CHAPTER - I

CHAPTER - I
INTRODUCTION OF FERRITES

1.1 INTRODUCTION

The field of ferrites has become the subject of tremendous interest to physicists, chemists and the engineers. Because of their potential applications as electronic and magnetic ceramics. The technological importance of magnetic materials can be visualized from the vast spectrum of their applications in high frequency and pulse transformer, inductor, deflection coil and other applications. Ferrites with square loop characters of characteristics find extensive use in computer memory devices.

The first known magnetic material to the man was the natural spinel magnetite or the ferrous ferrite (Fe_3O_4). Its saturation magnetization was measured by Du-Bois (1). The laboratory synthesis of spinal ferrites was done by Hilpert (2) in 1909. The preparation of ferrites by solid state reaction has been explained by Hedvall (3), Tammann (4) and Jonder (5). The strong foundation for improved properties of ferrites at high frequencies was laid down by Snoek (6) by establishing the importance of accurate oxygen content and homogenous product. Kato and Takai (7), Forestier (8), Barth and Posjank (9) studied the ferrites and reported

the structure of ferrite to be spinel type. Verway et.al. (10) proposed a model for conduction mechanism in ferrites called as hopping mechanism. He reported the investigations on the ordering of the divalent and trivalent iron ions in magnetite and suggested that the existence of neighbouring Fe^{2+} and Fe^{3+} ions can give rise to higher conductivity because of an easy exchange of electrons between them. He proved that inverse spinels are ferrimagnetic and normal spinels are non-magnetic (9). Neel (11) introduced the concept of two sublattice model to explain the magnetization. Anderson (12) and Van Vleck (13) developed the superexchange theory. Yafet and Kittle (14) extended the superexchange theory by postulating the triangular spin arrangement of the three sublattices.

During the last four decades, substantial amount of efforts are being spent to prepare the ferrite materials to fulfil the qualitative as well as quantitative demand in electronic and telecommunication industry. The most recent reason for the upsurge in ferrite interest has been the development of new, small, efficient switch mode power supplies for use in computer, microprocessor, communication and entertainment applications.

1.2 STRUCTURE OF FERRITES

Ferrites are classified in three different crystal types.

A) Spinel Structure

Spinel have general formula $M^{2+}Fe^{3+}{}_2\ O_4{}^{2-}$ where M^{2+} is divalent metal ion. In this structure there are 8 tetrahedral and 16 octahedral sites for the cations. Tetrahedral and octahedral sites are surrounded by four and six oxygen ions respectively.

B) Garnet Structure

With the general formula $A^{3+}Fe^{3+}{}_5O^{2-}{}_{12}$ where A^{3+} is rare earth element or yttrium ion, garnets are used in microwave and bubble domain devices.

C) Hexagonal Structure

With the general formula $A^{2+}Fe^{3+}{}_{12}O^{2-}{}_{19}$ where A^{2+} is Barrium, these are used as permanent magnet materials.

1.3 SPINEL STRUCTURE

Spinel is originally the naturally occurring mineral, $MgAl_2O_4$. The spinel has a cubic face centered crystal structural with space group $Fd_3mO^7{}_h$ as shown in (Fig. 1.1). The unit cell contains 8 formula units of MFe_2O_4. Hence the unit cell formula is $M^{2+}{}_8Fe^{3+}{}_{16}O^{2-}{}_{32}$. The 32 oxygen ions form two kinds of interstitial sites- tetrahedral or A sites (four oxygen neighbours) and octahedral or B sites (six oxygen neighbours) per unit cell. In all 64 being

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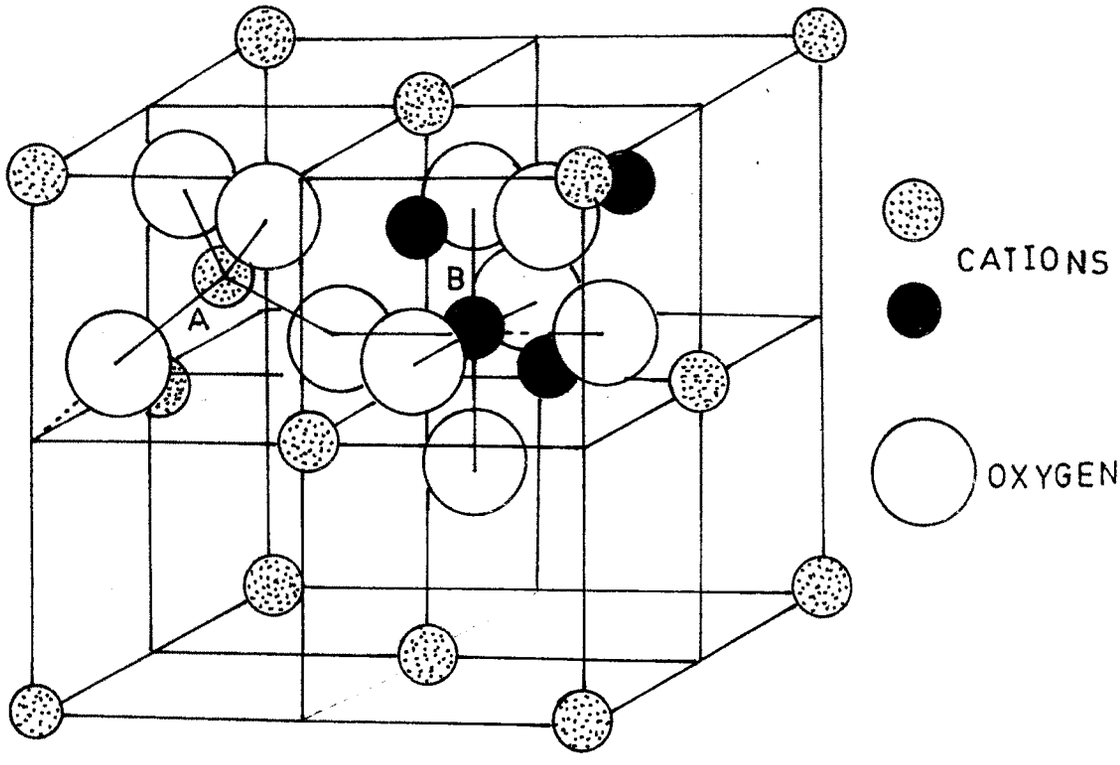
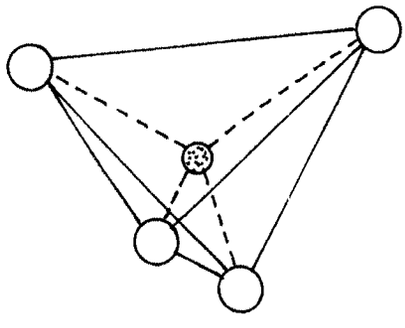


