# COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE

## DEPARTMENT OF PHYSICS

*CHARACTERIZATION AND APPLICATION OF FERRITE MATERIAL*

BY


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## DECLARATION

This is our review work has not been presented for a degree in any other university and that all sources or materials used for the project have been duly acknowledged.

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# LIST OF ABBREVIATION

| | |
|---|---|
| DSC | Differential Scanning Calorimetry |
| DTA | Differential Thermal Analysis |
| DTG | Differential Thermo Gravimetry |
| EDAX | Energy dispersive X-ray analysis |
| EDX | Energy Dispersive X-ray |
| EPR | Electron paramagnetic resonance |
| FESEM | Field Emission Scanning Electron Microscopy |
| FTIR | Fourier Transform Infra-red |
| FTIS | Fourier Transform Infrared Spectroscopy |
| FWHM | Full Width Half Maximum |
| HISTELCON | History of Electrotechnolgy Conference |
| JCPDS | Joint Commite on Powder Diffraction Standards |
| LCR | Liquidity Coverage Ratio |
| RF | Radio Frequency |
| SEM | Scanning Electron Microscope |
| VSM | Vibrating Sample Magnetometer |
| XRD | X-Ray Diffiraction |

# ABSTRACT

*The material characterization of ferrites includes the investigation of crystallography, structural morphology, chemistry (identification of chemical constituents, chemical composition, and their distribution), thermal properties, magnetic properties, and electrical properties.In this study, the main focus of the present work is to review synthesize nano magnetic particles of different ferrite (AFe2O4, where A represent Zn, Co, and Mn). The ferrite nanoparticles were effectively prepared by sol-gel, hydrothermal and chemical co-precipitation technique. The XRD analysis affirmed the pure phase development of cubic spinel structure with nanometric crystallite measurements of the powder XRD analysis revealed the high purity and single phase of the zinc ferrite sample average crystallite sizes are 21 nm and 27 nm for the zinc samples annealed in air atmosphere at 300 °C and 600 °C.and the calculated crystallite size was found to be 14.33 nm for cobalt, 27 nm for zinc ferrite and the particle size was calculated as 23.53 nm for manganese ferrite. Finally, Cyclic voltametric analysis, Electron paramagnetic resonance (EPR) spectroscopy, Energy dispersive X-ray analysis (EDAX) and liquidity coverage ratio (LCR), dielectric behaviour,frequency and proportion of highly liquid assets are not included in this study. Therefore, this will be considered in future studies to further enhance the understanding of the ferrite material.*

**KEY WORD:** ferrite material, magnetic properties, cobalt ferrite,zinc ferriete,manganese ferrite.

# CHAPTER ONE

## 1. INTRODUCTION

The term ferrite is commonly used generically to describe a class of magnetic oxide compounds that contain iron oxide as a principal component. Magnetite ($Fe_3O_4$), also called loadstone, is a genuine ferrite and was the first magnetic material known to the ancient people. Ferrites are a unique class of compounds comprising lanthanides and fast transition metal.(Srivastava & Yadav, 2012)

Ferrites are usually used as a core material in inductor. An Inductor is an impedance device which has a coil with or without core for introducing inductance to an electronic circuit. The ferrite core typically multiplies the inductance of a coil by the permeability of the core.Generally the core is in the shape of a rod or toroid. Ferrite should have not only high magnetic permeability but also have good DC characteristics i.e. as small decrease in magnetic permeability with DC.(Pradhan, 2012)

Ferrites are chemical compounds with the formula $AB_2O_4$, where A and B represent various metal cations; usually including iron. Ferrites are a class of spinels i.e. materials that adopt a crystal motif consisting of cubic closed pack oxides with A cations occupying 1/8th of the octahedral voids and B cations occupying half of the octahedral voids.

For inverse spinel structure, half the B cations occupy tetrahedral sites and both the A and B cations occupy the octahedral sites. Divalent, trivalent and quadrivalent cations can occupy the A and B sites and they include Mg,Zn,Fe, Mn, Al, Cr, Ti and Si.

Ferrites are usually non-conductive ferromagnetic ceramic compounds derived from iron oxides as well as oxides of other metals. Like most other ceramics, ferrites are hard and brittle.

### 1.1 TYPE OF FERRITE MATERIAL

The ferrites are ionic compounds with certain double oxides of iron and other metals. The magnetic properties of ferrites depend on the ions they contain. Several ferrites are found as naturally occurring minerals in rocks with impure state. ferrite material can be classified based on magnetic property and crystal structure (Vedrtnam et al., 2020)

### 1.1.1 Classification of Ferrite material based on magnetic property:

Due to the persistence of their magnetization, the ferrites are two types i.e**. hard** and **soft.** This classification is based on their ability to be magnetized or demagnetized. Soft ferrites are easily magnetized or demagnetized whereas hard ferrites are difficult to magnetize or demagnetize.

- **Soft ferrites:**

Soft Ferrites are those that can be easily magnetized or demagnetized. This shows that soft magnetic materials have low coercive field and high magnetization (shown in figure 1.1a) that is required in many applications. The hysteresis loop for a soft ferrite should be thin and long, therefore the energy loss is very low in soft magnetic material. Examples are nickel, iron, cobalt, manganese.etc

Soft ferrites have certain advantages over other electromagnetic materials including high resistivity and low eddy current losses over wide frequency ranges. They have high permeability and are stable over a wide temperature range. These advantages make soft ferrites paramount over all other magnetic materials.

- **Hard ferrites:**

Hard ferrites are difficult to magnetize or demagnetize. They are used as permanent magnets. A hard magnetic material has high coercive field and a wide hysteresis loop (shown in figure 1.1b). Examples are alnico, rare earth metal alloys etc.

Hard ferrites are compound of iron and barium or strontium oxides. Hard ferrites have high saturation flux density, low susceptibility and permeability, high eddy current losses, and high retentivity and coercivity.

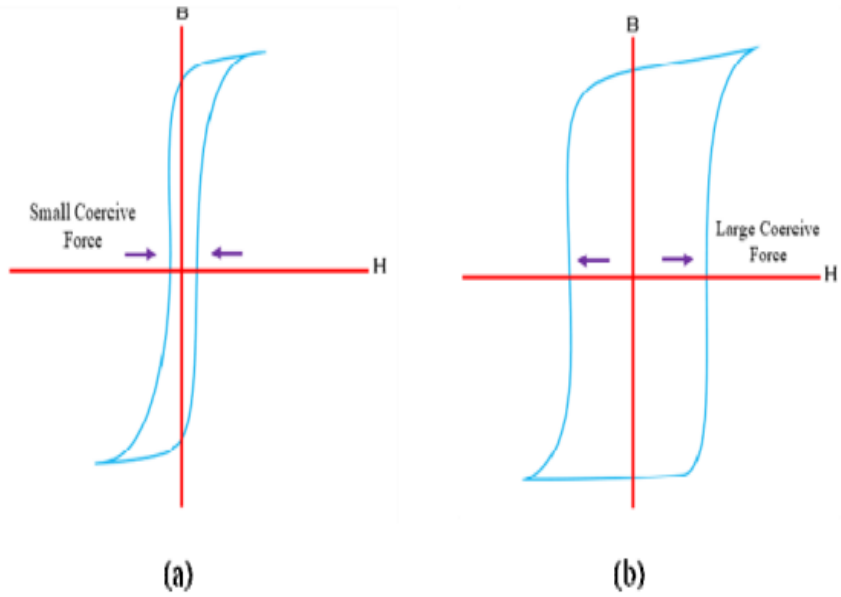



***Figure 1.1 B-H (magnetic flux - magneting force) curve for ferrites (a) soft ferrites and (b) hard ferrites (Vedrtnam, Ajitanshu & Kalauni,et al, 2020).***

### 1.2.2 Classification of Ferrite material based on crystal structure:

Ferrites have variety of crystal structures. Based on their crystal structures, ferrites can be classified in four types, i.e., spinel, garnet, ortho, and hexagonal ferrites (table 1.1).

***Table 1.1 Ferrites based on crystal structures***

| Sr. no. | **Types** | **Molar ratio** | **Representations** |
|---|---|---|---|
| 1 | Spinel | $Fe_2O_3$–1MO | MO is a transition metal oxide |
| 2 | Garnet | $5Fe_2O_3$–$3M_2O_3$ | $M_2O_3$ is a rare earth metal oxide |
| 3 | Ortho | $AFeO_3$ | A is rare earth elements (Ho, Dy, Er, Y, Yb, etc.) |
| 4 | Hexagonal | $6Fe_2O_3$–1MO | MO is a divalent metal oxide from group IIA (BaO, CaO, SrO, etc.) |

- ✓ **Spinel ferrites:**

They are also called cubic ferrites. Spinel is the most widely used family of ferrites. High values of electrical resistivity and low eddy current losses make them ideal for their use at microwave frequencies.

The spinels are metal oxides with the general composition $AB_2O_4$, where, A could be Mg, Fe, Zn, Mn, Ni, etc., B could be Al, Cr or Fe, and O is oxygen. The spinel group can be divided in three series (Figure 1.2), i.e., aluminium-spinel, chromium-spinel and iron-spinel series. The members

of aluminium spinel are spinel ($MgAl_2O_4$), gahnite ($ZnAl_2O_4$), hercynite ($FeAl_2O_4$) and galaxite ($MnAl_2O_4$)

