

C H A P T E R - I

INTRODUCTION

- 1.1 Introduction
 - 1.2 Historical Developments
 - 1.3 Theories of Ferrimagnetism
 - 1.3.1 Weiss molecular field theory
 - 1.3.2 Neel's Theory of ferrimagnetism
 - 1.3.3 Yafet-Kittle theory
 - 1.4.A Electromagnetic properties
 - 1.4.A(a) Saturation magnetisation
 - 1.4.A(b) Magnetostriction
 - 1.4.A(c) Anisotropy
 - 1.4.A(d) Shape anisotropy
 - 1.4.A(e) Permeability
 - 1.4.A(f) Hysteresis and domains
 - 1.4.B Electrical properties
 - 1.4.B(a) D.C. electrical conductivity
 - 1.4.B(b) Hall effect
 - 1.4.B(c) Thermoelectric power
 - 1.4.B(d) Electrical switching and memory phenomena
 - 1.4.B(e) Dielectric dispersion
 - 1.5 Applications of Ferrites
 - 1.6 Orientation of the Work
- References

CHAPTER - I

1.1 Introduction :

Ferrites are complex magnetic oxides which contain the ferric oxide (Fe_2O_3) as the basic constituent; and certain other divalent metal oxides. The most versatile and important properties of these materials are such as, high electrical resistivity, high permeability, small cohesive force, low loss factor and low thermal conductivity, that enable them to develop high and ultra high frequency electronics.

The resistivity of all commercial ferrites is in the range of 10 to 10^5 ohm cm. Hence they are used in the solid, crystalline form without laminating or powdering. The high resistivity with good dielectric properties allows them in microwave applications. High permeability and low loss factor at high frequencies find their suitability in high frequency and pulse transformers, deflection coils, antennas, inductors and modulators.

Square loop hysteresis curve exhibited by some ferrites find extensive applications in the field of computers, flip-flops and memory devices. The lower permeability and larger magnetostriction necessitates in mechanical filters and ultrasonic generators. Besides these and other numerous applications they are the firmly established magnetic materials, which suits the optimum requirement of the modern day electronics, and have occupied the unique position. The broad spectrum of their applications clearly brings out their importance and uniqueness.

Almost all the properties of them are governed by chemical composition and thermophysical history. Hence it makes essential to have a good tailor making of them to suit the requirements of particular application. For the complete investigation of them, it is essential to know the crystal structure cation distribution and the nature of magnetic interactions along with the preparation conditions and microstructure. This broad band of investigations therefore imposes the limitations on the actual investigation.

In this chapter efforts are being made to take brief survey of the historical developments, theoretical models and the electromagnetic behaviour along with the orientation of the work undertaken.

1.2 Historical Developments :

Magnetite (Fe_3O_4) is the first magnetic material known to man, often referred as ferrous ferrite or Lodestone. Hilpert¹ in (1909) with the prime object of reduction of eddy current loss had prepared for the first time synthetic ferrites but without success. The striking contribution due to him is the basic molecular formula MeOFe_2O_3 ; where Me is the divalent metal ion.

The investigations in the field of ferrites are not significant upto 1930 s, in which Forestier², Kato and Takai³, Barth and Posjanak⁴ started research simultaneously. Later on Snoek⁵, Verway⁶ and their coworkers extensively studied the influence of preparation conditions and compositional variation on their electromagnetic behaviour.

Verway (1936) and De.Boer⁶ (1937) have envisaged conduction mechanism ended with sound conclusion that the inverse spinels are magnetic while

normal spinel are paramagnetic at room temperature. Neel⁷ (1948) proposed the theory of spin spin interaction in ferrites and extended his two sublattice model of anti-ferromagnetism to account successfully the observed magnetisation in ferrites. The theory of superexchange interaction was developed by Anderson⁸ (1950) and Van-Vleck⁹ (1951).

Gorter¹⁰ and Guillaud¹¹ gave the direct experimental evidence of Neel's modified theory. Smart¹² and Gorter¹³ correlated independently cation distribution and magnetisation. Yafet and Kittle¹⁴ (1952) introduced the idea of triangular spins and division of B sublattice into two equivalent lattice sites B1 and B2 due to strong negative interaction existing in sublattice.

Gilleo¹⁵ developed a formula related to curie temperature, magnetisation and cation distribution for a ferrite containing non-magnetic divalent cation. Koops¹⁶ introduced the model after studying the ac parameters of ferrites.

Recent studies on ferrites leap on all fronts, from single crystal aspects to many of the electromagnetic properties of polycrystalline materials with desired microstructure with a view of particular application.

1.3 Theories of Ferrimagnetism :

Neel coined the word ferrimagnetism to account the spontaneous magnetisation analogous to ferrimagnetism below Curie temperature. This class of materials distinguishes themselves from anti-ferromagnetics due to their unequal antiparallel magnetic momenta. The elementary magnetic momenta in this class interact with one another through interposed nonmagnetic ion by indirect exchange called 'super exchange', analogous to antiferromagnetics. The

net magnetisation in ferrimagnetics arises due to two possibilities such as the magnetic ions situated on two different sublattices will have unequal magnetic momenta, or the no. of magnetic ions on two sublattices are different in number. The types of magnetic interactions within sublattices are same to that of antiferromagnetics.

The study of measurement of magnetic susceptibility variation with temperature will throw light on the entire process of magnetisation in support with Weiss molecular field theory and Neel's two sublattice model. The observed reduction in magnetisation and the explanation of related anomalies can be had from Yafet-Kittel triangular spin concept.