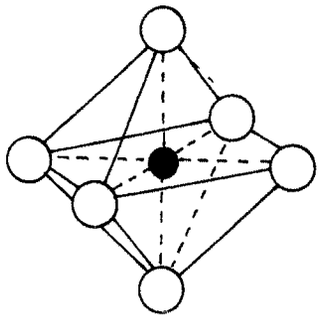
(a)

THE SPINEL STRUCTURE (SCHEMATIC)



(b)

TETRAHEDRAL SITE



(c)

OCTAHEDRAL SITE

FIG 1-1

tetrahedral and 32 octahedral. Out of these 8 tetrahedral and 16 octahedral sites are occupied by the cations.

The interstices available in an ideal close packed structure of oxygen anions, can incorporate in tetrahedral sites the metal ions with a radius $r_{tetra} < 0.30A^0$ and in octahedral sites ions with radius $r_{oct} < 0.55A^0$. In order to accommodate cations such as Co, Cu, Mg, Mn, Ni and Zn etc., the lattice needs to expanded. The difference in the expansion of tetrahedral and octahedral sites is characterized by a parameter called "oxygen parameter". In an ideal lattice the tetrahedral and octahedral sites are enlarged in the same ratio and distance between tetrahedral site (0,0,0) and oxygen site (3/4,3/4,3/4) is 3/8 and U_{ideal} = 3/8. However the incorporation of divalent metal ions in tetrahedral site induces a larger expansion of tetrahedral sites and hence U_{obs} is always larger than U_{ideal}. The inverse spinel structure has the lowest lattice energy for $U < 0.379$.

1.4 CLASSIFICATION OF SPINEL FERRITES

On the basis of cation distribution, spinel ferrites are classified in three groups -

1) Normal Spinel Ferrites
2) Inverse Spinel Ferrites
3) Random Spinel Ferrites

1) Normal Spinel Ferrites

In normal spinel ferrites, all the divalent metal ion occupy A site and all the trivalent ions occupy B site. The structural formula for such ferrite is

$$[M^{2+}]_A\ [Fe^{3+}\ Fe^{3+}]_B\ O^{2-}{}_4$$

e.g. $CdFe_2O_4$ and $ZnFe_2O_4$ have this type of structure and they are non magnetic.

2) Inverse Spinel Ferrite

In inverse spinel ferrites, all the divalent metal ions occupy B sites and trivalent Fe^{3+} ions are equally distributed among the A and B sites. They are represented as

$$[Fe^{3+}]_A\ [Fe^{3+}\ M^{2+}]_B\ O^{2-}{}_4$$

e.g. $NiFe_2O_4$ and $CoFe_2O_4$ have this type of structure and they are ferrimagnetic.

3) Random Spinel Ferrites

In random spinel ferrites all the divalent metal ions and trivalent iron ions are randomly distributed on A and B sites depending on the sintering conditions. The general formula for cation distribution is -

$[M^{2+}{}_{x}\, Fe^{3+}{}_{1-x}]_A\, [M^{3-}{}_{1-x}\, Fe^{3+}{}_{1+x}]_B O^{2-}{}_4$

where x = 1, for normal spinel

x = 0, for inverse spinel

0 <x<1 for random spinel

e.g. $CuFe_2O_4$ and $MgFe_3O_4$ have this type of structure and they are ferrimagnetic.

1.5 TYPES OF FERRITES

According to chemical composition, ferrites are classified into three groups.

a) Simple Ferrites

When a divalent ferrous ion in Fe_2O_4 is replaced by other divalent metal ions like Cu, Co, Ni, Mn etc. then the ferrites are called as simple ferrites.

b) Mixed Ferrites

When a divalent ferrous ion in Fe_3O_4 is replaced by two other divalent metal like Cu, Co, Ni, Mn and Zn etc. maintaining the stoichiometry of the system, it constitutes a mixed ferrites.

The general formula for this system can be written as -

$A^{2+}{}_{1-x}\, B^{2+}{}_{x}\, Fe^{3+}{}_2 O_4{}^{2-}$

c) Substitutional Ferrites

When a divalent metal ions or trivalent iron ions are replaced by other magnetic or non-magnetic ions in the spinel structure, the resulting ferrites are called substitutional ferrites.

e.g. $NiFe_{2-x}Cr_xO_4$, $CuFe_{2-x}Al_xO_4$ and $Ni\,Al_x\,Fe_{2-x}O_4$ etc.

1.6 ELECTRICAL PROPERTIES OF FERRITES

The ferrites over take the conventional magnetic materials in their applications due to high electrical resistivity.