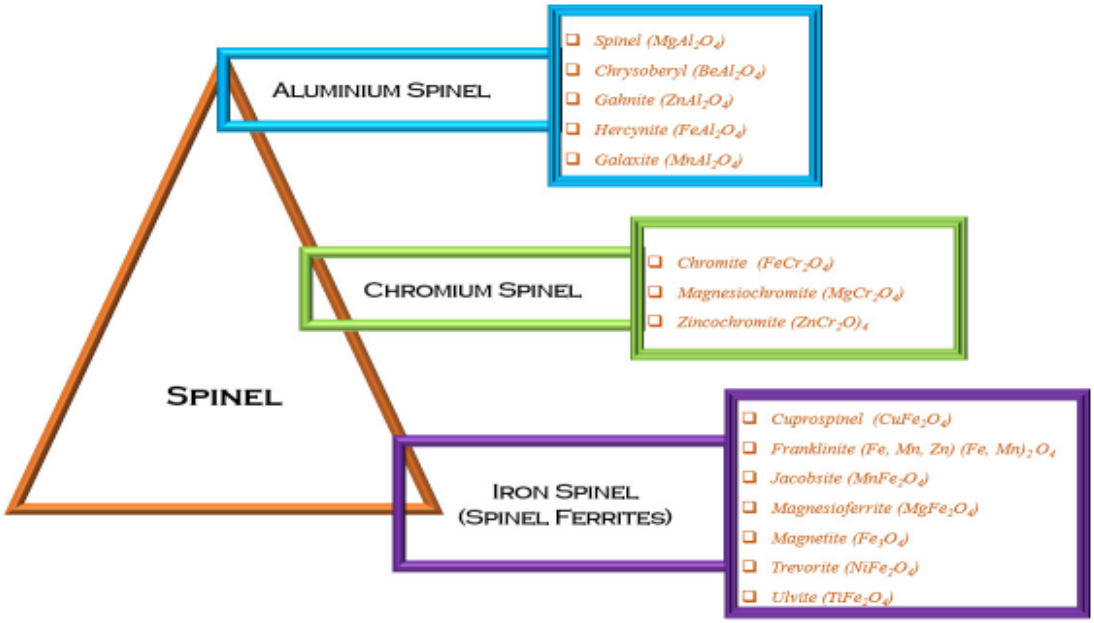



***Figure 1.2. Types of spinel structure (Vedrtnam, Ajitanshu & Kalauni,et al, 2020).***

The iron spinel is found as Cuprospinel ($CuFe_2O_4$), Franklinite [(Fe, Mn, Zn) $(Fe, Mn)_2O_4$], Jacobsite (MnFe2O4), Magnesioferrite ($MgFe_2O_4$), Magnetite ($Fe_3O_4$), Trevorite ($NiFe_2O_4$), Ulvite ($TiFe_2O_4$) (Table 1.2) (Dubey, (2022)) . Cuprospinel was first characterized by the Australian mineralogist Ernest Henry Nickel, in 1973.

***Table 1.2 : Short description of different types of SFs.***

| Sr.no | Spinal ferrites | Molecular compositions | Density (g/cm3) |
|---|---|---|---|
| 1 | Cuprospinel | $CuFe_2O_4$ | 5.25 |
| 2 | Franklinite | $(Zn, Fe^{2+})\ (Fe^{3+})_2O_4$ | 5.07–5.22 |
| 3 | Jacobsite | $MnFe_2O_4$ | 4.76 |
| 4 | Magnesioferrite | $MgFe_2O_4$ | 4.56–4.65 |
| 5 | Magnetite | $Fe_3O_4$ | 5.17 |
| 6 | Trevorite | $NiFe_2O_4$ | 5.38 |
| 7 | Ulvite | $TiFe_2O_4$ | 4.77 |

- ✓ **Garnet ferrites**

Garnet ferrites, also known as garnet-based ferrites or garnet magnetic materials, are a class of magnetic materials that combine the properties of garnet crystals and ferrite materials. They are a type of ferrimagnetic material, which means they exhibit a combination of ferromagnetic and antiferromagnetic behavior. According to Yoder and Keith reported in in 1951 that substitutions can be made in ideal mineral garnet $Mn_3Al_2Si_3O_{12}$. (Pradhan A. K., (2021)).

They produced the first silicon free garnet $Y_3Al_5O_{12}$ by substituting YIII+AlIII for MnII+SiIV. Bertaut and Forret prepared $Y_3Fe_5O_{12}$ in 1956 and measured their magnetic properties. In 1957 Geller and Gilleo prepared and investigated $Gd_3Fe_5O_{12}$ which is also a ferromagnetic compound. (Sultana, (2023)) The general formula for the unit cell of a pure iron garnet have eight formula units of $M_3Fe_5O_{12}$, where M is the trivalent rare earth ions (Y, Gd, Dy). Their cell shape is cubic and the edge length is about 12.5 Å. They have complex crystal structure.

- ✓ **Ortho ferrite**

Ortho ferrite is possess extremely high velocity of domain wall ortho ferrite are also have the general formula of $AFeO_3$,where A is large trivalent metal ion,such as rare earth ion.its orthorhombic unit cell structure.

- ✓ **Hexagonal ferrite**

Hexaferrites are hexagonal or rhombohedral ferromagnetic oxides with formula $MFe_{12}O_{19}$, where M is an element like Barium, Lead or Strontium. In these ferrites, oxygen ions have closed packed hexagonal crystal structure. They are widely used as permanent magnets and have high coercivity. They are used at very high frequency. Their hexagonal ferrite lattice is similar to the spinel structure with closely packed oxygen ions, but there are also metal ions at some layers with the same ionic radii as that of oxygen ions. Hexagonal ferrites have larger ions than that of garnet ferrites and are formed by the replacement of oxygen ions. Most of these larger ions are barium, strontium or lead.

## 1.2 property of ferrite material

Ferrites exhibit permanent type of magnetism referred as ferrimagnetism. Ferrimagnetism was originally proposed by Neel to define the magnetic order phenomenon in ferrites. ferrimagnetic, meaning they can be magnetized or attracted to a magnet, and are electrically nonconductive (Hossain, (2015))

In ferrimagnetism, the magnetic moments of atoms align themselves in both parallel (as in ferromagnetism) and antiparallel (as in anti-ferromagnetism) directions. The overall magnetic field of ferrite is lesser strong than ferromagnetic materials because there is a partial cancellation of magnetic field (kumar, (2009))

The significant properties of ferrites include high electrical resistivity, low eddy current and dielectric losses, high saturation magnetization, high permeability, moderate permittivity, spontaneous magnetization and conductivity behaviour. In comparison with diamagnetics or paramangetics the saturation magnetization of ferrites is high, but as ferrimagnetics they exhibit saturation magnetization significantly lower than ferromagnetics, like amorphous or nanocrystalline alloys. So in comparison with other materials considered as magnetic materials the saturation magnetization of ferrites is not that high. The same is with permeability.

The ferrimagnetic materials exhibit a magnetic moment even in the absence of magnetic field (spontaneous magnetic moment) similar to ferromagnetic materials and the hysteresis phenomenon below the Curie temperature as shown in Figure 1.3

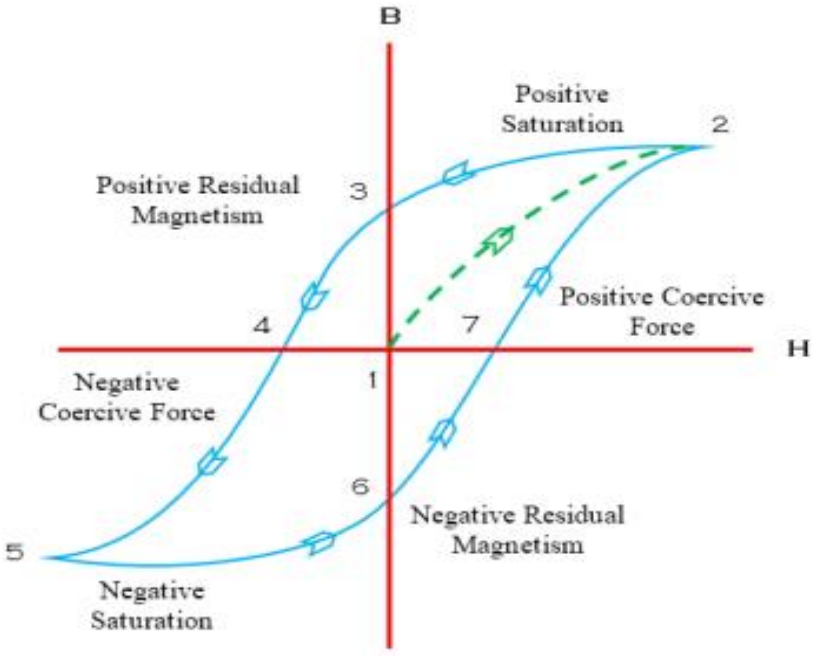



***Figure 1.3 Flux density(B)-field strength (H) curve for magnetic material (Vedrtnam, Ajitanshu & Kalauni,et al, 2020).***

### 1.2.2 magnetic property of ferrite material

Magnetic properties of material arise from the alignment of atomic or molecular spins, generating magnetic fields. Materials exhibit varying degrees of magnetism: ferromagnetism, paramagnetism, diamagnetism. These behaviors stem from interactions between magnetic moments, impacting material responses to external fields (Sieklucka, (2017)).

Magnetic materials can be classified based on their properties in particular permeability. Major types of magnetic materials fall into categories of diamagnetism, paramagnetism and ferromagnetism.

#### 1.2.2.1 Diamagnetism

Diamagnetism is a form of magnetism which is exhibited by a substance in the presence of an externally applied magnetic field (Kaufman, (2008)). It is the result of changes in the orbital motion of electrons. The applied magnetic field creates a magnetic force on a moving electron which is given by F = q (v x B). This magnetic force changes the centripetal force on the electron, causing it to either speed up or slow down in its orbital motion. This changed electron speed modifies the magnetic moment of the orbital in a direction opposing the external field

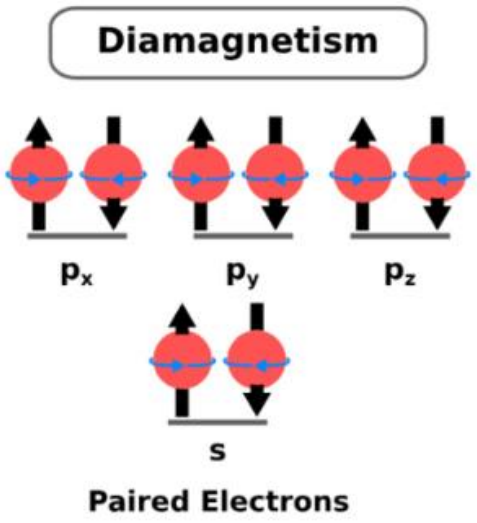



***Figure 1.4 a) Direction of spin orantation of Diamagnetism (Team PSIBERG, 2022)***

### 1.2.2.2 Paramagnetism

Paramagnetism is a form of magnetism, which occurs only in the presence of an externally applied magnetic field (Mohamed, (2019)). Paramagnetic materials are attracted to magnetic fields; hence have a relative magnetic permeability greater than one, while the positive magnetic susceptibility. However, unlike ferromagnets, which are also attracted to magnetic fields, paramagnets do not retain any magnetization in the absence of an externally applied magnetic field. This generally occurs due to the presence of unpaired electrons in the atomic orbital. In pure paramagnetism, the dipoles are randomly oriented in the absence of an external field and do not interact with one another, resulting in zero net magnetic moment.

