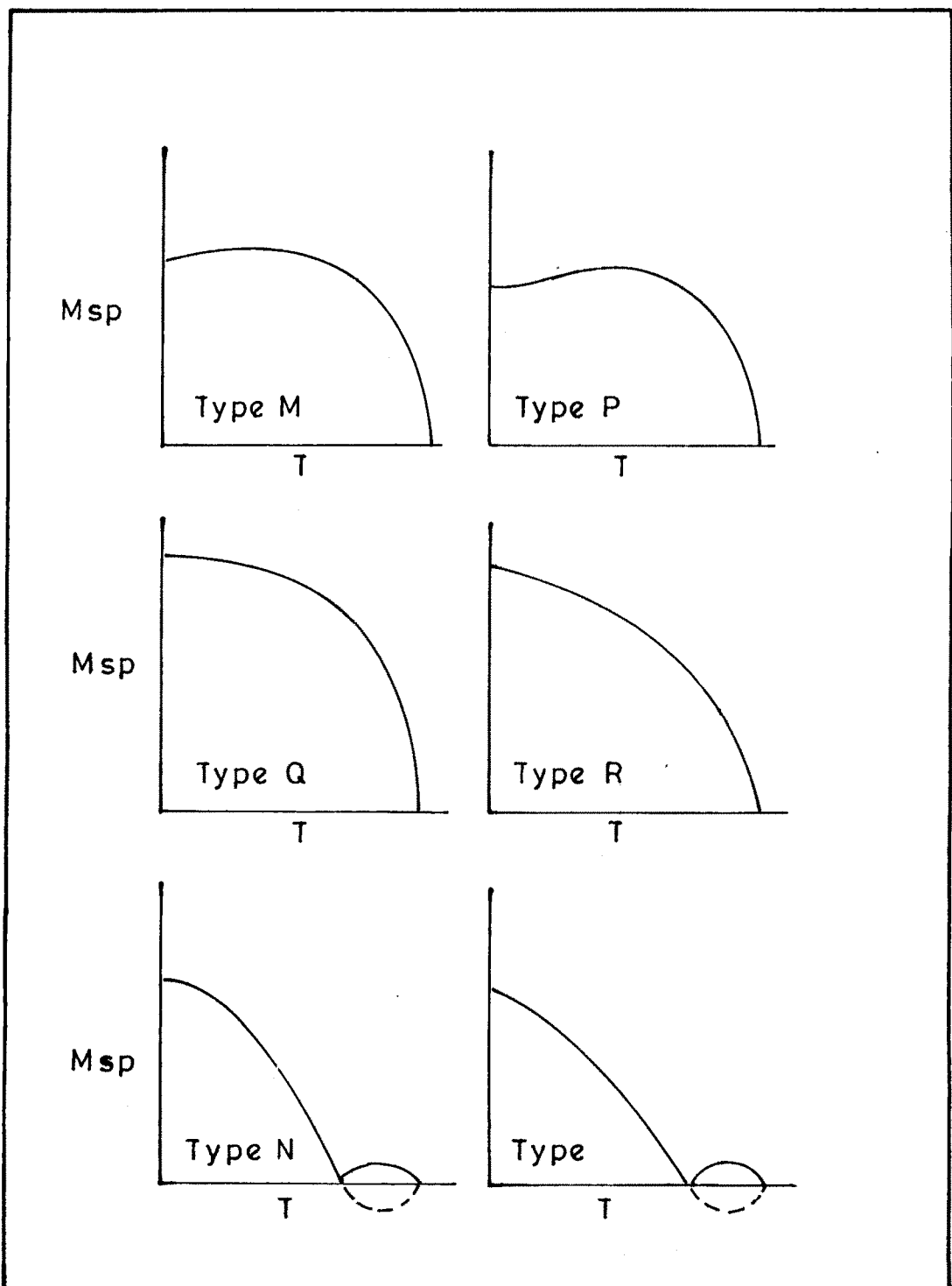


FIG. 1·4 - M_{sp} VS T CURVES FOR FERRIMAGNETIC SUBSTANCES PREDICTED BY NEEL'S THEORY.