Spinel ferrites are semiconducting in nature whose resistivity varies from 10^{-2} to 10^{11} ohm-cm at room temperature. Their conductivity can be controlled by controlling the sintering temperature, sintering atmosphere and the addition of impurities. The conductivity in ferrites is due to the presence of Fe^{2+} and Fe^{3+} ions. The excess presence of Fe^{2+} results in n-type behaviour and lack of these in p-type behaviour.

The conductivity arises due to the mobility of an extra electron through the crystal lattice. The movement is described by hopping mechanism, in which charge carriers jump from one ion to the next. In Fe_3O_4 high conductivity is due to the excess presence of Fe^{2+} and Fe^{3+} ions in the crystallographically equivalent sites.

The temperature dependence of electrical resistivity of ferrite is given by the relation -

$$\rho = \rho_o \exp(-\Delta E/kT) \quad ....1.1$$

where ρ_o = constant

ΔE = activation energy for conduction

k = Boltzmann constant

The plots of log ρ vs 1/T is a straight line and breaks occur closely at the ferrimagnetic Curie temperature (15). The value of ΔE is associated with high resistivity at room temperature. During the course of ferrite preparation oxygen dissociation sets up above 1200^0C (16) to give rise to Fe^{2+} ions. The Fe^{2+} ions are responsible for the electron conduction.

The resistivity in ferrites is caused by the following factors.

1) Porosity and pores filled with air.

2) The grain size of individual crystallites influences the conduction path due to number of grain to grain contacts (17).

3) Chemical inhomogenity caused during preparation or heat treatment.

According to Heiks and Johnson (18) the mobility (μ) of charge carrier is given by

$$\mu = [e^2a^2\omega_o/kT] \exp(-\Delta E/kT) \quad ...1.2$$

where e = charge of an electron

a = distance between the nearest neighbouring cations

ω_o = frequency of vibration of crystal lattice

ΔE = activation energy required for the electron to jump from one iron ion to another.

The value of mobility (μ) obtained from the value of conductivity (σ) and number of charge carriers (η) is given by the equation -

$$\sigma = ne\mu \qquad ....1.3$$

and is called as drift mobility (μ_D).

The Seebeck coefficient Q and number of charge carriers n are related by the equation -

$$Q = k/e\ [\ln (N/n) + a\ k] \qquad ....1.4$$

where

Q = Seebeck coefficient (μv/deg)

N = concentration of lattice sites available for the charge carriers

η = carrier concentration

and k = constants related transport of K.E.

The prominent charge carriers in ferrites can be determined by using thermoelectric power measurements. The thermoelectric properties and Hall effect are widely used in the interpretation of conduction mechanism in semiconductors. The sign of thermoemf gives the information about the type of conduction in semiconductor i.e. whether it is p-type or n-type. Another significance of thermoemf is that it enables one to calculate the value of Fermi energy, drift mobility and carrier concentration (18).

1.7 MAGNETIC PROPERTIES OF FERRITES

The properties of ferrites are intrinsic as well as structure sensitive. The intrinsic properties like susceptibility, saturation magnetization depend upon divalent metal ion, where as structure sensitive properties like hysteresis behaviour, resistivity, a. c. conductivity depends upon grain structure and porosity. The details of magnetic behaviour of ferrite were studied by Neel. Magnetic materials exhibit different kinds of magnetic ordering depending upon spin orientation. Ferrimagnetic materials with the moments of ions oriented in the same direction give rise to high values of magnetic moment, while antiferromagnetic substances, with spins aligned in a antiparallel fashion, show a resultant magnetic moment of zero value.

In ferrites there are three kinds of magnetic interactions between the ions situated on A and B sites. The magnetic interaction is explained by considering the intermediate O^{2-} ion and is known as superexchange interaction. It has been established that the interaction energies are negative and hence induce antiparallel orientation which gives the lowest energy. An angle of 180^0 gives rise to the greatest exchange energy. The energy decreases rapidly with increasing distance between the ions.

The various possible configurations of ion pairs in spinel ferrites with distances and angles for effective magnetic interaction are given by Gorter (19) and shown in Fig. 1.2.

Based on the values of the distances and angles, it may be concluded that there are three prominent interactions viz. A-A, B-B and A-B interactions. A-B interaction is of greatest magnitude. The two configurations for A-B interaction have small distance (p, q and p, r) and the values of angle ∅ are fairly high. Of the configuration for B-B interaction only the first one will be effective since in second configuration the distance is too large for effective interaction. The A-A interaction is the weakest, as the distance r is large and angle is 80^0. With A-B interaction predominating the spins of A and B site ions in ferrites are oppositely oriented,