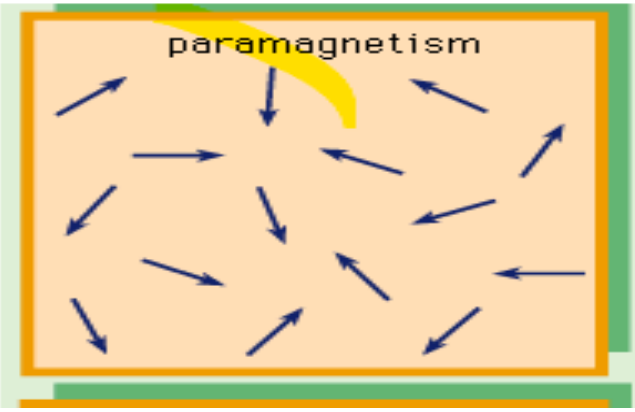



***Figure 1.4 b) the spin orientation of paramagnetism (Awadallah, (2015)***

Paramagnetic behaviour can also be observed in ferromagnetic materials only above their Curie temperature, and in antiferromagnetic above their Neel temperature. In general, the paramagnetic effects are quite small and thus possess the magnetic susceptibility of the order of 10-3 to 10-5, while it is high as 10-1 for synthetic paramagnets such as ferrofluids. For low levels of magnetization, the magnetization of paramagnets is approximated by Curie‟s law:

$$M = \frac{C.B}{T}$$

where,

**M** is the resulting magnetization

**B** is the magnetic flux density of the applied field in Tesla

**T** is absolute temperature, measured in Kelvin

**C** is a material-specific Curie constant

### 1.2.2.3. Ferromagnetism.

Ferromagnetism is characterized by the strong attraction of one magnetized body for another. Atomic magnetic moments arise when the electrons of an atom possess a net angular momentum magnetic moment (Coey, (2020)). The combined effect of the atomic magnetic moments can give rise to a relatively large magnetization for a given applied field. Above the Curie temperature, a ferromagnetic substance behaves as paramagnetic. Thus susceptibility approaches the Curie-Weiss law. The Curie temperature marks a transition between order and disorder of the alignment of the atomic magnetic moments. The ferromagnetic possess a spontaneous magnetization in the absence of an applied magnetic field below the Curie temperature. But under the 4 application of a weak magnetic field, the magnetization increases rapidly to a high saturation magnetization, which is in general a function of temperature.

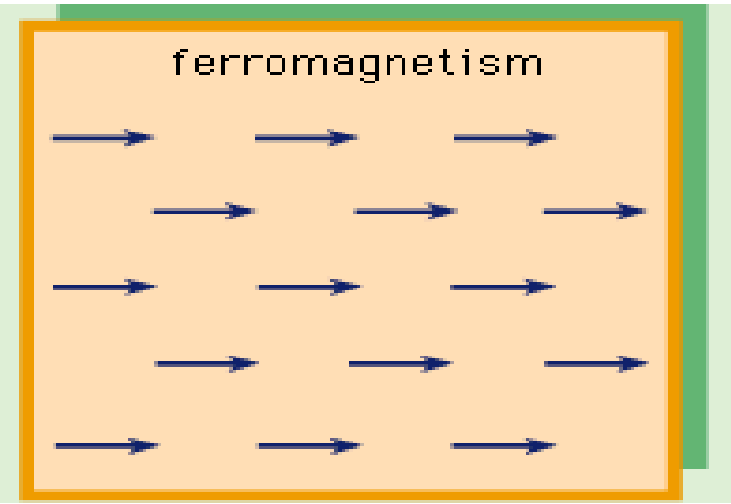



***Figure 1.4 c) the spin orientation of ferromagnetic (Awadallah, (2015)***

### 1.2.2.4. Anti-ferromagnetism.

antiferromagnetic materials are similar to ferromagnetic materials, but the exchange interaction between neighboring atoms leads to the antiparallel alignment of the atomic magnetic moments (Van Vleck, (1951)). Therefore, the magnetic field cancels out, and the material appears to behave

in the same way as a paramagnetic material. Like ferromagnetic materials, these materials become paramagnetic above a transition temperature, known as the Néel temperature, TN (Cr: TN = 37°C) (Reddy, (2023))

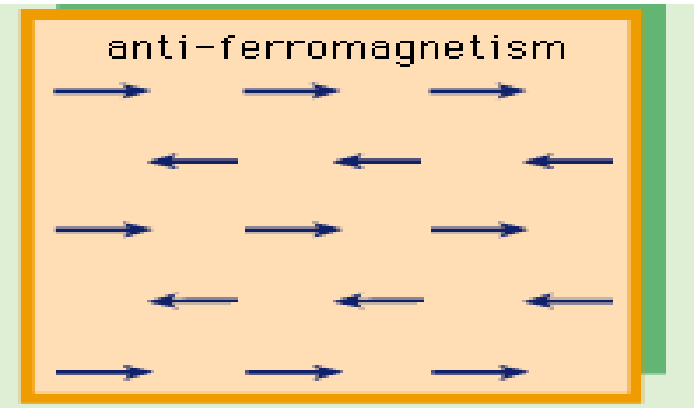



***Figure 1.4 d) spin orientation of anti ferromagnetism (Awadallah, (2015)***

### 1.2.2.5. Ferrimagnetism.

Ferrimagnetic materials are like ferromagnetic, where they hold a spontaneous magnetization below the Curie temperature, and show no magnetic order (are paramagnetic) above this temperature. However, below the Curie temperature at which the two sub-lattices have equal moments, resulting in a net magnetic moment of zero; this is called the magnetization compensation point. This compensation point is observed easily in garnets and rare earth–transition metal alloys. Furthermore, ferrimagnetic may also exhibit an angular momentum compensation point at which the angular momentum of the magnetic sub-lattices is compensated. This compensation point is a crucial point for achieving high speed magnetization reversal in magnetic memory devices.

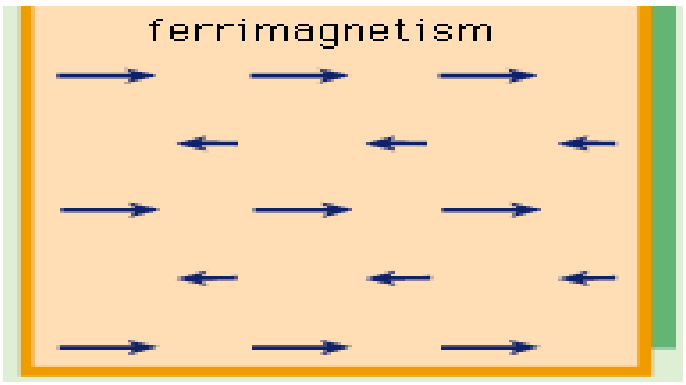



***Figure 1.4 e) spin orientation of ferrimagnetic (Awadallah, (2015)***

Ferrimagnetic materials have high resistivity and have anisotropic properties. The anisotropy is actually induced by external applied field. When the applied field aligns the magnetic dipoles it causes a net magnetic dipole moment and causes the magnetic dipoles it to presses at a frequency controlled by the applied field called Larmour or precession frequency.

## 1.3. Application of ferrite material

Ferrite materials have numerous applications across various fields due to their unique magnetic properties, which include high magnetic permeability, low electrical conductivity, and excellent resistance to demagnetization (Dastjerdi, (2023))

Considering the cation type and synthesis route, the structure of the ferrite and its particle size and shape changes and thus also its properties, which further lead to different applications. Ferrite materials find applications in microwave devices such as phase shifters, isolators, and circulators. They exhibit low loss at microwave frequencies and are used to control and manipulate microwave signals in communication systems and radar systems and also Ferrite materials are used in radio frequency (RF) components such as circulators, isolators, and antennas due to their low electrical conductivity and high magnetic permeability, which enable efficient RF signal transmission and isolation.the most frequent application of material can be expressed in figure 1.4

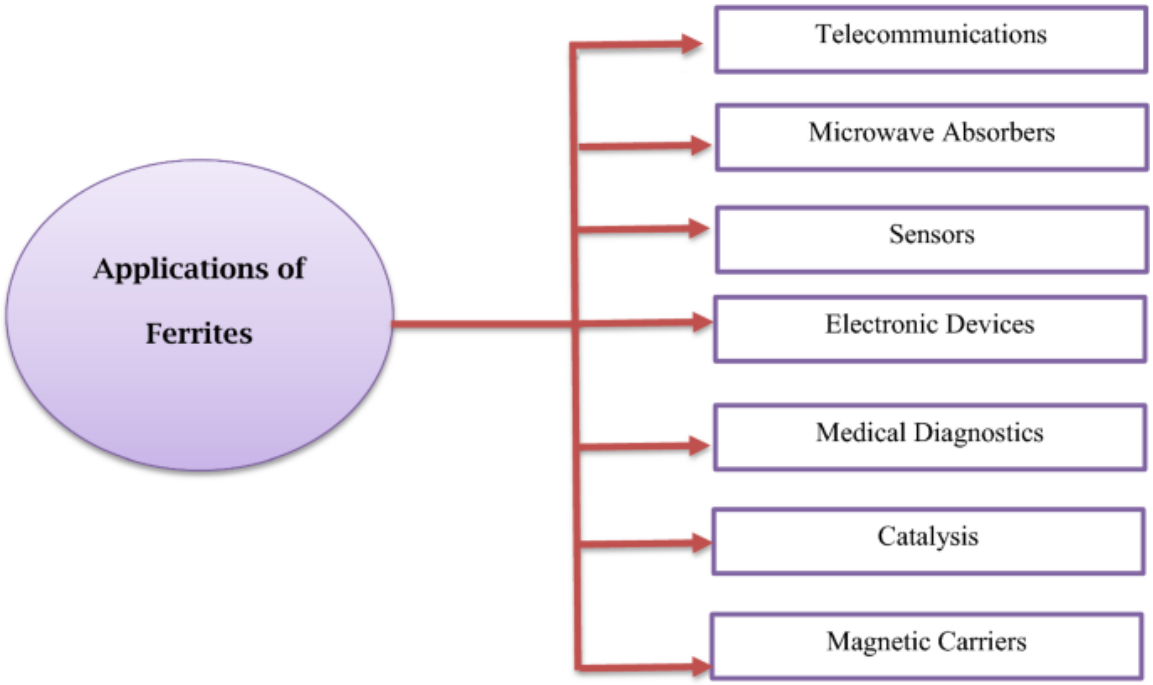



***Figure 1.5 some application of ferrites (Sambhudevan, 2021)***

### 1.3.1. magnetic application

The dependence of the magnetization on the grain size is due to the variations of exchange interaction between tetrahedral and octahedral sites (Anandan, Lee, Yang, Ashokkumar, & Wu, 2012). For their application in high-density magnetic recording, the magnetic particles should have nanosize to prevent the exchange interaction between adjacent grains, and thus reducing the media noise in the materials. The particles must also possess high HC values to obtain high storage density (Newman, (2007)). The magnetic properties (MR, MS, and HC) of spinel ferrites depend upon the composition, particle size, crystal structure, and cationic distribution between octahedral and tetrahedral sites.