1.3.1 Weiss molecular field theory

Langevin's¹⁷ theory of paramagnetism leads to Curie law based on the assumption that the individual magnetic momenta do not interact with one another unless and until aided by applied field or thermal agitation. Weiss¹⁸ in 1907 pointed out that the elementary magnetic momenta did interact with one another to give rise to an enormous internal field called the 'molecular field' (H_m) which acts in addition to the applied field (H_o).

The origin and nature of the Weiss field was further explained by Heisenberg on the basis of exchange interaction, without touching to origin and nature of molecular field, he had successfully explained the principle of magnetisation in ferromagnetics simply assuming that the intensity of molecular field is directly proportional to the magnetisation M given by

$$H_m = r \cdot M \quad \dots \quad (1.1)$$

where r = Molecular field constant.

Hence the total field acting on the material is

$$H = H_o + H_m \quad \dots \quad (1.2)$$

where H_o = applied field

H_m = internal Weiss field

Taking into consideration Weiss nature of molecular fields and super exchange by Anderson and Vanvleck. Neel extended his two sublattice model of antiferromagnetics to account for the observed magnetisation in ferrimagnetics.

1.3.2 Neel's theory of ferrimagnetism

The net magnetic moment vanishes in anti-ferromagnetics because the individual magnetic momenta are equal and antiparallel. The non-zero value of magnetic moment in ferromagnetic material may be due to two possibilities such as, the individual spin magnetic momenta are not equal or the number of magnetic ions situated on two different lattice sites will have different number.

Consider a ferrimagnetic material with only one type of species of magnetic ions, out of which λ will occupy one site (A site) and μ will occupy B site, such that

$$\lambda + \mu = 1 \quad \dots \quad (1.3)$$

The type of magnetic interactions within the sublattices are similar to that of antiferromagnetics, such as A - A, B - B and A-B interactions.

Where A-A and B-B are the interactions for the neighbouring magnetic ions situated on the same lattice site while A-B is the interaction between the two magnetic ions situated on two different lattice sites A and B. The sign of

magnetic interaction is given by the sign of molecular field coefficient λ . The molecular field coefficients for different types of interactions are given by λ_{aa} , λ_{ab} and λ_{bb} for A-A, A-B and B-B interactions respectively.

Now by applying Weiss molecular field theory we can write the molecular field at each lattice sites as

$$H_a \approx H_{AA} + H_{AB} \quad \dots \quad (1.4)$$

$$\text{and } H_b = H_{BB} + H_{BA} \quad \dots \quad (1.5)$$

where

$$H_{AA} = \lambda_{aa} M_A ; H_{BB} = \lambda_{bb} M_B \quad \dots \quad (1.6)$$

$$H_{AB} = \lambda_{ab} M_B ; H_{BA} = \lambda_{ab} M_A$$

M_A and M_B be the magnetic moment of the A and B sublattice. If the sites are identical then $\lambda_{ab} = \lambda_{ba}$ and $\lambda_{aa} = \lambda_{bb}$. According to Neel $\lambda_{ab} < 0$, favours antiparallel arrangement of M_A and M_B resulting in ferrimagnetism.

The total magnetic fields on each lattice site in the presence of an applied field H_o can be written as

$$\begin{aligned} H_a &= H_o + H_A \\ &= H_o + \lambda_{aa} M_A + \lambda_{ab} M_B \end{aligned} \quad \dots \quad (1.7)$$

and

$$\begin{aligned} H_b &= H_o + H_B \\ &= H_o + \lambda_{ab} M_B + \lambda_{ab} M_A \end{aligned} \quad \dots \quad (1.8)$$

Paramagnetic region :

The magnetisation of each lattice site is given by

$$M_A = \frac{\lambda q^2 \mu B^2 J(J+1)}{6K_B T} H_a \quad \dots \quad (1.9)$$

and

$$M_B = \frac{\mu q^2 \mu B^2 J(J+1)}{6K_B T} H_b \quad \dots \quad (1.10)$$

where λ - Number of magnetic ions on A site.

μ - Number of magnetic ions on B site.

H_a - Effective field on A site.

H_b - Effective field on B site.

As we have seen in antiferromagnetic materials, that the magnetic quantum number J is replaced by s , due to weak L-S coupling and quenching of orbital magnetic moment. This is also true for ferrimagnetic materials, hence equation (1.9) and (1.10) can be written as

$$M_A = \frac{\lambda g^2 \mu B^2 S (s+1)}{6K_B T} H_a \quad \dots \quad (1.11)$$

and

$$M_B = \frac{\lambda g^2 \mu B^2 s (s+1)}{6 K_B T} H_b \quad \dots \quad (1.12)$$

Let c be the curie constant given by

$$C = \frac{2 g^2 \mu B^2 s(s+1)}{3 K_B} \quad \dots \quad (1.13)$$

hence equation (1.11) and (1.12) becomes

$$M_A = \frac{\lambda c}{T} H_a \quad \dots \quad (1.14)$$

and

$$M_B = \frac{\mu c}{T} H_b \quad \dots \quad (1.15)$$

Substituting values of H_a and H_b from (1.7) and (1.8) in above equations we write

$$M_A = \frac{\lambda c}{T} (H_0 + \lambda_{aa} M_A + \lambda_{ab} M_B) \quad \dots \quad (1.16)$$

and

$$M_B = \frac{\mu c}{T} (H_0 + \lambda_{bb} M_B + \lambda_{ab} M_A) \quad \dots \quad (1.17)$$