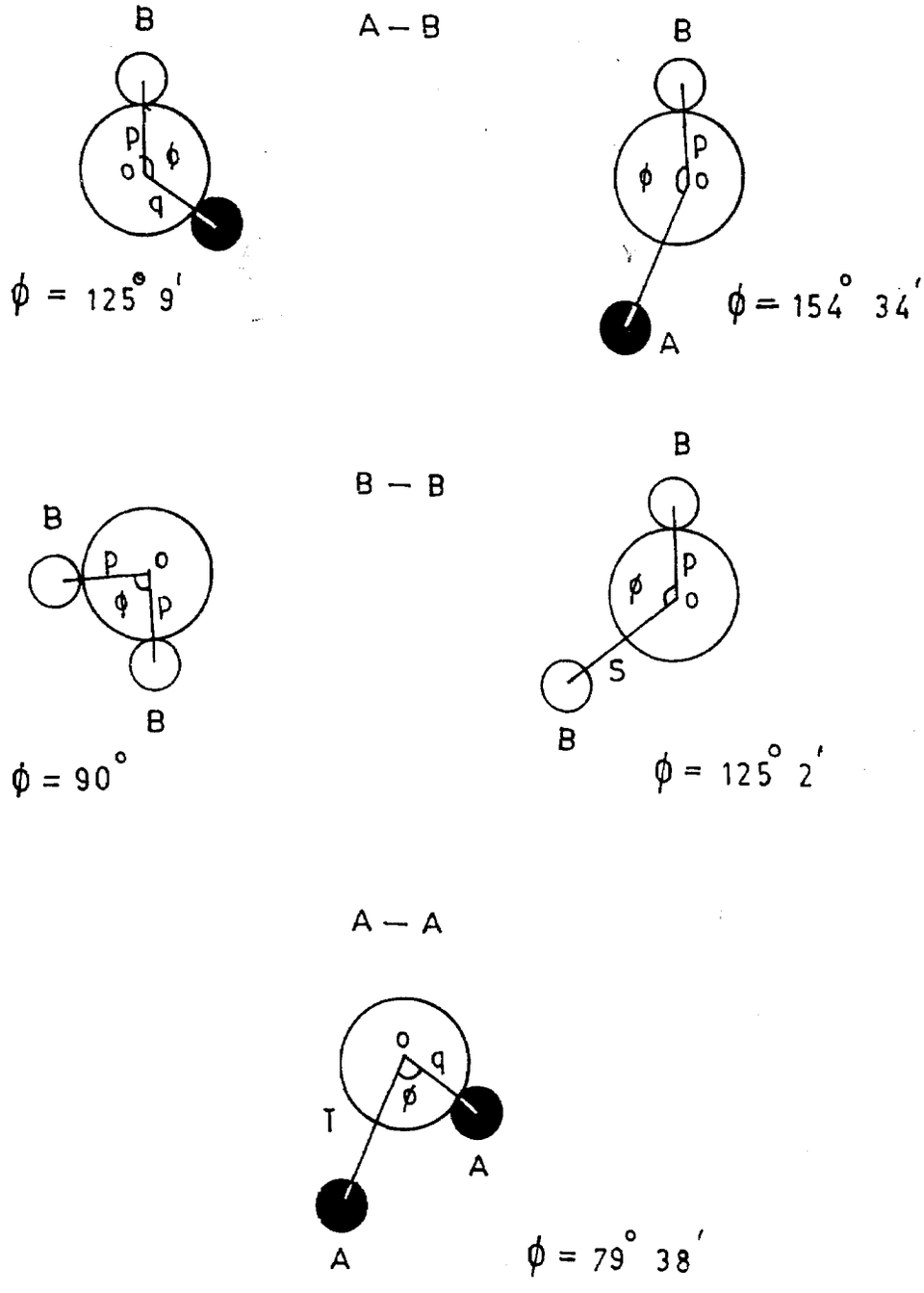


FIG. 1·2 – ANGLE BETWEEN A–A, B–B & A–B CATIONS IN A SPINEL STRUCTURE.

with a resultant magnetic moment equal to the difference between those of A and B site ions.

In general the value of saturation magnetic moment for B sublattice (M_B) is greater than that of A sublattice (M_A) so that the resultant magnetization (M_S) is written as -

$$M_S = |M_B - M_A| \qquad ....1.5$$

Hysteresis study of ferrites gives valuable information on saturation magnetization, coercive force and remanance ratio.

Ferrites are mainly classified into two categories based on their coercivity. The coercive force of soft ferrites lies in the range from 10 Oe to 1.5 kOe. For hard ferrites it is about 1.5 kOe.

1.8 DIELECTRIC PROPERTIES OF FERRRITES

Dielectric properties of ferrites are dependent upon several factors including the method of preparation, chemical composition, grain structure and size. When the ferrite is sintered under slightly reducing conditions, the valence state changes the individual cation formation in the sample leads to high conductivity and when such material is cooled in a oxygen atmosphere, it is possible to form films of high resistivity over the constituent grains. Such a ferrite in which the individual grains are separated by either air gaps or low

conductivity layers separate the individual grains behaves, as inhomogeneous dielectric materials. This aroused considerable interest in low frequency (in the range of 10^2 Hz to 10^5 Hz) dielectric behaviour of ferrites. Among many workers involved in this type of studies, the prominent ones are Koops (20), Moltgen (21), Kamiyoshi (22), Iwauchi et. Al. (23, 24), Rezlescu (25, 26), Brockman (27, 28), Avramenko (29) and Josyulu (30) etc.

Recently the polarization studies were further extended to understand and interpret the earlier theories in a microscopic manner relevant to different materials. These theories were also extended to interpret the low frequency dielectric properties of ceramic materials that include ferrites. Jonscher (31) interpreted the possible mechanism in this class of materials.

When the electric field is applied to the dielectric material, there is tendency for positive and negative charges within the material to be displaced relative to one another. Hence the system acquires an electric dipole moment. The dipole moment per unit volume is called the polarization (P). Total polarization of dielectric can be represented as -

$$P = Pe + Pi + Po + Ps \quad ....1.6$$

Where Pe = electronic polarization

Pi = ionic polarization

Po = orientational polarization

Ps = interfacial or space charge polarization

In electronic polarization the center of gravity of electron is shifted relative to nucleus in an electric field. In ionic polarization there is displacement of positive and negative ions relative to one another. In orientational polarization electric dipoles orient by the application of an external field. The space charge also tends to turn its own polarization in the case of ferrites. These mechanisms and their frequency dependence are represented in Figs. 1.3a and 1.3b. The visible range is occupied by the electronic polarization whereas ionic polarization is infrared region. The frequency range is occupied by space charge polarization.