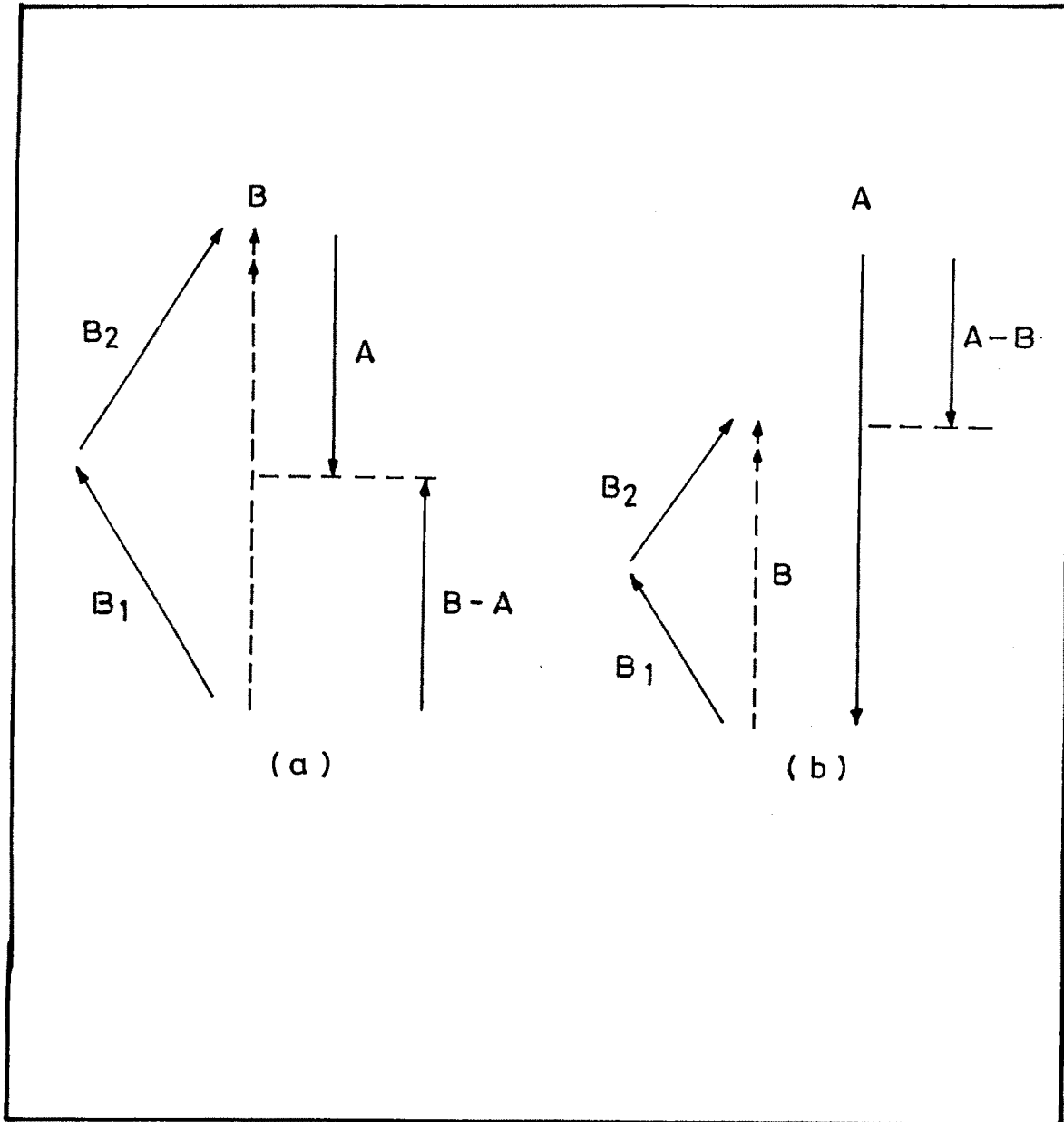


FIG.1-5 - TRIANGULAR SPIN CONFIGURATION .

1.7 Magnetic properties of ferrites

The details of magnetic behaviour of ferrites were studied by Neel [10]. Magnetic materials exhibit different kinds of magnetic ordering depending on the spin orientation. Ferrimagnetic materials with the movement of ions orientated in the same direction give rise to high value of magnetic moments, while antiferromagnetic substances with spins aligned in an anti parallel fashion, show a resultant magnetic moment of zero value. Ferrites exhibit magnetic properties like hysteresis, susceptibility, anisotropy, magnetostriction, permeability, Curie temperature etc. The parameters like saturation magnetization, remanence ratio and coercive force are obtained from hysteresis studies. Hysteresis properties depend on chemical composition, sintering temperature, cation distribution and final fabrication. Ferrites with low coercive force are called "soft ferrites" and those with high coercive force are called "hard ferrites".