The ferrimagnetic susceptibility in this region is given by

$$\chi = \frac{M_A + M_B}{H_0} \quad \dots \quad (1.18)$$

substituting value of M_A and M_B from (1.16) and (1.17) and rearranging the same we get

$$\frac{1}{\chi} = \frac{T^2 - c \lambda_{ab} (\lambda_{aa} \mu c + \mu c^2) + c^2 \lambda_{ab}^2 (\alpha \beta - 1)}{c (T - \lambda_{ab} \mu c (2 + \alpha + \beta))}$$

where

$$\alpha = \frac{\lambda_{aa}}{\lambda_{ab}} ; \quad \beta = \frac{\lambda_{bb}}{\lambda_{ab}}$$

$$\text{Let } \frac{1}{\chi_0} = \lambda_{ab} (2\lambda_{ab} - \lambda_{aa}^2 - \mu^2 \beta^2),$$

$$\theta = \lambda_{ab} \lambda_{ab} \mu c [2 + \alpha + \beta]$$

$$\text{and } e = \lambda_{ab}^2 \lambda_{ab} \mu c [\lambda (1 + \alpha) - \mu (1 + \beta)]^2$$

Substituting these in eqn. 1.9 we get

$$\frac{1}{\chi} = \frac{T}{C} + \frac{1}{\chi_0} - \frac{e}{T - \theta} \quad \dots \quad (1.20)$$

The first two terms on R.H.S. of equation (1.20) denotes the temperature dependence of susceptibility of the Curie-Weiss law in ferrimagnetics above Curie point. The third term does not contribute at high temperature in ferrimagnetic material. The plot of equation (1.20) that is $1/\chi$ versus T in $^{\circ}\text{K}$ represents the hyperbola as shown in figure (1.1). The asymptotic to the line is given by

$$\frac{1}{\chi} = \frac{T}{C} + \frac{1}{\chi_0} \quad \dots \quad (1.21)$$

The intercept on $\frac{1}{\chi}$ axis gives the value of $\frac{1}{\chi_0}$. If the line is extrapolated it cuts T axis at $\theta_A = -c/\chi_0$, which is called as asymptotic Curie point by Neel.

The Ferrimagnetic material is paramagnetic above T_p and will be spontaneously magnetised in the region of $0 \leq T < T_p$, where T_p is the paramagnetic Curie point given by

$$T_p = \frac{\lambda_{ab}}{2} c [\lambda\alpha + \mu\beta + \{(\lambda\alpha - \mu\beta)^2 + 4\lambda\mu\}^{\frac{1}{2}}] \quad \dots \quad (1.22)$$

If T_p is negative, the material remains with paramagnetic values of susceptibility down to absolute zero. If $T_p \rightarrow 0$, χ becomes theoretically infinite below which there is spontaneous magnetisation with finite value, when external field is reduced to zero.

Spontaneous Magnetisation : ($T < T_p$)

We take T_p be Curie point when sublattices are spontaneously magnetised with M_A and M_B antiparallel, by taking positive square root at each time it can be written as

$$T_p = \frac{1}{2} \lambda_{abc} [(\lambda\alpha + \mu\beta) + \{(\lambda\alpha - \mu\beta)^2 + 4\lambda\mu\}^{\frac{1}{2}}] \quad \dots \quad (1.23)$$

When M_A and M_B are spontaneously magnetised with parallel spins then Curie point T_p taking positive root at each time can be written as

$$T_{p'} = \frac{1}{2} \lambda_{abc} [(\lambda\alpha + \mu\beta) - \{(\lambda\alpha - \mu\beta)^2 + 4\lambda\mu\}^{\frac{1}{2}}] \quad \dots \quad (1.24)$$

since $T_p \gg T_{p'}$, we may expect the antiparallel arrangement of the M_A and M_B which is in good agreement with the assumption of negative A-B interaction.

The individual magnetism of M_A and M_B of the sublattices cannot be observed, but the net magnetisation $M = M_A + M_B$ is measured. As the two lattice sites are magnetised in opposite direction and of magnetisation of B sublattice is greater than A site, then net magnetisation will be

$$|M| = |M_B| - |M_A| \quad \dots \quad (1.25)$$

Employing the statistical treatment developed by Neel to account M_A and M_B in the form of Brillouin function, in which J is replaced by s as previously discussed.

$$M_{A \text{ sp}} = \lambda N g \mu_B B_J (\mu_{og} J \mu_B H_A) / K_T \quad \dots \quad (1.26)$$

$$M_{B \text{ sp}} = N_g J B_J (\mu_{og} J \mu_B H_B) / K_T \quad \dots \quad (1.27)$$

and

$$M_{\text{sp}} = M_{B \text{ sp}} - M_{A \text{ sp}} \quad \dots \quad (1.28)$$

The theoretical analysis point out the possibility of the different shapes for the net magnetisation curves depending upon the parameters of exchange interactions and relative magnetisation of each lattice site. The curves provide useful data about the ferrite from the application point of view. The temperature effect on A-B and B-B interactions in substitutional ferrites¹⁹ leads to Lotgering²⁰ triangular arrangement. The energy minimisation sometimes leads to formented and helical configurations²¹. The experimental results on susceptibility variation with temperature in paramagnetic region found excellent agreement with the theoretical one, and hence successful demonstration of molecular field treatment to explain the phenomena of ferrimagnetism.