The soft materials are used for inductor cores, transformers, and microwave devices, while hard materials are used for permanent magnets. Generally, the HC value is low in soft ferrites and the

magnetization can be tailored for cutting-edge applications in electronic engineering such as microwave components, high frequency inductors and transformer cores (Dippong, (2021)). Furthermore, due to the high HC values of hard ferrites, it is not so easy to magnetize, and hence it is used as enduring magnets with applications in washing machine, refrigerator, communication systems, microwave absorbing systems, loudspeaker, TV, switch-mode power supplies, DC-DC converters, and high-frequency applications (Dippong, (2021)).



***Figure 1.6. magnetic application of ferrite material (Chang T. H., (2020).)***

### 1.3.2. catalytic application of ferrite material

Using ferrite as a catalyst in organic reactions has been widely carried out and combined with other green synthesis methods. It offers a more environmentally friendly pathway by shortening reaction times, avoidance of harmful by-products, as well as advantages of stability in reuse (Bosica, (2022))

Spinel ferrites have been extensively used as heterogeneous catalysts as they can be simply recovered from the reaction mixture by filtration or in the presence of an external magnetic field and recycled numerous times, making the process more economically and environmentally feasible. Ferrite materials, particularly those containing transition metals like cobalt or manganese, have been investigated for their potential use as catalysts in water splitting reactions. These reactions involve the decomposition of water into hydrogen and oxygen, which is crucial for the development of renewable energy technologies such as hydrogen fuel cells (Xiao, (2012)).

Ferrite materials have been investigated for use as electrocatalysts in electrochemical reactions, including oxygen reduction and evolution reactions in fuel cells and metal-air batteries. Their electronic and structural properties can influence catalytic activity and stability in these energy conversion devices (Si, (2017)).

### 1.3.3. application of ferrite in electronic device

Ferrites become very important components in those devices in order to provide power conversion with high efficiency and to attain high reliability of network communications on vehicles which will be a basis of automated cruising technologies (A. Okamoto and S. Nakagawa, 2017).

Soft ferrite material are widely used in electromagnetic cores of transformers, switching circuits in computers and RF inductors, e.g., Lithium ferrite, Nickel ferrite and Mn-Zn ferrite

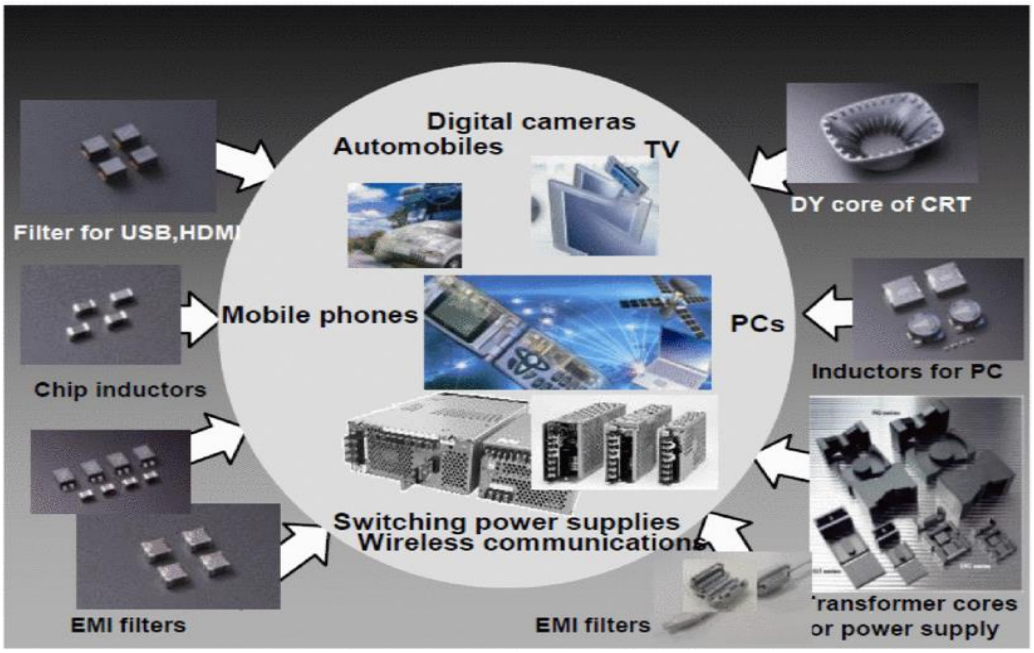



***Figure 1.7. Ferrite plays important roles in electric and electronics field (Okamoto, 2009).***

### 1.3.4. sensor application

Sensors are devices used for signaling changes that appear in a specific material in a certain environment (Kefeni, Msagati, & Mamba, 2017). Sensors based on ferrite NPs are highly sensitive, have low detection limits, and a high signal to noise ratio (Kefeni, Msagati, & Mamba, 2017).see the figure 1.7. One of the most frequent uses of sensors is for detecting changes of humidity. The monitoring of humidity is frequently used in industrial and domestic environments in order to assure human comfort and the appropriate storage of various goods, as well as the optimal functioning condition for industrial process and various instruments. Generally, the humidity-sensing phenomenon is based on the surface effect of water vapor–solid interaction. The ceramic type humidity sensors based on metal oxides displayed superior advantages comparing to polymer films in terms of physical stability mechanical strength, thermal capability, and resistance to chemical attack, making them promising materials for electrochemical humidity sensor applications

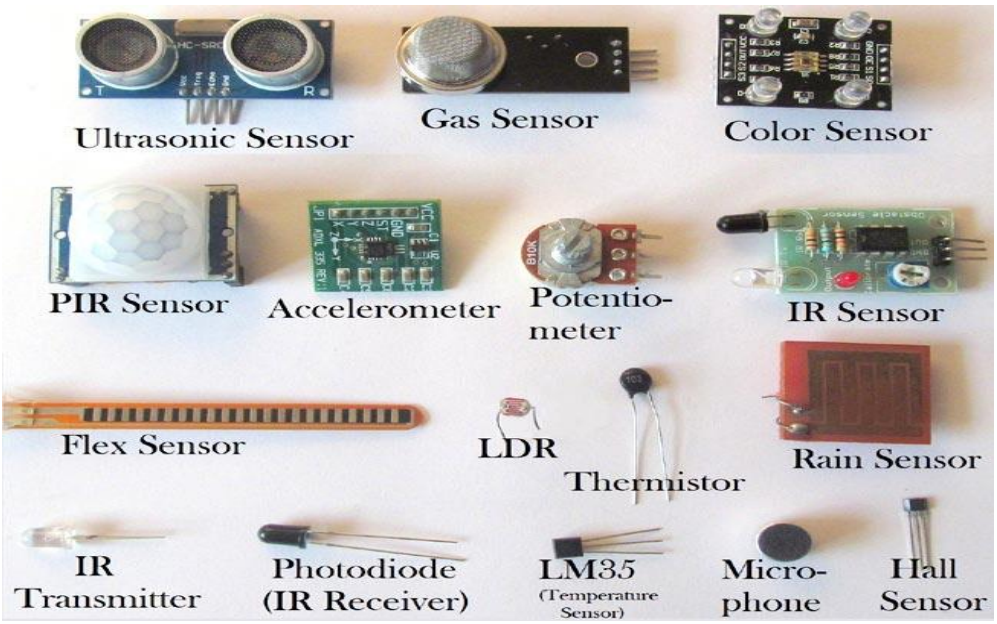



***Figure 1.8. different type of sensors (Vetelino, 2017)***

## 1.4. statement of the problem

Ferrite materials are used in diverse applications ranging from electronics to catalysis.While ferrite materials have diverse applications, there is often a gap between desired properties for a particular application and the properties that can be achieved through material synthesis and processing. Further research is needed to develop strategies for tailoring ferrite properties more precisely to meet the requirements of specific applications. studing the property of ferrite material is used to reengineering the material to develop the application in new area. For example, in magnetic recording media, understanding the magnetic properties of ferrite materials is crucial for achieving high-density data storage and read/write stability.

Ferrite materials exhibit unique magnetic, electrical, and structural properties that are critical for various applications. studying the properties and characterization of ferrite materials is crucial for advancing scientific understanding, optimizing performance in applications, ensuring quality control, predicting behavior under different conditions, facilitating materials design and development, fostering technological innovation, and addressing societal and environmental challenges.

## 1.5.Objective of the study

### *1.5.1. General Objective*

- ❖ The general objective of this study is to review the study on characterization and application of ferrite material.

### *1.5.2 Specific Objective*

The specific objectives of this study are:

- ✓ To review magnetic property of the ferrite material $AFe_2O_4$ (where A=Zn,Co,Mn.) detail**.**
- ✓ To review structural property of of the ferrite material $AFe_2O_4$ (where A=Zn,Co,Mn.)
- ✓ To review their performance for specific applications by selecting the appropriate composition, microstructure, and processing conditions.

## 1.6. purpose of the study

In this study,the review different ferrite material,to identifies the type and application depend on magnetic property.

In this review the experimental processes, as well as the thermal, structural, and optical characterization techniques were performed carefully using advanced instruments. The obtained results of the review are great interest and significance. The findings of this review study are believed to contribute to a better understanding of the impact of Co, Zn, and Mn doping on the thermal, structural, and optical property of $Fe_2O_4$ in ferrite material. the synthesis of ferrite powders by Sol-Gel Auto-combustion route, Hydrothermal synthesis method and Co-precipitation method was followed. The raw materials used for this were as follows: Zincacetate dihydrate $Zn(CH_3COO)_2{\cdot}2H_2O$, manganese dioxide ($MnO_2$), erythrite($Co_3(AsO_4)_2{\cdot}8H_2O$), Iron Nitrate [$Fe(NO_3)_3.9H_2O$], Lanthanum Oxide [$La_2O_3$], Citric Acid [$C_6H_8O_7.H_2O$]. All the chemicals were of standard grade and purity.

# CHAPTER TWO

## LITRATURE REVIEW

The property and application of ferrite material is studied by many researcher some of those researcher view are explained below:

Ferrite materials are easy to synthesize and have useful properties and applications in the field of sensor. The laboratory model of the sensor using ferrite is a better device for sensing humidity as well as gas. A great advantage of ferrites is their porosity, which is necessary for a sensor. These pores serve as humidity or gas adsorption sites and the sensitivity of sensor depends on the size of these pores (Srivastava, (2012)).