1.9 THEORIES OF FERRIMAGNETISM

For many applications of magnetic materials Ms should be large. Material with a low value of Ms is used for some microwave applications. The following factors determine the value of Ms.

1) Magnitude of the atomic magnetic moment and number of these ions per unit volume.

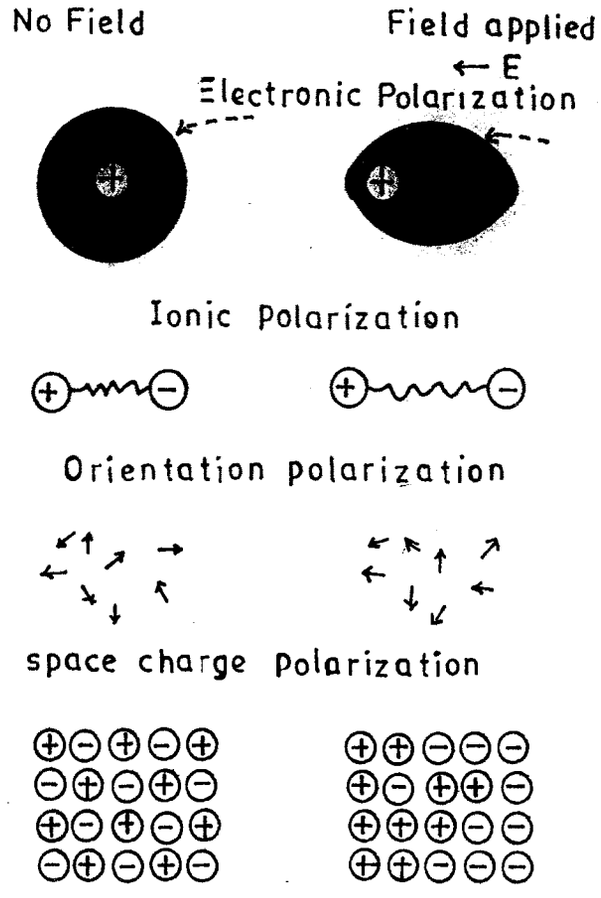


FIG. 1·3 a – SCHEMATIC REPRESENTATION OF DIFFERENT MECHANISMS OF POLARIZATION.

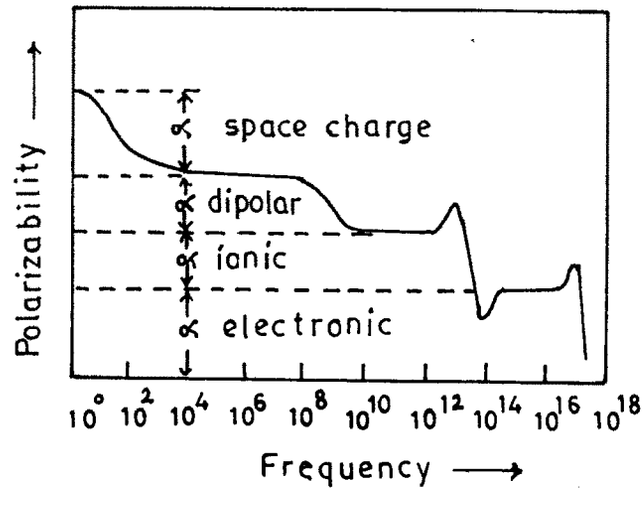


FIG. 1·3 b – FREQUENCY DEPENDENCE OF SEVERAL CONTRIBUTION TO THE POLARIZABILITY.

2) The magnetic ordering temperature (Tc).

3) The pattern in which the magnetic moment are ordered i.e. all parallel or partly antiparallel.

1.9 a NEEL'S THEORY OF FERRIMAGNETISM

Neel assumed that the ferrimagnetic crystal lattice could be divided into two sublattices formed by A site (tetrahedral) and B site (octahedral) in a spinel structure. The magnetic field acting upon an atom or ion is written as -

$$H = Ho + Hm \qquad ....1.7$$

where Ho = external applied field

Hm = molecular or internal field

When the concept of molecular field is applied to ferrimagnetic material we have

$$H_A = H_{AA} + H_{AB} \qquad ....1.8$$
$$H_B = H_{BB} + H_{BA}$$

The molecular field components may be written as,

$$H_{AA} = \gamma_{AA} M_A$$
$$H_{AB} = \gamma_{AB} M_B$$
$$H_{BB} = \gamma_{BB} M_B \qquad ...1.9$$
$$H_{BA} = \gamma_{BA} M_A$$

where γ's are appropriate molecular field coefficients and M_A and M_B are magnetic moments of A and B sublattices.

i) Paramagnetic Susceptibility

In paramagnetic region magnetization is given by,

$$M = Ng.J.\mu_B B_j(x) \qquad ...1.10$$

where N = number of free paramagnetic ions per unit volume

J = angular momentum quantum number

$B_j(x)$ = Brillioun function

$$B_j(x) = \frac{2J+1}{2J} \coth \frac{(2J+1)x}{2J} - \frac{1}{2J} \coth \frac{x}{2J} \qquad ..1.11$$

where $x = \mu_0 g.J. \mu_{BH}/kT$ ...1.12

k = Boltzmann constant

T = absolute temperature

Writing $X = \frac{M}{Ho}$ and

$M = M_A + M_B$

Neel rewrites the equations of susceptibility as -

$$\frac{1}{X} = \frac{T}{C} + \frac{1}{Xo} - \frac{\xi}{T-\theta} \qquad ...1.13$$

where λ = fraction appearing on A site

μ = fraction appearing on B site

such that $\lambda + \mu = 1$

e. g. 1.14 represents hyperbola Fig.