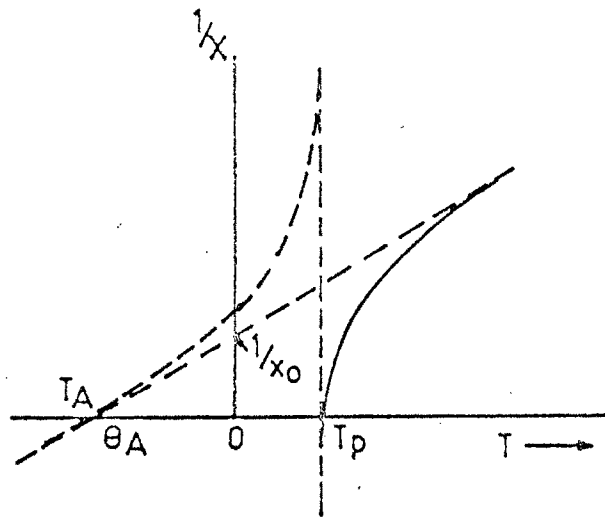


Fig. 1.1 A SKETCH OF THE INVERSE SUSCEPTIBILITY OF A FERRIMAGNETIC SUBSTANCE AS A FUNCTION OF ABSOLUTE TEMPERATURE.

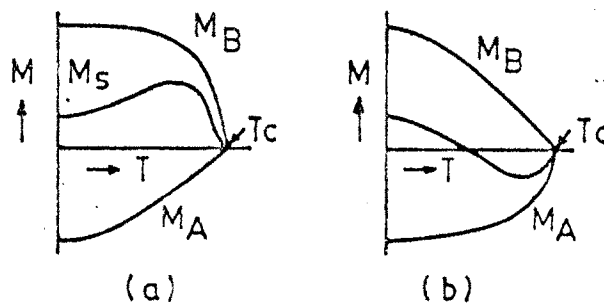


Fig. 1.3 THE ANOMALOUS SHAPES OF THE SPONTANEOUS MAGNETISATION vs TEMPERATURE CURVES FOR FERRIMAGNETIC SUBSTANCES ACCORDING TO NEEL'S THEORY. $M_s = M_B - M_A$ IS THE RESULTANT MAGNETIZATION.