NiCuZn ferrite is a very important material for multilayer chip inductor core material. La & Mg substituted NiCuZn ferrites have been reported in different literature for their improved electromagnetic properties. However, there is no report of simultaneous substitution La and Mg in NiCu Zn ferrite. All the compositions were synthesized through auto-combustion method (Pradhan P. , 2012). The nano-crystalline ferrite powders were successfully synthesized by this method. The powders were characterized for their phase formation using XRD. After calcination at 7000 C the powders were pressed in to pellet and toroid specimens. The specimens were sintered at different temperatures and characterized for their bulk density, microstructural development, dielectric and ferromagnetic properties (Pradhan P. , 2012)

Ferrites are prepared by standard solid state reaction technique. The samples prepared from each composition are sintered at various temperatures (1150, 1200, 1250, 1300, and 1350 $^{o}$C) in air for 3 hours. Structural, surface morphology and compositional analysis are characterized by X-ray diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) spectroscopy, respectively. The magnetic properties of these ferrites such as frequency and temperature dependent complex initial permeability are measured by Wayne Kerr Impedance Analyzer and the DC magnetizations as a function of applied magnetic field are performed by Vibrating Sample Magnetometer (VSM) (Islam N. , 2016).

Superparamagnetic zinc ferrite ($ZnFe_2O_4$) nanoparticles were prepared by a surfactant assisted hydrothermal method and subjected to the heat treatment. The structure, vibrational, morphology, and magnetic properties of synthesized product were characterized by XRD, FT-IR, HR-SEM, and VSM measurements. XRD result confirms the formation of regular spinel structured $ZnFe_2O_4$ with space group of Fd3m and an average crystalline size was calculated as 21 nm and 28 nm for the samples annealed in air atmosphere at 300 °C and 600 °C (Rameshbabu, R. & Ramesh, et Al., 2013).

The crystal structures, morphology and chemical properties of the as-synthesized nanoparticles were characterized using X-ray diffraction, scanning elec-tron microscopy, energy dispersive X-ray, vibrating sample magnetometer techniques and UV–Vis diffuse reflectance spectroscopy. The photocatalytic activity of $CoFe_2O_4$ was investigated by degradation of methyl orange (MO) as cati-onic dye in aqueous solution under UV irradiation. The results indicate that about 77% of MO were degraded after 80min (Talebi R. , 2017).

Magnetic manganese ferrite powder was synthesized via chemical co-precipitation techniques using metallic chlorides of manganese and iron. Sodium hydroxide (NaOH) base was used as precipitant agent. The calcinations were performed at 600°C for 5 h. The structural investigation of the prepared sample was performed with X-ray diffractometer (XRD) and scanning electron microscope (SEM). The crystallite size was 26.53 nm, calculated using Sherrer formula. Magnetic properties were studied by vibrating sample magnetometer (VSM) techniques at room temperature (Elahi, Irfan & Zahira, et Al., 2012).

Characterizing the ferrites' properties, including the complex permittivity, the saturation magnetization, and the resonance linewidth, will be discussed. We then utilize these properties to design and fabricate various microwave devices, such as phase shifters, circulators, and isolators (Chang T.-H. , 2020). Ferrites are ceramic materials and suitable for the high-frequency operation. The electromagnetic properties of ferrite materials are difficult to understand in that the magnetic susceptibility is a tensor and depends on the saturated magnetization Ms, the internal bias field H0 and the resonance linewidth $\Delta H$. The magnetic susceptibility also depends on the frequency of the microwave $\omega$ as well as the polarization of the wave. The first two sessions explain the basic properties (Chang T.-H. , 2020).

The novel co-precipitation technique has been employed to create the manganese ferrite nanoparticle. The prepared sample was annealed for various temperatures 400 °C, 600 °C and 700 °C. Based on TG/DT analysis the optimal temperature was found to be 700 °C and further additional analysis was performed for the sample annealed at 700 °C. Their morphology and properties were determined using SEM, HR-TEM, EDX, FTIR, XPS, BET, and CV techniques. Using the X-ray diffraction technique, the prepared sample's structural characteristics were demonstrated. The SEM as well as HR-TEM images showed the nanoparticles had a roughly spherical shape. The EDX analysis confirmed the presence of the elements Fe,O, and Mn in the sample; there was no evidence of contamination by other elements. The specific surface area of the nanoparticles was estimated by BET analysis, which provides details of the material's porosity and surface area (Abisha D,and Gibin S.R, et Al., 2023).

# CHAPTER THREE

# METHODOLOGY

## 3.1. Material and Equipment Used

The chemicals that were used for sample preparation are presented in Table 3.1.

***Table 3.1. List of chemicals, their chemical formula, purpose, purity***

| **Sr. no** | **Raw material** | | **purpose** | **Purity %** |
|---|---|---|---|---|
| | **Chemical name** | **Chemical formula** | | |
| **1** | Zincacetate dihydrate | $Zn(CH_3COO)_2 \cdot 2H_2O$ | Source of zn | 99 |
| **2** | Iron(III) Nitrate | $Fe(NO_3)_3.9H_2O$ | Source of Fe | 98 |
| **3** | manganese dioxide | $(MnO_2)$ | Source of Mn | 95 |
| **4** | erythrite | $(Co_3(AsO_4)_2 \cdot 8H_2O)$ | Source of Co | 92 |

## 3.2. Synthesis methods of ferrites

The properties of ferrites can be significantly affected by the synthesis method of ferrites. The most popular methods for synthesis of ferrites are sol-gel (RC, 2012), hydrothermal (Nejati K, 2012) (RC, 2012), co-precipitation (Rane AV K. K., 2018) and solid-state method (Rane AV K. K., 2018) .some other method are also used such as inert gas condensation (Rane AV K. K., 2018), micro-emulsion (Rane AV K. K., 2018), electrochemical method, thermal decomposition, electro-spinning method (RC, 2012), etc. for synthesis of ferrites.

### 3.2.1. sol-gel synthesis method

The sol-gel method is a low temperature process based on hydrolysis and condensation reactions of metal precursors (salts or alkoxides), leading to the formation of a three-dimensional inorganic network (Sajjia, Oubaha, Hasanuzzaman, & Olabi, 2014).

Sol gel is the multi-step process involving chemical and physical processes associated with hydrolysis, polymerization, gelation, condensation, drying and densification. The flowchart of synthesis of ferrite through sol gel process is shown in Figure 3.1. In sol gel technique, materials are obtained from chemical solution via gelation. There are two type of routes, i.e., the metal-organic route with metal alkoxides in organic solvent and the inorganic route with metal salts in aqueous solution (chloride, oxychloride, nitrate). The inorganic route is much cheaper and easier to handle than metal alkoxides, but their reactions are more difficult to control. This method allows more accurate control over the phase formation, desired stoichiometry and uniformity in particle size (LM, 2015).

Unlike solid state reaction route, sol gel processing does not require any grinding procedures to achieve homogeneous single phasic ceramics, thereby no chance of a potential source of contamination. There are also some disadvantages of sol gel method such as raw materials for this process is expensive compared to mineral based metal ion sources, products would contain high carbon content, several steps are involved; close monitoring of the process is needed, long period of time for processing and difficulty related to phase separation (LM, 2015).

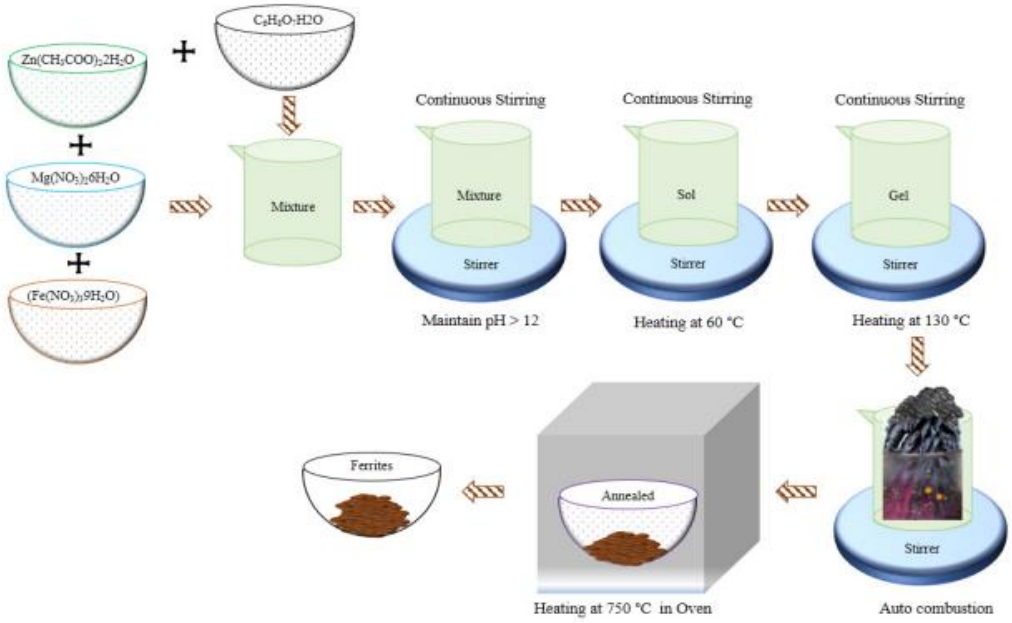



***Figure 3.1. The flowchart for synthesis of ferrite via solgel method (Vedrtnam, Ajitanshu & Kalauni, et Al, 2020).***

### 3.2.2. Hydrothermal synthesis method

The hydrothermal method is simple, low-cost and one of the most common method for preparation of ferrites. This route provides an enhanced reaction rate to produce multi-metal oxide compounds (Allaedini G, 2015). In this method, crystalline structures (films, nanoparticles, single crystals, etc.) have synthesized from aqueous solutions under high vapor pressure. For ferrites (mostly HFs), in general, iron nitrate and metal nitrate are dissolved in distilled water to prepare metal salts. Then the suspension of precipitated precursors is put in a sealed autoclave and heated very slowly for different temperatures and time. The temperature inside autoclave starts decreasing after some time due to the relatively large thermal capacity. Surfactants like oleic acid may be used to avoid agglomeration of nanoparticles during hydrothermal treatment. After this process, each product is thoroughly washed with a diluted solution of acetic acid because acetic acid easily dissolves metal-rich compounds formed as a by-product. Finally, particles are washed with deionized water and dried as shown in Figure 3.2.

In this process, the particle size depends on the hydrolysis rate and the solubility of the metal oxide. The advantages of this non-conventional process are high purity, chemical homogeneity,

small and uniform particle size, and controlled particle shape. The drawbacks associated with this synthesis method are prior knowledge on solubility of starting materials, the expensive autoclave, hydrothermal slurries are potentially corrosive, accidental explosion of the high-pressure vessel, etc (Vedrtnam, (2020)).