Kakatkar et al [28] studied the x-ray and bulk magnetic properties of Al^{3+} substituted Ni-Zn ferrites and observed that the coercive force increases with increase in Al^{3+} content. They have attributed it to decrease of anisotropy constant (K_1) on addition of Al^{3+} . V.R.K. Murthy et al [29] have reported magnetic properties of lithium substituted ferrites. They have observed decrease in coercive force on addition of zinc. The saturation magnetization of Ni-Zn ferrites with respect to zinc content has been determined by various

workers [30-34]. To explain this behavior various theories have been proposed based on

- i) the occupation of octahedral site by Zn^{2+} ions.
- ii) The statistical consideration taking into account of random incomplete linkage A-O-B, which results when non magnetic ion replaces magnetic ions in the structure
- iii) the occurrence of non -collinear magnetic structure [24]. The occurrence of non-collinear spin arrangements in the Ni-Zn system is suggested by Yafet and Kittel [13]. P. Zaveri et al [35] have carried out studies on the magnetic properties of copper substituted zinc ferrites and observed that both magnetization and Curie temperature decreases with the addition of Zinc. Variation in Curie temperature in Ni-Zn ferrites has been studied by Srinivasan et al [36] and Moye et al [37].

AC susceptibility studies have been done by number of workers [38-42] for Ni-Zn and Ni-Zn substituted ferrites to explore the Curie temperature and domain structure of the particles in the polycrystalline ferrite materials. Murthy et al [43] have shown the existence of MD, SD and SP domains in ferrimagnetic materials by studying variation of χ_{ac} with temperature.

Studies on thermal and frequency variation of initial permeability of ferrites gives information about domain nature [44], Curie temperature [45] and factors contributing to permeability changes [29]. Many workers have reported permeability variation as a function of Zn^{2+} concentration in Ni-Zn

ferrites and observed decrease of anisotropy field and increase of permeability [46-48]. M. Igarashi et al [49] studied effect of grain size on permeability and showed that permeability is directly proportional to cube root of grain size for Ni-Zn ferrites. Murthy and Rao [50] studied magnetostriction of Ni-Zn and Co-Zn ferrites.

1.8 Electrical properties of ferrites

Ferrites exhibits interesting electrical properties such as electrical conductivity, thermoelectric power, hall effect, electrical switching etc., that could be used in electronic devices. The electrical properties of the ferrites are dependent on the method of preparation, stiochiomerty, porosity, sintering temperature, sintering atmosphere etc. In ferrites the temperature dependence of mobility affects the conductivity and the carrier concentration is almost unaffected by temperature variation. Van Uitert [51] studied the conductivity of Nickel and nickel zinc ferrites as a function of firing temperature and atmosphere. Hall effect and thermoelectric properties are widely used in the interpretation of conduction mechanism. Thermoelectric power study gives information about the type of conduction in ferrites, whether it is p-type or n-type. Ram Narayana et al [52] studied the dielectric properties of iron excess and an iron deficient compositions of Ni-Zn ferrites with varying contents of V_2O_5 . Rustamov et al [53] have investigated the composition and temperature dependence of electrical conductivity, thermo emf and hall effect of nickel-zinc ferrites. Murthy and Sobhanadri [54] have investigated the dc

conductivity and seebeck coefficient of some nickel -zinc ferrites as a function of temperature from room temperature to 300 °C. Sinha and Pran Kishan [55] reported the dc resistivity and seebeck voltage of a sample of substituted nickel ferrite. The temperature dependence of electrical conductivity and seebeck coefficient was carried out by Secrist and Truk [56] on high density iron deficient nickel- zinc ferrites. Irvine and West [57] have reported the ac electrical and magnetic measurements of Ni-Zn ferrites. Bhatia and Joshi [58] studied the electrical conductivity and thermoelectric power of undoped and zinc doped magnetite. Koops [16] has studied the dispersion of resistivity of Ni-Zn ferrites. Yamsahiro [59] reported the electrical switching phenomenon in slow cooled and quenched copper ferrites. Vasamberkar et al [60] studied the electrical switching in Co-Cd ferrites system.