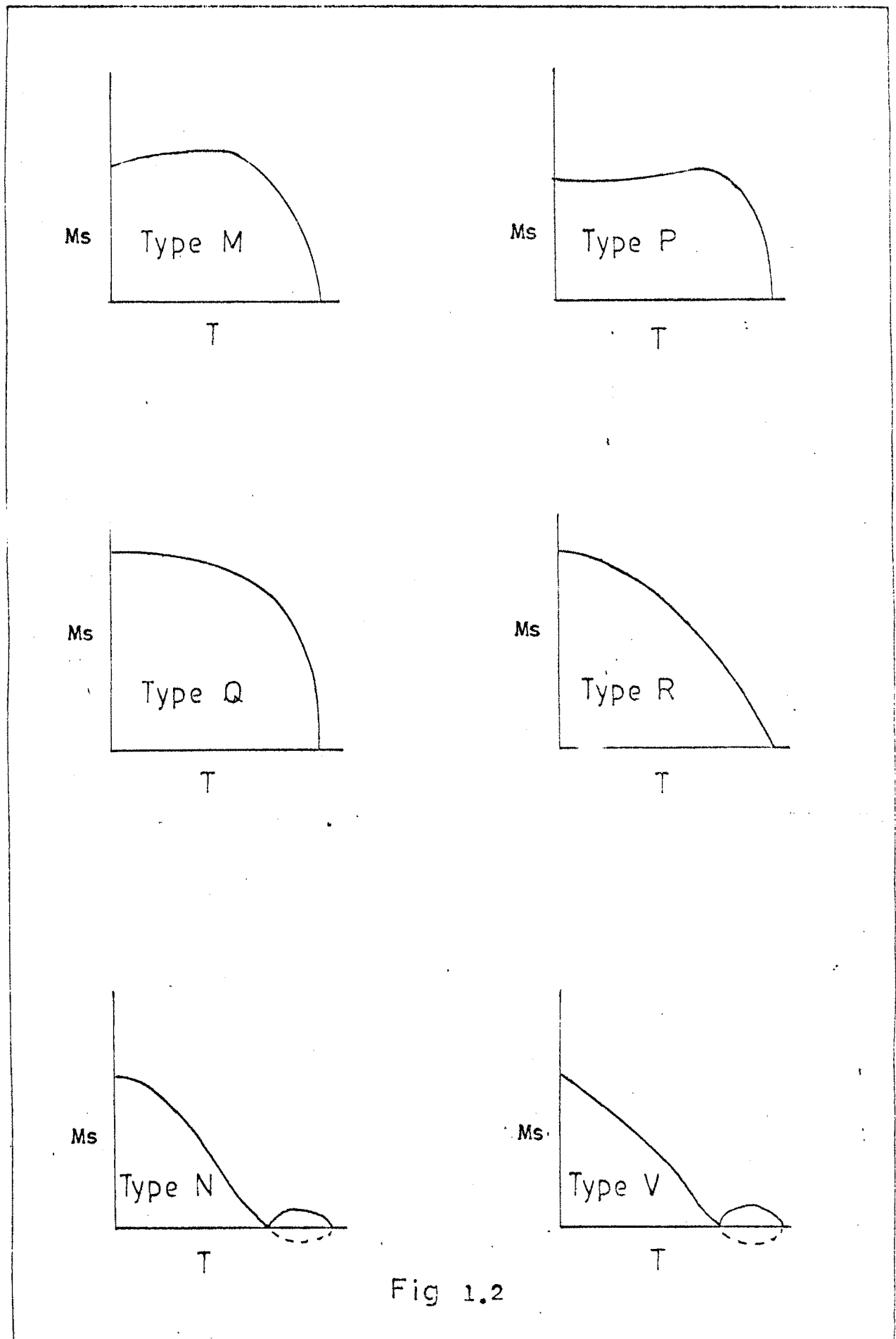


Fig 1.2

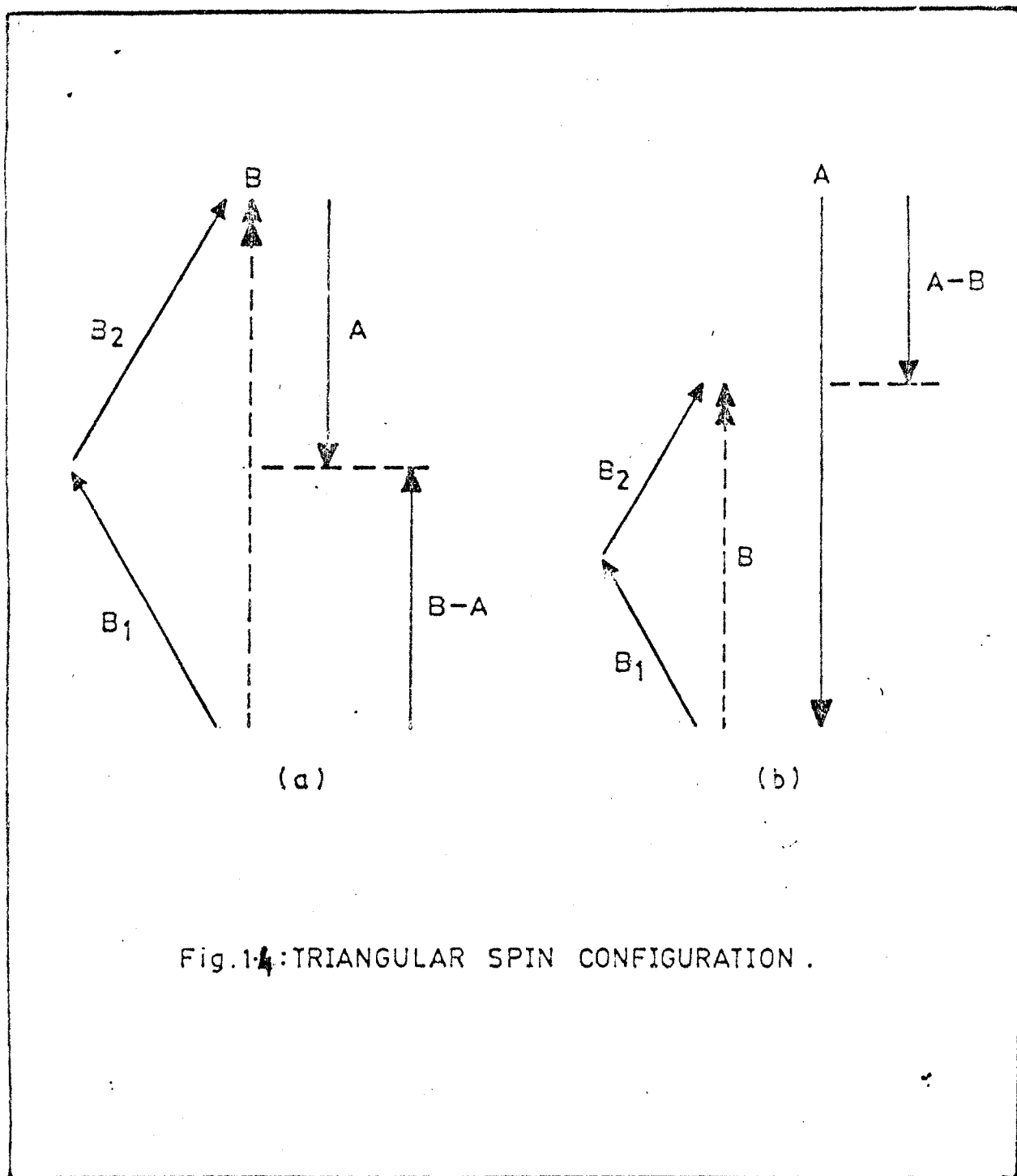


Fig.1.4: TRIANGULAR SPIN CONFIGURATION .

1.3.3 Yafet-Kittle theory

Neel's theory fails to account for the observed magnetisation in substituted ferrites and also it cannot explain the variation in magnetisation at absolute zero. The various plots of spontaneous magnetisation versus temperature shown in figure (1.2) and the anomalies shown in fig. (1.3) cannot be explained only with Neel's theory. Therefore to account the observed reduction in magnetisation Yafet and Kittle²² in (1952) extended Neel's theory by suggesting the idea of triangular spin arrangement within the sublattices.

If a strong negative interaction exist within the B sublattice then B sublattice gets divided into B_1 and B_2 with their magnetisation neither exactly antiparallel to each other or to a sublattice. Therefore net magnetisation can be calculated by taking the resultant of B_1 and B_2 antiparallel to A as shown in fig. (1.4).

1.4 A: Electromagnetic properties :

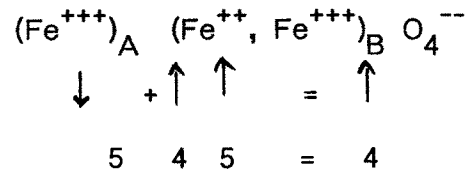
Wide spectrum of ferrite applications is rooted in their electromagnetic behaviour. The properties of ferrites are classified into two categories such as intrinsic (structure insensitive) and extrinsic (structure sensitive). The saturation magnetisation, magnetostriction, anisotropy and Curie temperature are the intrinsic ones, while resistivity hysteresis, permeability, dielectric constant and several other losses are structure sensitive. The microstructure of ferrites markedly affect the structure sensitive properties.