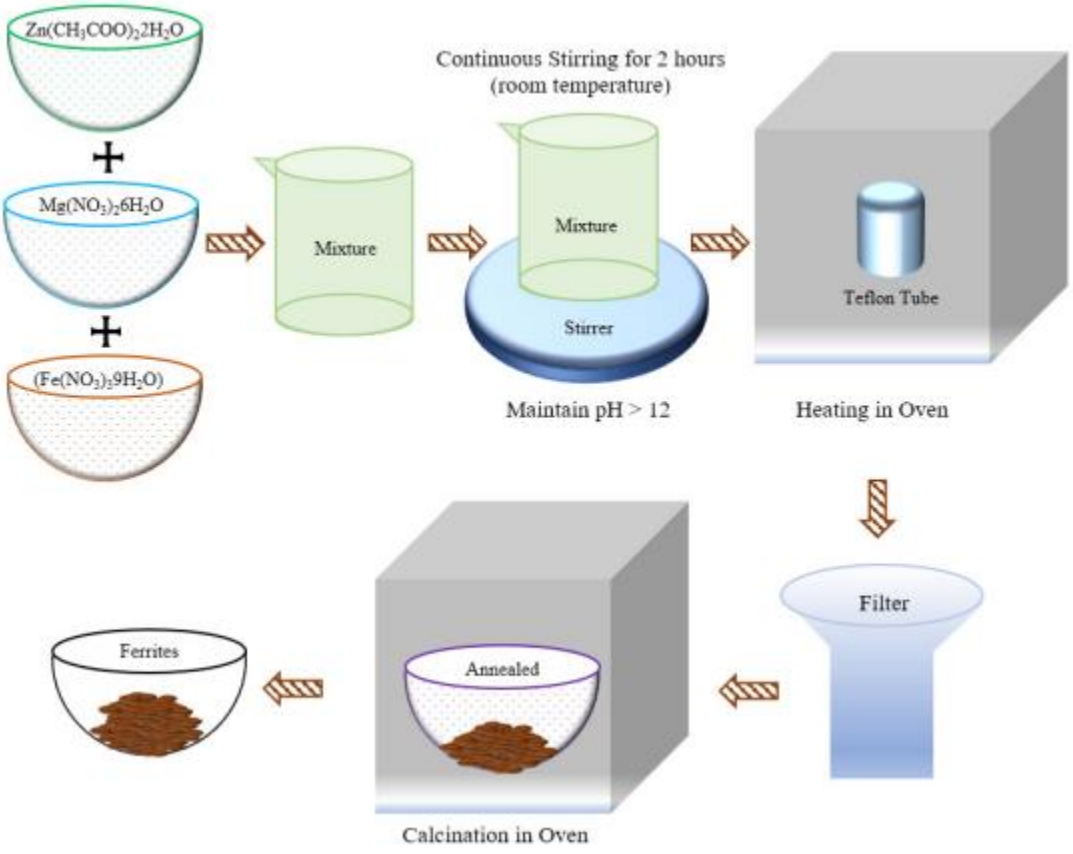



***Figure 3.2 The flowchart for synthesis of ferrite via hydrothermal method (Vedrtnam, Ajitanshu & Kalauni, et Al, 2020).***

### 3.2.3. Co-precipitation method

The chemical co-precipitation method is the simplest and convenient method to synthesize magnetic particle. In this method, a uniform composition is obtained by precipitation reaction of two or more cations (Liu S, 2019). This method involves four steps, i.e., the simultaneous occurrence of nucleation, growth, coarsening and agglomeration (Rane AV K. K., 2018).

In the co-precipitation method, precipitation is conducted by adding a mixture solution containing chloride of cations (Fe, Sr, etc.) dropwise into a $NaOH/Na_2CO_3$ solution. Carbonate or nitrate of cations can be used in place of chloride cations to synthesis HFs. However, in the latter case cations of carbonate such as $SrCO_3$ are converted into cations of chloride by hydrochloric acid. The formed precipitates are filtered, washed with water a few times, by washing with ethyl alcohol until no NaCl could be detected, and the pH value should be kept below 8. The washed powders are dried and then calcined at 950 °C for 3 h as shown in figure 3.3. This method has certain advantages such as simple method, easy control of particle size, homogeneity of nanomaterial with small size,

bulk production of magnetic nanoparticles energy efficient, etc. Some of the disadvantage of this methods are trace impurity.

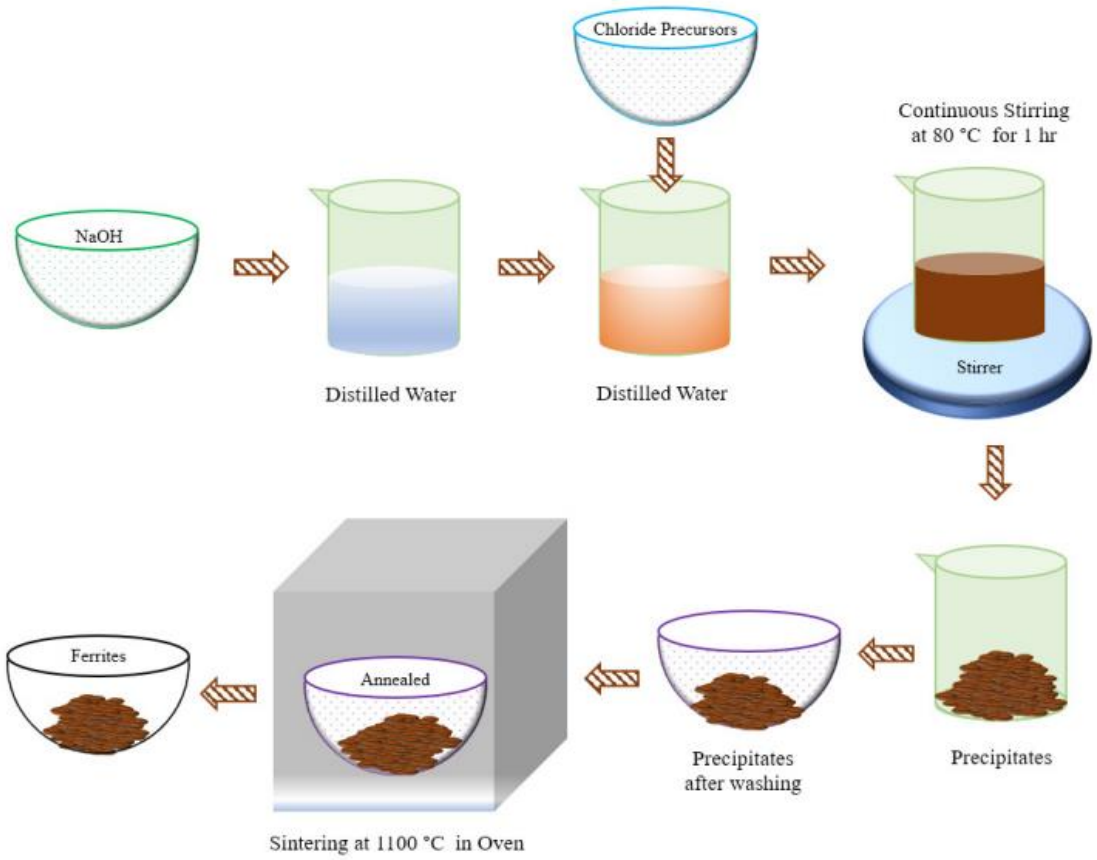



***Figure 3.3 The flowchart for synthesis of ferrite via chemical coprecipitation method (Vedrtnam, Ajitanshu & Kalauni, et Al, 2020).***

## 3.3. Materials characterization

The material characterization of ferrites includes the investigation of crystallography, structural morphology, chemistry (identification of chemical constituents, chemical composition, their distribution), thermal properties, magnetic properties, electrical properties, etc.

### 3.3.1. x-ray diffiraction(XRD)

X-ray diffraction is a quick analytical technique that can offer information on unit cell dimensions and is mostly used for phase identification of crystalline materials. The studied material is finely powdered and homogenized before determining the average bulk composition (Bunaciu, 2015). as shown in Fig.3.4. The crystal structure, lattice parameters, strains and crystallite size were determined from these studies.



***Figure 3.4: Rigaku-make powder x-ray diffractometer, National Physical Laboratory, New Delhi***

In this review, the principle of XRD is that for a fixed wavelength (λ), the constructive interference occurs for a fixed set of an interplanar spacing (d) and incidence angle (θ). The relationship between wave length of incident X-rays, the distance between the layer and the angle of diffraction, Bragg's have given a mathematical equation (AK, 2001)

$$n\lambda = 2d\ sin\ \theta$$

where n = an integer (1, 2, 3, 4, …etc.) which represents the serial order of diffracted beams.

Figure 3.5 shows the basic features of an XRD experiment set up; the diffraction angle 2θ is the angle between the incident and diffracted x ray

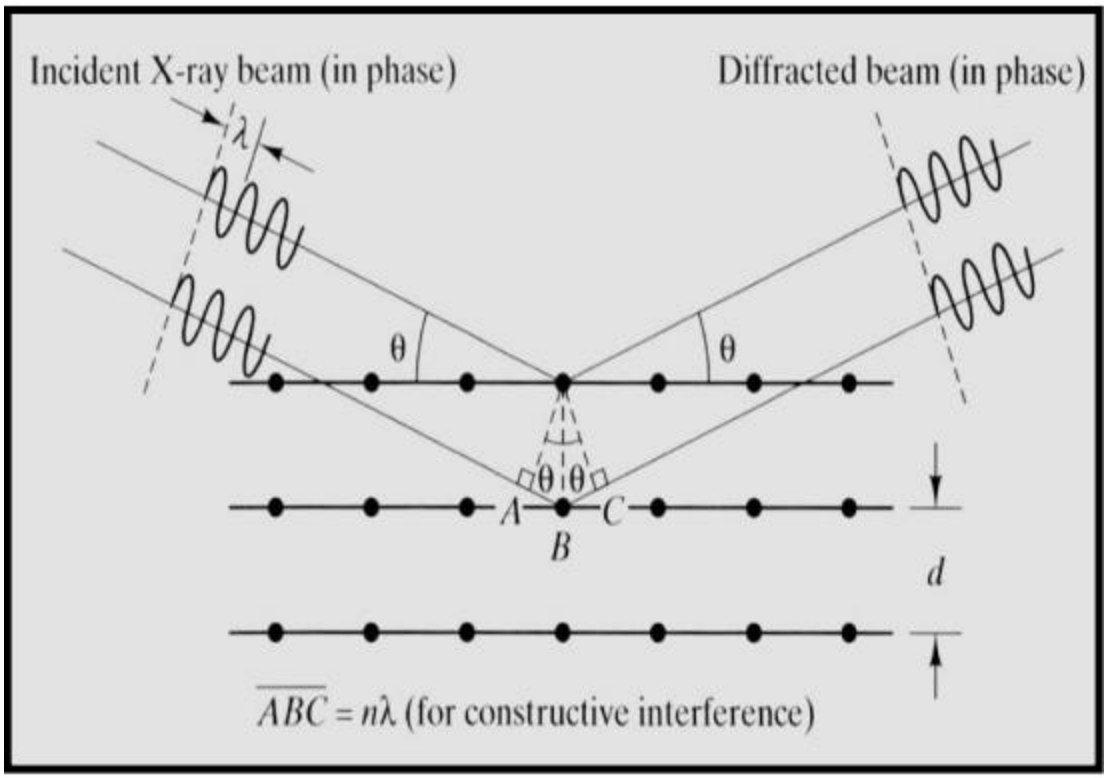



***Figure 3.5: Basic features of a typical XRD experiment (S. Baron, 2020)***

Particle size is obtained from the full width at half maximum (FWHMs) of the diffraction peaks. The FWHMs ($\beta$) can be expressed as

$$\frac{\beta \cos\theta}{\lambda} = \frac{1}{L} + \frac{\varepsilon \sin\theta}{\lambda}$$