The asymptote is given by

$$\frac{1}{X} = \frac{T}{C} + \frac{1}{Xo} \qquad ...1.14$$

It cuts temperature axis at T_A = -C/Xo and is called as asymptotic Curie point. The paramagnetic Curie point Tp is found by equating $1/\lambda$ to zero. Which yields

$$Tp = \upsilon_{AB} \frac{C}{2} [\lambda a + \mu_B \{(\lambda a - \mu_B)^2 + 4 \lambda\mu\}^{1/2}] \qquad ...1.15$$

where Tp is Curie temperature when M_A and M_B are antiparallel.

ii) Spontaneous Magnetization

Equation 1.15 may be written as,

$$T^1p = \upsilon_{AB} \frac{C}{2} [\lambda a + \mu_B - \{(\lambda a - \mu_B)^2 + 4 \lambda\mu\}^{1/2}] \qquad ...1.16$$

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where T^1 is the Curie temperature when M_A and M_B are parallel.

In ferromagnetic material,

$$Msp = Ng\ J.\ \mu_B\ Bj(x) \qquad ..1.17$$

In the absence of applied field the Brillouin function parameter becomes

$$X = \frac{\mu_{og} J\ \mu_B v\ Msp}{kT} \qquad ...1.18$$

$$\therefore\ M = M_A + M_B \qquad ...1.19$$

Spontaneous magnetization can be written by assuming the similar behaviour below and above Curie point.

$$\frac{M_{ASP}}{M_B sat} = BJ\ (\mu_o\ g\ \mu_B\ J\ \mu_B J - H_A/kT) \qquad ...1.20$$

and

$$\frac{M_{ASP}}{M_B sat} = BJ\ (\mu_o\ g\ \mu_B\ J\ \mu_B J/kT) \qquad ...1.21$$

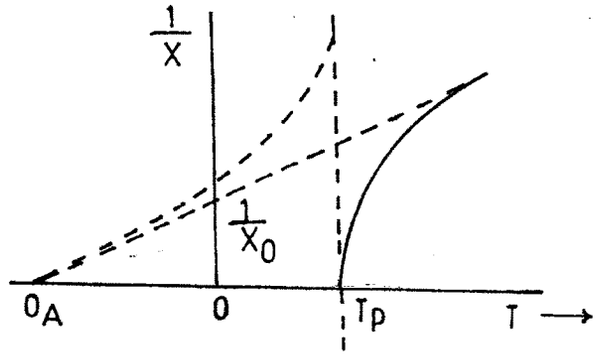
The observed total spontaneous magnetizations is given by

$$M_{SP} = M_{BSP} - M_{ASP} \qquad ...1.22$$

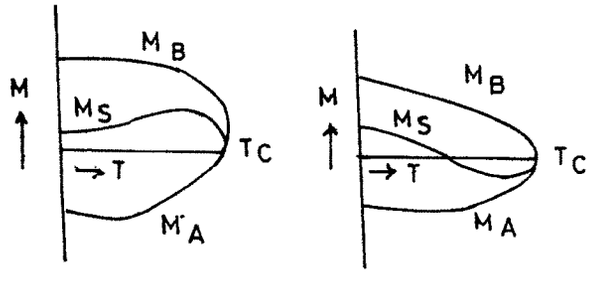
Graphs are shown in Fig.1.4

1.9b YAFET – KITTLE THEORY

The Neel's theory fails to explain the reduction in magnetization with antiparallel spin arrangement as well as the



A SKETCH OF THE INVERSE SUSCEPTIBILITY OF A FERRIMAGNETIC SUBSTANCE AS A FUNCTION OF ABSOLUTE TEMPERATURE.



THE ANAMOLUS SHAPES OF THE SPONTANEOUS MAGNETIZATION VERSUS TEMPERATURE CURVES FOR FERRIMAGNETIC SUBSTANCES ACCORDING TO NEELS THEORY $M_S - M_B - M_A$ IS THE RESULTANT MAGNETIZATION.

FIG. 1.4

behaviour of mixed ferrites. Yafet and Kittel (14) proposed a new model based on triangular spin arrangement. They concluded that a strong negative interaction exists within the B sublattice. The two equivalent sublattices B_1 and B_2 get spontaneously magnetized. The magnetizations are not exactly antiparallel but are aligned at an angle (Fig.1.5). This triangular arrangement within the lattice results in values of reduced magnetization of same order and magnitude as those stated by Neel's model. The interaction energy E for this case is given by

$$E = 8N\,[6\,J_{ab}\,S_a\,S_b\,\mathrm{Cos}\,\theta - K_{bb}\,S^2_b\,(2\,\mathrm{Cos}\,\theta - 1)] \qquad ...1.23$$

where θ = angle between A and sub division of B

J = exchange integrals

Interaction energy is minimum for J_{ab} negative and J_{bb} is positive. If $\theta = 0$. Neel state will be obtained. If J_{bb} is also negative the ratio of exchange energies is given by

$$vex = J_{bb}\,S_b/J_{ab}\,S_a > 3/4 \qquad ...1.24$$

Under this condition, Neel's state will not be minimum and magnetization of sublattice B_1 and B_2 will be inclined to sublattice A at on angle given by