Magnetic properties :

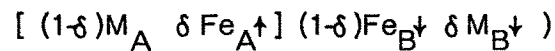
1.4.A(a) Saturation magnetisation:

An intrinsic property governed by physico-chemical constitution, cation distribution and thermophysical history. The degree of inversion in spinel

ferrites, alongwith cation distribution decides the net magnetic moment. Consider a case of magnetite (Fe_3O_4) in which Fe^{+++} and Fe^{++} occupies B site while Fe^{+++} occupies A site giving us net upspin of 5 B as shown



In general if δ is the degree of inversion then for single ferrite (MeFe_2O_4) in which Me be the transition element with n electrons in 3d shell, then μ_B per formula unit will be $n\mu_B$ or $(10-n)\mu_B$. By using δ , the coefficient of inversion the cation distribution can be written as



The net moment μ_B will be then

$$\begin{aligned}
 \mu_B &= M \{ [(1-\delta) - \delta] - 5(1+(1-\delta) - \delta) \} \\
 &= M (1 - 2\delta) - 10(1-\delta) \quad \dots (1.29)
 \end{aligned}$$

The value of exchange interaction is greatest for an angle of 180° between the near to next nearest cation via oxygen.

1.4.A (b) Magnetostriction

Change in dimensions of the material when it is magnetised from ideal demagnetised state to saturation is known as the magnetostriction effect. It is denoted by a letter λ called as magnetostriction coefficient. Magnetostriction coefficient λ has the different values along all crystallographic axis. The magnetostriction effect can be useful for many applications like transducer etc. The effect of magnetostriction can be minimised by using substituted ferrites²³.

1.4.A (c) Anisotropy (Magnetocrystalline)

The preferred magnetisation direction in ferromagnetic material leads to the properties such as hysteresis loss, finite susceptibility and permeability. Magnetocrystalline energy arises from spin orbit interaction²⁴. It depends upon the orientation of the magnetisation with respect to crystallographic axis. It is given by

$$fK = K_1 (\alpha_1^2 \alpha_2^2 + \alpha_2^2 \alpha_3^2 + \alpha_1^2 \alpha_3^2) + K_2 (\alpha_1^2 \alpha_2^2 \alpha_3^2) \dots \quad (1.30)$$

where K_1 and K_2 are the first and second anisotropy constants and α_1, α_2 and α_3 are the directional cosines.

1.4.A (d) Shape anisotropy

The magnetic anisotropy that depends on the physical shape of specimen is called as shape anisotropy. It is independent of magnetic moment of the material, and is given by the equation

$$fmg = \frac{1}{2} [N_x M_x^2 + N_y M_y^2 + N_z M_z^2] \dots \quad (1.31)$$

where N_x, N_y and N_z are the demagnetising coefficients. The physical origin of this anisotropy energy lies in pores and nonmagnetic inclusions in an apparently solid substance. The local demagnetising fields near the pores will have an appreciable effects on anisotropy.

1.4.A (e) Permeability

Permeability arises in ferrimagnetic material due to reversible displacement of domain wall motion within the material, while domain rotation does not contribute much more to permeability because of higher magnetocrystalline anisotropy. In general, it is defined as the ratio of induced magnetisation 'B'

to the magnetising field H, given by

$$\mu = \frac{B}{H} \quad \dots \quad (1.32)$$

The pores, grain size, density and temperature can affect the permeability²⁵. Also it is affected by stress internal and external.

1.4.A (f) Hysteresis and domains

The data of coercive force, remanance, saturation magnetisation and permeability can be had from the hysteresis study. All these data helps to know the suitability of ferrite from application point of view. The coercive force and permeability values are applicable to wide spectrum of applications. In general the magnetic materials and ferrites as well can be classified into hard and soft on the basis of coercive force and permeability values.

Hysteresis properties of materials are mainly governed by crystal structure, chemical composition, cation distribution and thermal history. Hysteresis measurements are done according to Maxwell's²⁶ techniques, while loop is traced by hysteresis loop tracer.

According to Weiss²⁷ concept, domains are small regions of magnetic material in which spins are aligned to saturation in external magnetic field and will have zero magnetisation when an external field is reduced to zero. The origin of domain lies in the minimisation of energy of a magnetic system. The anisotropy field, magnetostatic field energy and exchange energy are the domain energy contributors. The size and shape of domain is determined by above energy concepts, along with pores, stresses and the nonmagnetic inclusions.

The entire cycle of magnetisation that is the coercive force, remanance, saturation magnetisation etc. are the consequences of domain behaviour

in applied field. In low applied field magnetisation is due to domain growth, while in strong applied field it is due to domain rotation. The rotation of domain have been observed by Barkhausen²⁸. There are also strong evidence for domains.

1.4.B Electrical properties

The resistivity of ferrites has a wide range of variation from $10^{-3} \Omega \text{cm}$ to $10^{11} \Omega \text{cm}$ ²⁹. Almost all physical and chemical properties are related to the process of charge transport, hence it is essential to know the charge transport mechanism.

The mechanism of charge transport can be understood from study of measurement of electrical resistivity with temperature, Hall effect, thermoelectric effect. The properties mentioned above are structure sensitive properties, hence physicochemical and thermal history of material are the main factors that influence the mechanism of charge transport in a complicated way.