Where **ε** = strain and **L** = particle size.

### 3.3.2. Scanning electron microscopy (SEM)

The morphology of ferrites can be determined by using scanning electron microscopy (SEM) or field emission scanning electron microscopy (FESEM). It refers to the study of shape, size and structure of ferrites.

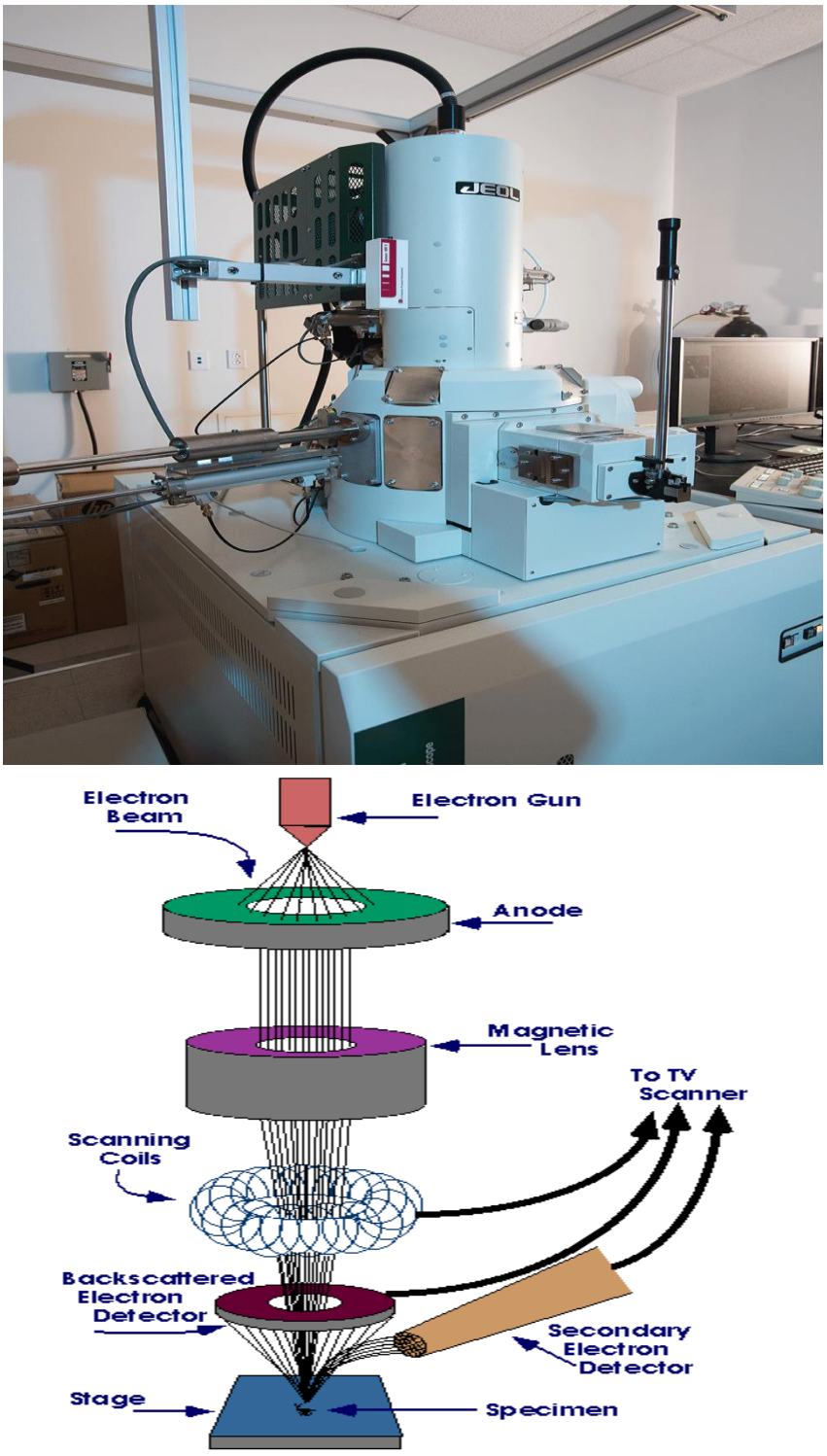



***Figure 3.6: Scanning Electron Microscope-TCU magazine and purdue university***

SEM is only an instrument for considering undetectable universes of smaller scale space to Nano-scale.that employed for inspecting morphology, topographical features, compositional mapping and crystallographic information at quite high magnifications using a piece of device (Brandon, 2013).

### 3.3.4 Vibrating sample magnetometer (VSM).

VSM is a scientific instrument that measures magnetic properties as a function of magnetic field. It operates on Faraday's Law of induction, a changing magnetic field will produce an electric field. This electric field can be measured and can obtain information about the changing magnetic field.By applying VSM technique, the important magnetic properties include saturation magnetization (Ms), coercivity (Hc), retentivity (Mr) and magneto-crystalline anisotropy is calculated (Ateia, 2021).

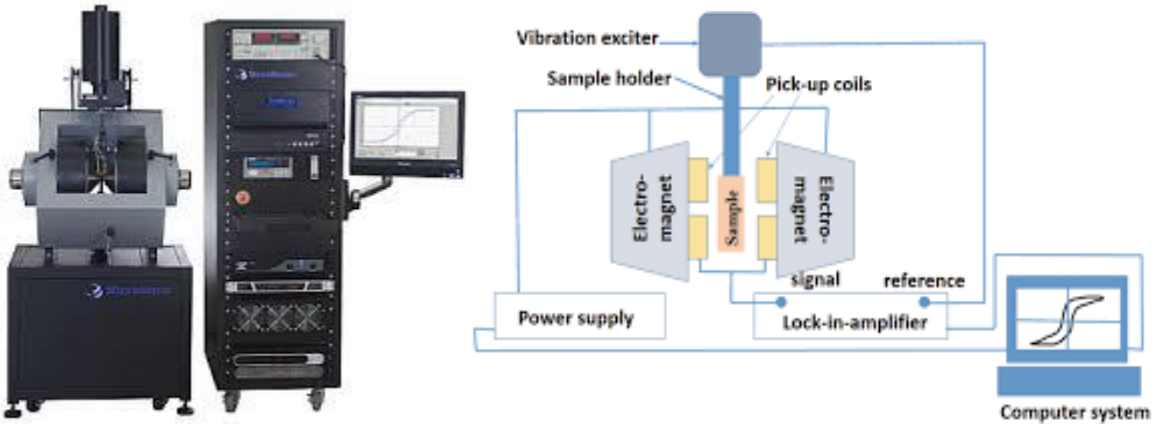



***Figure 3.7:*** **Vibrating Sample Magnetometer** ***(Shukla, 2022)***

### 3.3.5. Spectroscopy

Infrared spectroscopy is the analytical technique in which the chemical substance shows selective absorption in the infrared region and molecules of the substance vibrates at various rates. These vibration rises the closed pack absorption bands and known as infrared absorption spectrum, which may extend with wavelengths. These infrared spectrums signify a pattern of a material with absorption peaks corresponding to the frequencies of vibrations between the bonds of the atoms ***(Thompson, 2018)***.

Fourier transform infrared spectroscopy (FTIS) is a non-destructive technique that detects vibrational characteristics of chemical functional groups the analysed sample. Using fingerprints, infrared spectroscopy can identify the structure of materials and unknown materials. The infrared region constitutes three fundamental regions: near infrared, middle infrared and far infrared Among all, the middle infrared region which has a wavenumber from 4000 to 400 cm-1 is active enough to excite molecular vibrations to higher energy states (Dutta, 2017)

### 3.3.6. Thermal analysis

Thermal analysis is used to determine the traces of water content in nanoferrites with the help of Differential Thermal Analysis (DTA), Thermogravimetry (TG), Differential Thermo gravimetry (DTG), and Differential Scanning Calorimetry (DCS). The TG curve represents the change in weight as a function of temperature while DSC curve display the change in energy as a function of temperature (Jotania, 2014)

When performing thermal analysis on a material, it is important to consider the specific properties of the material that are being studied, as well as the temperature range and heating rate that will be used during the analysis. Additionally, it is important to ensure that the sample is properly prepared and that any necessary precautions are taken to prevent damage to the instrument or the sample.

# CHAPTER FOUR

# RESULT AND DISCUSSION

This chapter focuses on analyzing and interpreting the research findings. The analysis includes the results obtained from measurement techniques such as TGA/DTA for thermal property, XRD and FTIR spectroscopy for structural analysis and VSM analysis as well as SEM for physical property. Ferrite material studied are $MFe_2O_4$ (M = Co, Mn, Zn, or other metals).The findings are presented through graphs and tables, and their implications are discussed in subsequent sections.