1.8 Applications of ferrites

Ferrites have number of applications in the fields such as telecommunications, microwave devices, absorbers, magnetic recording media, permanent magnet, computers, radio and television etc. The applications of ferrites are classified on the basis of their properties like low loss and high stability, high permeability and high saturation magnetic flux density [61]. Some of the ferrite applications are in antenna rods, carrier telephony, computer circuitry, logic devices, relays, loud speakers, phase shifter, switches, isolators, circulators, bubble memory, delay line cores, electromagnetic cores etc. [1]. In the fields of electronics, the ferrites are

finding interesting applications in the manufacture of microwave integrated circuits [62]. Various types of multilayer ferrite chip inductors are used in television receivers, video equipment, headphone stereos, personal computers, automobile parts, hard disk drive systems, cordless telephones etc. [63].

The new attractive applications of ferrites are in the magnetic parts of the direct current driving motor in electrically powered automobiles [61]. Recently developed wave absorbers are used in anechoic chamber, countermeasure for television ghosting, suppressing unnecessary echo in ship's radar signals, leakage wave from electric devices [64].

Vaingankar et al; [65] and Kwon et al [66] have studied the applications of ferrites as humidity sensors and thermojunction. Currently ferrites are applicable in i) transformation of solar energy to hydrogen energy using ferrites as catalysts [67]. ii) Heat decomposition of CO_2 using a mixture of carbon and ferrite powders heated at 300- 700 °C [68]. iii) Heat decomposition of NO_x gas using spinel ferrite [69].

Applications and properties of Ni-Zn ferrites are summarised in Table 1.1 [1].

Table 1.1*Applications and properties of Ni-Zn ferrites [1]*

| Applications | Properties |
|------------------------|---|
| IF transformers | High μ Q shapes |
| Antenna cores | High rod μ Q shapes |
| Wide band transformer | High μ , low losses, assembled core structures |
| Adjustable inductors | High μ shapes |
| Tuners | Various mechanical structures μ variation in dc field |
| Miniature inductors | Cup shapes |
| Miniature transformers | High μ cup shapes |
| Suppression beads | High loss above critical frequency |
| Recording heads | Mechanical rigidity, low loss. |

1.9 Orientation work

For various applications of ferrites, the most important properties are saturation magnetization, Curie temperature, permeability, resistivity and losses. These properties required for any application can be controlled by varying the composition by introducing additives or by varying the preparation technique [70]. Nickel -zinc ferrites are widely used in high frequency and pulsed field applications due to their small coercivity, unique combination of relatively high flux swing and high electrical resistivity [71].

High density Ni-Zn and Mn-Zn ferrites are of importance due to their application in read write heads used in high speed digital tapes or discs [2]. Ni²⁺ ions have strong preference to B sites, whereas Zn²⁺ ions occupy A sites. With addition of Zinc upto 40%, saturation magnetization (Ms) increases and Curie temperature decreases [72]. The electrical and magnetic properties of ferrites prepared by ceramic method have been studied by many workers [72-77, 38-42]. The ceramic method has several disadvantages. This method requires high sintering temperature, which may cause evaporation of certain elements and changes the desired Stiochiometry. High density nickel-zinc ferrites prepared by ceramic method require high sintering temperature. Because of high sintering temperature, zinc in nickel -zinc ferrites evaporates and results in formation of Fe²⁺ ions, thereby increasing the electron hopping and reducing the resistivity [78]. Another disadvantages of this method is that, the particle size gets increased which causes the increase in porosity. This affects the bulk magnetic properties [2].

The chemical method overcomes all these drawbacks in the preparation of ferrites. Therefore it was decided to prepare Ni-Zn ferrites by oxalate precipitation method. The advantage of this method is the mixing of the metal ions on a molecular scale giving homogenous mixtures. By this method high density ferrites can be prepared [79].

It was proposed to prepare and study the electrical and magnetic properties of Ni-Zn ferrites in the following stages.

1. Preparation of sample of $\text{Ni}_{1-x}\text{Zn}_x\text{Fe}_2\text{O}_4$ series ($x= 0, 0.20, 0.40, 0.60, 0.80$ and 1.00)
2. Characterization by x-ray and far IR techniques
3. Study of DC electrical resistivity
4. Study of Hysteresis, Susceptibility and Curie temperature

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