1.4.B (a) D.C. electrical conductivity

Ferrites are semiconductor by nature. The variation of resistivity with temperature can be given by a similar expression to semiconductor as

$$\rho = \rho_0 \exp^{-E/KT} \quad \dots \quad (1.33)$$

where E is the activation energy.

Verway has explained the conduction mechanism in ferrites on the basis of charge transfer which takes place from Fe^{2+} to Fe^{3+} that are situated on the crystallographically same lattice site i.e. on B (octahedral) site in magnetite. Klinger³⁰ has reviewed the conduction mechanism and have

suggested two phase hopping mechanism. According to him the hopping of polarons is the main process of conduction. The details of conduction mechanism is given in chapter third along with the experimental method and data obtained of the system under investigation.

1.4.B (b) Hall effect

Measurement of conductivity alone is not sufficient for determination of both the number of conducting charges and their mobility. Neither do they permit determination of the predominant charge carriers nor its sign. However, a very simple experimental procedure is at hands which can determine both the sign and concentration of conducting charges is the Hall effect.

When a current carrying conductor is placed in magnetic field, the charge carriers are deflected laterally along the sides of conductor. If a magnetic field is perpendicular to the direction of flow, these charge carriers accumulates at the surface perpendicular to both magnetic field and an applied electric field giving Hall voltage is known as Hall effect. It is a very very powerful tool that determines

i) sign of current carriers, ii) density of current carriers, iii) Mobility, iv) Electronic structure v) If Hall coefficient is known one can measure high unknown fields. vi) Also support the concept of negative mass given by Bleancy

1.4.B (c) Thermoelectric power

Ferrites are characterised by their high resistivities that lie in the range of $10^{-3} \Omega \text{ cm}$ to $10^{11} \Omega \text{ cm}$ ³¹. Therefore, it makes easy for one to study the thermo electric power by virtue of which we can have the precise understanding of the charge transport mechanism. The sign of thermoelectric

voltage will determine whether the charge carriers are electrons or holes; or which of them are the predominant carriers.

Experimental determination of Seebeck coefficient is useful in accordance with the theory, but it requires fine grinding and polishing of the surface. If both are not achieved to desired accuracy the results are not reproducible will ruin the measurements.

1.4.B (d) Electrical switching and memory phenomena

The study of switching and memory phenomena have developed considerable interest because of their applications in switching devices and computers as well as data processing circuit. The study of slow cooled and quenched copper ferrites also have been reported by Yamashiro³² who had attributed it to Jahn Teller distortion transformation. Later on Histake³³ et al. have also studied the same on copper and lithium ferrites. An interesting study in this respect is also reported by Vaingankar³⁴ et al on copper ferrite.

1.4.B (e) Dielectric dispersion

The credit of studies on dielectric dispersion goes to Koops³⁵ who had put forth a phenomenological theory of dielectric dispersion at low frequencies. It is based on the parallel capacitances and resistances of a material resulting from an equivalent circuit can be comparable with a dielectric solid of fine grains compacted and being separated by conducting layers.

The resistivity of the surface layer of a semiconductor material is not the same as that of the interior. Therefore, d.c. electrical resistivity measurement will give a little insight in to the actual conductivity of a bulk material.

Displacement currents in the layers gives rise to corresponding variation in measured dielectric constant. Koops³⁵ has reported variation of resistivity and dielectric constant with frequency for Ni-Zn ferrites.

Dispersion phenomena has been studied on sintered metal oxides by Volger³⁶, Haberey and Wijn³⁷. According to Koops and Moltgen³⁸ the phenomena is due to inhomogeneous dielectric structure suggested by Maxwell³⁹.

1.5 Applications of Ferrites :

The technological sophistication in the manufacturing process of ferrites suits the commercial requirements of known reproducible properties with modest aim. The high resistivity and high permeability of soft ferrites are very useful for transformer chokes because they give lossless operation at high frequency. Therefore, they suit the requirement of high frequency devices such as high frequency transformer cores, induction turners, antenna rods etc. Now-a-days, ferrite antennas are having more attention because of their noiseless operation along with high directional sensitivities.

The T.V. manufacturers also have used successfully ferrite yoke rings to achieve high linearity and high deflection sensitivity in T.V. receivers. High resistivity property of ferrites is being utilized in some audio applications such as recording and erasing heads in all commercial tape recorders. They also have proved their suitability in data storing and processing equipments.

The added advantage of ferrite broad-band chokes have been satisfactorily used to decrease spurious radiation and to avoid undesired coupling in radio and T.V. receivers, converters, ignition circuits and motors. The high uniaxial anisotropy, a characteristics of hard ferrites allows their uses in

loudspeakers, motors, generators, sticking devices and magnetic therapy. The high remanance and moderately high coercivity finds their use in magnetic recording. Besides this hard ferrites have also occupied the position in the list of permanent magnetic materials, and is successfully used to prepare high quality permanent magnets.

1.6 Orientation of the Work :

Since 1950, ferrites are extensively used on all the technological fronts such as electrical, magnetic, electronic, microwave and computers. Due to their versatile electro-magnetic properties, they have almost replaced the metals and alloys, and have occupied unique position in the field of modern day electronics. They have almost changed the face of microwave communications.

It is indeed important to prepare the ferrites with desired electro-magnetic properties, so as to meet the technological requirements. The sophistication in the preparation techniques, now-a-days can enable one to prepare the ferrites with desired properties and microstructure, in a known and reproducible manner. These materials have therefore, a large potential from the point of view of application and research and development. This study therefore was thought worth undertaking.