$$\mathrm{Cos}\,\theta = 3/4\ \frac{J_{ab}\,S_a}{J_{bb}S_b} \qquad ...1.25$$

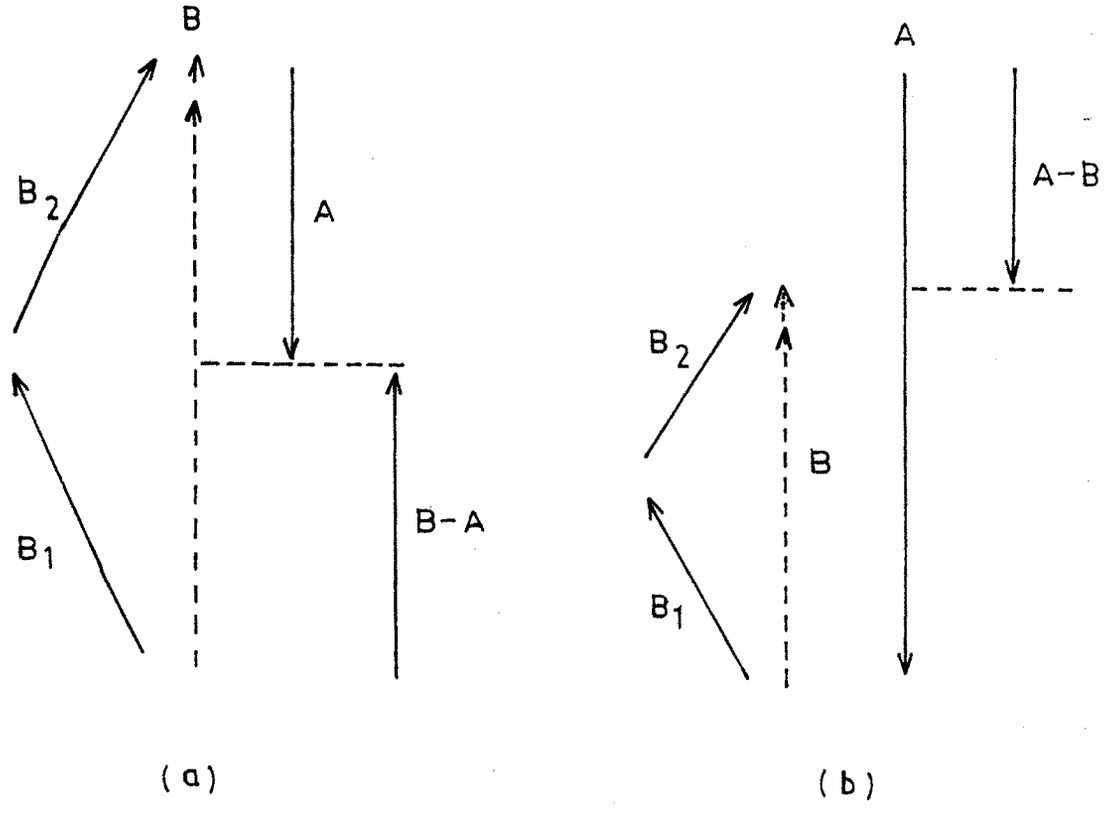


FIG. 1-5- TRIANGULAR SPIN CONFIGURATION.

Yafet and Kittel stated that the Neel's model is stable for vex > ¾, if the total number of sublattices is restricted to six.

This theory of triangular spin arrangement has been further developed by Lotgering (32) and approved by many workers (33-38).

1.10 APPLICATIONS OF FERRITES

The magnetic materials have become a part of modern industrial society. They play a key role in power distribution, conversion between electrical and mechanical energy and in many other products such as home appliances, equipment and data processing devices etc.

The ferrites can be used in magnetic amplifiers as non linear circuit elements. For this purpose ferrite with very small coercive force are to be used which give a sharp kink in the hysteresis curve. Storm (39) and Attura (40) used in Mn-Zn ferrites for this purpose in order to get low coercive force.

The high permeability and high resistivity characteristics of ferrites are used for low and high frequency applications. The low frequency soft magnetic materials are used principally in motors, generators, magnetic recording heads, filter cores, transformer and

related equipment. The high frequency applications of soft ferrites include a large number of microwave components such as circulators, isolators and phase shifter.

In large nuclear particle accelerators the near circular path of charged particles can be obtained by the use of guiding magnetic fields. The design of such huge machine is of great importance and many hundreds of tons of commercial ferrite materials have been used in the proton synchrotrons. A large crystalline anisotropy is a characteristic of hard ferrites. Due to large coercivity and suitable $(B_H)_{max}$ hexaferrites find applications in motors, generators, loudspeakers and telephones, etc.

Today ferrites are used in radio, television, microwave and satellite communications bubble devices, audio, video and digital recording. The various applications of ferrites, are given by Bahadur (41) in the form of a ferrite application tree (Fig. 1.6).

1.11 ORIENTATION OF THE PROBLEM

Ferrites are iron oxide based ceramic magnetic materials that behave as ferrimagnets. Their resistivity varies from 10^{-3} Ω -cm to 10^{11} Ω -cm depending upon the chemical composition, nature of the constituent ions and heat treatment. Because of their high electrical resistivity and low eddy current losses, they have vast