In spinel ferrites, the electromagnetic properties, as we know, are structure sensitive and can be influenced by impurity doping, chemical composition and heat treatment. The effect of additives such as pentavalent vanadium in Ni-Zn ferrites and Ti^{4+} in Mn-Zn ferrites with several others like Bismath; on their electromagnetic behaviour is reported in literature. It is worthy to note that the rare earth oxides have changed the face of low temperature

conductivity. Hence it becomes relatively important to study the effect of doping of these materials in magnetic oxides.

Magnesium ferrites have a high resistivity and low magnetic and dielectric loss, and its derivatives have wide application in microwave technology. By taking into account the above points and their importance, we have proposed to undertake study of $Zn_xMg_{1-x}Fe_2O_4$ ferrite system doped with 0.01 mol.wt.% ZrO_2 . It is also proposed to carry out the investigations so as to understand the effect of additives on crystal structure and electromagnetic properties. The proposed work is carried in the following steps.

- 1) (a) Preparation of $Zn_xMg_{1-x}Fe_2O_4$ ferrite system (where $x=0, 0.2, 0.4, 0.6, 0.8, 1.0$) by standard ceramic technique.
(b) Preparation of $Zn_xMg_{1-x}Fe_2O_4$ ferrite system doped with 0.01 mol. wt.% ZrO_2 , by standard ceramic technique, and to prepare the pellets by using hydraulic pressure.
- 2) The confirmation of homogenous and single phase ferrite formation and crystal structure characterisation is to be done by X-ray diffraction technique.
- 3) To understand conduction mechanism, it is proposed to study d.c. electrical resistivity with composition and temperature. The transition temperature can be verified by actual measurement of T_c the Curie temperature of the samples.
- 4) The Seebeck coefficient measurement is also proposed to understand the type of conductivity and the role of impurity in determining the type of conductivity.
- 5) To study effect of additives on bulk magnetic properties, the hysteresis study of the samples is proposed.

REFERENCES

1. Hilpert S., Ber Deut Chem Ges., 42, 2248 (1909).
2. Forestier H., Anneales Chemie Xe serie, Tome IX, 353 (1928).
3. Kato Y. and Takei T., Journal of the Institute of Electrical Engineers, Japan 53, 408 (1933).
4. Barth T.F.W., Posjank E., Z.Krist 82, 325 (1932).
5. Snock J.L., Physica, 3, 463 (1936).
6. Verway F.J.M., De Boer F., Van Santen J.H., J.Chem.Phys., 16, 1091 (1948).
7. Neel L., Proc. Phys. Soc., London, A 65, 869 (1948).
8. Anderson P.W., Phys.Rev., 79, 350 (1950).
9. Van-Vieek J.H., Phys. Rev., 78, 266 (1951).
10. Gorter E.W., Phillips Res. Repts., 9, 295 (1954).
11. Guillaud C., J.Phys.Radium, 12, 239 (1951).
12. Smart J.S., Phys. Rev., 94, 847 (1954).
13. Gorter E.W., Nature, 173, 123 (1954).
14. Yafet Y. and Kittle C., Phys.Rev., 87, 290 (1952).
15. Gilleo M.A., J.Phys.and Chem. Solids (G.B.), 13, 33 (1960).
16. Koops C.G., Phys. Rev., 83, 121 (1951).
17. Cullity B.D. "Introduction to Magnetic materials", Addison-Wesley Publishing Company, 96 (1972) Ed.
18. Weiss P., J.Phys. theor. appl. 6, 667 (1907).
19. Yafet, Y. and Kittle,C., Phys. Rev. 87, 290 (1952).
20. Lotgering,F.K., Phillips Res. Repts, 11, 190 (1956).

21. Kaplan T.A., et. al., J.Appl.Phys., 32, 135 (1961).
22. Yafet, Y. and Kittel, C. Phys. Rev., 87, 290 (1952).
23. Rodrigue G.D., J.appl.physics, 40, 929 (1969).
24. Van-Vleck J.H., Rev.Mod.Phys., 17, 27 (1945).
25. Pippin J.E. and Thiess G.H., J. appl. phys., 30, 4, 805 (1954).
26. Maxwell S.P., The Marconi Rev., 1st quarter, p.20 (1970).
27. Weiss P., J. de Phisique, 6, 661 (1907).
28. Barkhausen H., Phys. Zeite, 20, 401 (1919).
29. Van Utiret L.G., Proc. I.R.E., 44, 1294 (1956).
30. Klinger, M.I., Phys.Stat.Solidi (B), 79, 9 (1977).
31. Van Uitert L.G. Proc. T.R.E., 44, 1294 (1956).
32. Yamashiro T., Jap. J.Appl. Phys., 12, 148 (1973).
33. Histake K., Nakayama K. and Ohta K., Jap.Appl.Phys.,
12, 116 (1973).
34. Vaingankar A.S., Patil S.A., Todkar M.M., Khot A.Y. and Devale V.B.
Proc.N.P. and SSP Symposium, 23C, 250 (1980).
35. Koops C.G., Phys. Rev. 83, 121 (1951).
36. Volger J. Physica, 20, 49 (1954).
37. Haberey F. and Wijn H.P., J.Phys. Stat. Sol.,26, 231 (1968).
38. Moltgen G., Z. Angew Phys., 4, 216 (1952).
39. Maxwell J.C., "Treatise on Electricity and Magnetism" vol.I,
Clarendon Press, Oxford (1892).