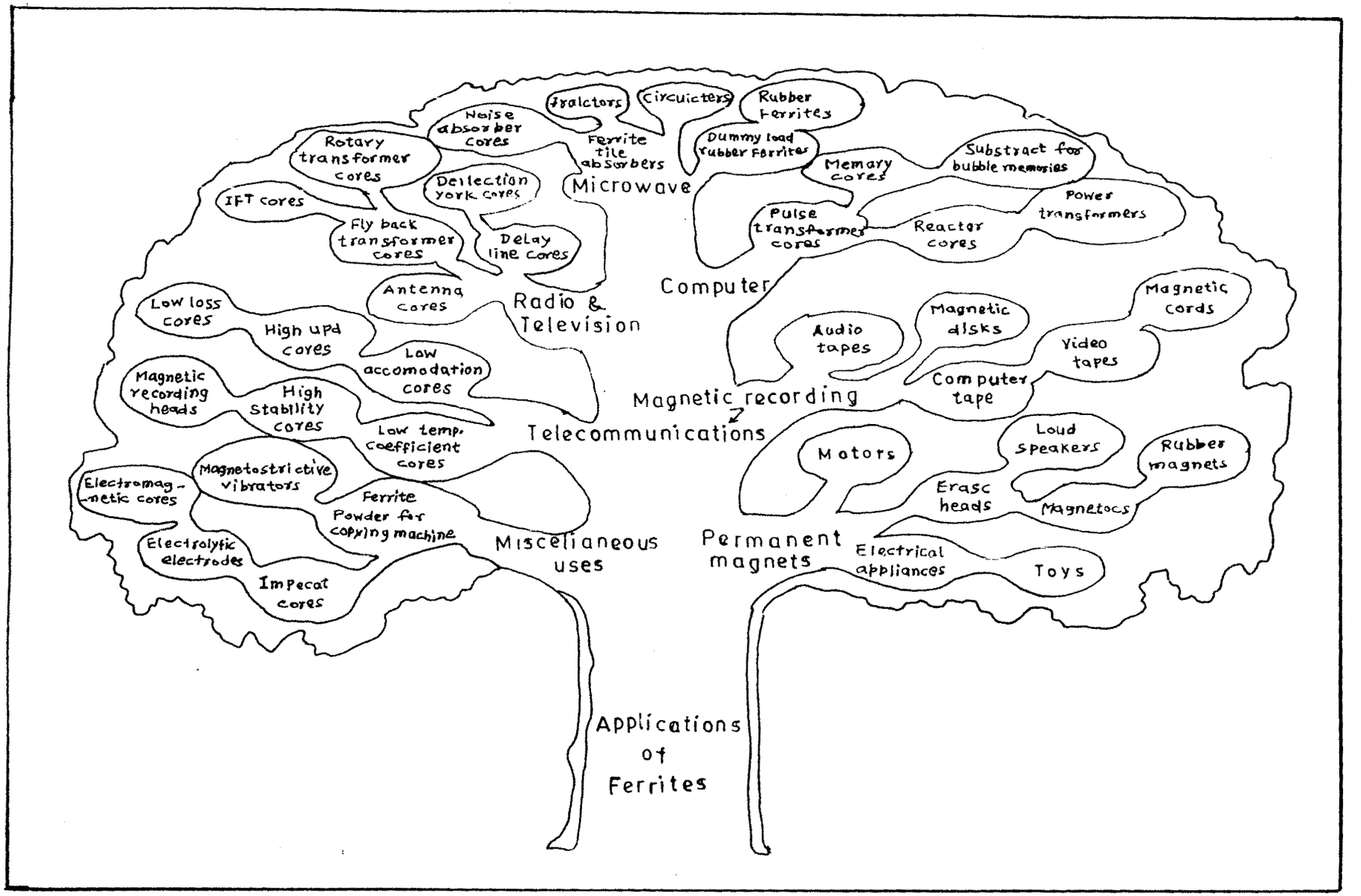

Applications of Ferrites
Microwave
Radio & Television
Computer
Magnetic recording
Telecommunications
Permanent magnets
Miscelianeous uses
Noise absorber cores
Ferrite tile absorbers
Circuicters
Rubber Ferrites
Dummy load rubber Ferrites
Rotary transformer cores
Deflection york cores
IFT cores
Fly back transformer cores
Delay line cores
Memary cores
Substract for bubble memories
Power transformers
Pulse transformer cores
Reactor cores
Antenna cores
Low loss cores
High upd cores
Low accomodation cores
Magnetic recording heads
High Stability cores
Low temp. coefficient cores
Magnetic cords
Audio tapes
Magnetic disks
Video tapes
Computer tape
Motors
Loud speakers
Rubber magnets
Erasc heads
Magnetocs
Electromag-netic cores
Magnetostrictive vibrators
Ferrite Powder for copying machine
Electrolytic electrodes
Impecat cores
Electrical appliances
Toys

FIG. 1-6

applications from microwave to radio frequencies. The practical applications of ferrites include household, electronics and computers. This has created considerable interest among the research workers for the development of newer ferrites. Now a days the study of ferrites has occupied an important place in the area of electronics technology.

The substituted Ni ferrites find a range of applications at radio and microwave frequencies where electrical and magnetic losses are required to be minimum (42, 43, 44,). The substitution of Mg ions in Ni ferrite has been found to affect the resistivity, dielectric constant and eddy current losses (45). Mg addition inhibits grain growth and improves the mechanical strength of ferrite (46). Substitution of Zn^{2+} in the ferrites reduces the saturation magnetization, Curie temperature and enhances the conductivity. The Co^{2+} ions, which have positive magnetic anisotropy also influence the magnetic parameter. Many research workers have reported their results on Ni-Zn and mixed Ni-Zn ferrites (47-56).

In order to see the effect of these substitutions on the electrical and magnetic properties the present work on Ni-Mg mixed ferrites with the general formula

$Ni_{0.5-x}\ Mg_{x-0.01}Zn_{0.5}\ Co_{0.01}Fe_2O_4$

where x = 0.1, 0.2, 0.3, 0.4 and 0.5 was undertaken.

The work involves the following -

1) Preparation of ferrites by ceramic method.

2) X-ray diffraction studies to confirm the homogenous and single phase formation of the samples alongwith determination of lattice parameter, bond lengths and site radii.

3) Infrared absorption studies to investigate the intrinsic vibration of cations at different sites.

4) DC resistivity measurements to study the conduction mechanism.

5) The hysteresis studies to understand the magnetization behaviour and cation distribution.

6) Initial permeability measurements.

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