## 4.1. X-ray diffiraction(XRD) pattern analysis

Phase identification was performed by Panalytical X ray diffractometer using Cu Kα radiation (40 KV, 20 mA). Peak intensities were collected by step scanning over a 2θ range from 150 to 750 with a step size of 0.020 remaining for 10s at each step. As shown in figure 4.1a, The $ZnFe_2O_4$ nanoparticles have a degree of crystallinity.The XRD pattern shows the peaks at(111), (220), (222), (311), (400), (422). (511), (440), (533) and (622) which confirm the presence of single-phase zinc ferrite with face centered cubic structure. Except some impure phases of ZnO all the phases correspond to the standard pattern of Zinc ferrite (cubic, a = 0.8441 nm, space group: Fd3m, Z = 8; ICDD PDF: 22-1012).

Figure 4.1.b shows the XRD pattern of cobalt ferrite The average crystallite size of calcined sample obtained at 923 K, for five planes with higher intensities that consist of (311), (440), (220), (511), and (400), was estimated as 8.357 ± 0.003 A◦, which is in relatively good agreement with the bulk value of 8.377 A◦

The prominent peak at (311) are used to calculate the crystalline size through Debye Scheror formula as equation below

$$D = \frac{0.9\lambda}{\beta \cos\theta}$$

Further The lattice parameters were calculated using the formula

$$\frac{1}{d^2} = \frac{4}{3}\left\{\frac{h^2 + k^2 + l^2}{a^2}\right\} + \frac{l^2}{a^2}$$

Using this formula, the value of a is found to be 0.8478 nm for zinc, the calculated crystallite size was found to be 14.33 nm for cobalt ,27 nm for zinc ferrite and the value of particle size is calculated as 23.53 nm for manganese ferrite.which is slightly higher than reported in standard pattern JCPDS data.

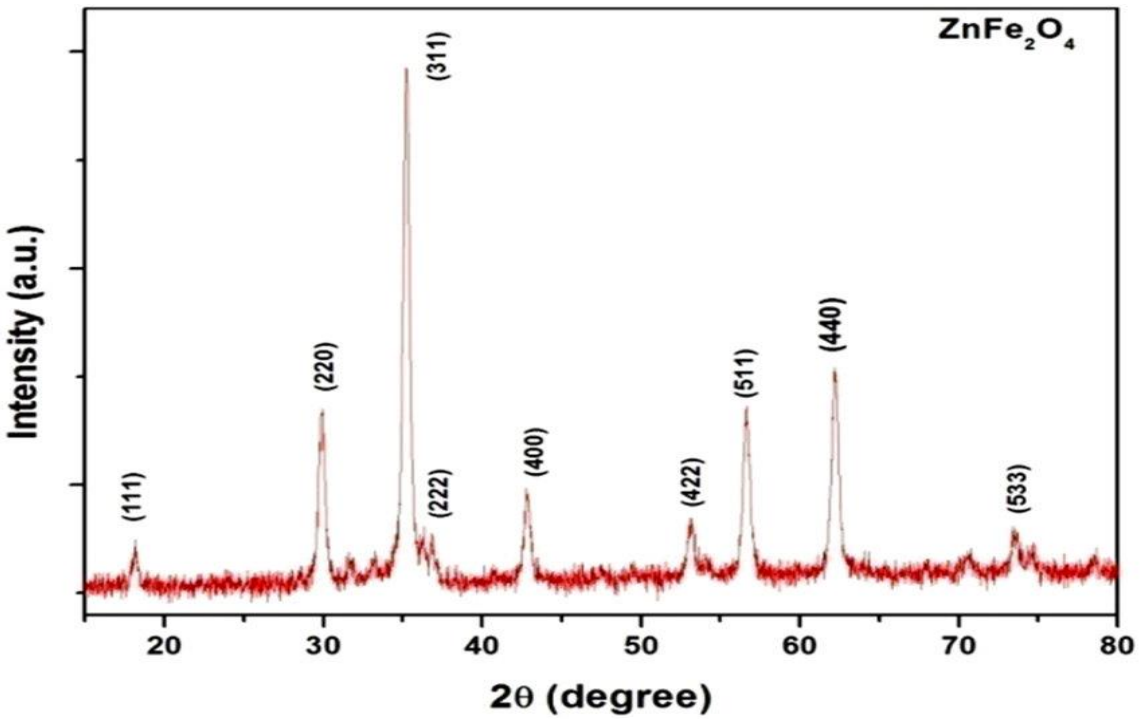



*Figure 4.1.a XRD graph of zinc ferrite nanoparticle (Borade, Ravikumar & Somvanshi,, 2020).*

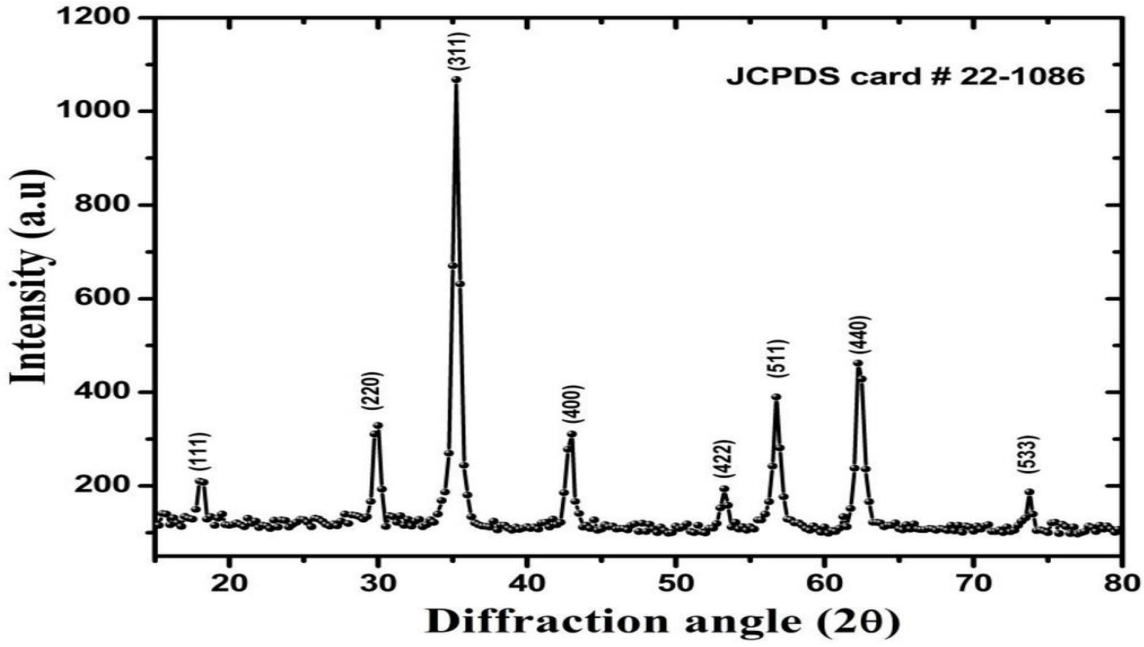



*Figure 4.1.b X-ray diffraction patterns of CoFe2O4 ferrite nanoparticles (Liang, C.,and Zou,et Al. , 2020).*

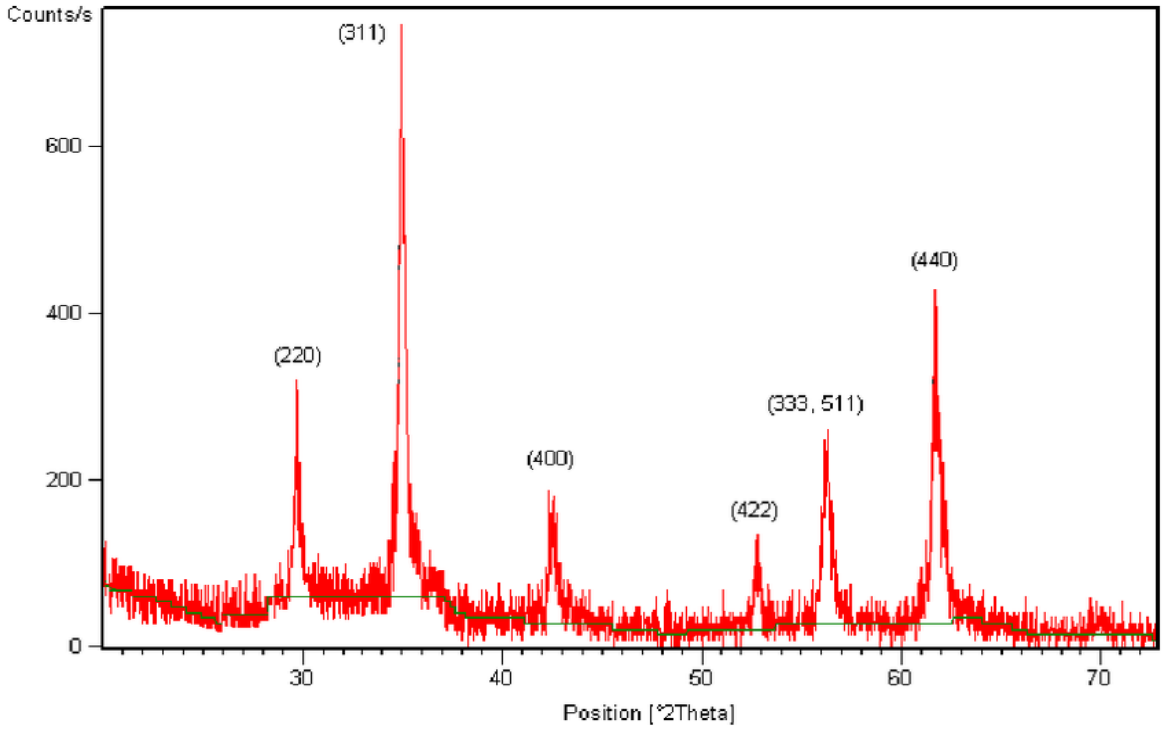



***Figure 4.1.c X ray diffraction pattern of manganese ferrite powder (Elahi, Irfan & Zahira, et Al., 2012)***

The crystallite size of ferrite (zinc,cobalt, manganese) nanoparticles is based on x ray diffraction line broadening and is calculated by using Debye Scherrer formula as

$$D = \frac{0.9\lambda}{\beta \cos\theta}$$

Where **D** is the average crystallite size **β** is full width half maxima of the peak in XRD pattern **θ** is Bragg's angle. λ is X- ray wavelength.

## 4.2. Scanning Electron Microscope (SEM) Analysis

It refers to the study of shape, size and structure of ferrites. It is clearly noticed in cited literature that the ferrite particles have consisted several different shapes such as spherical, needle shaped, regular hexagonal, flat platelet, large ball shaped, polygonal and etc. The SEM image demonstrated the development of homogeneous microstructure as shown figure 4.2. The results from SEM images demonstrate that the morphology, development of microstructures, and increase or decrease of grain size is highly dependent on substitutions and their doping percentage level.

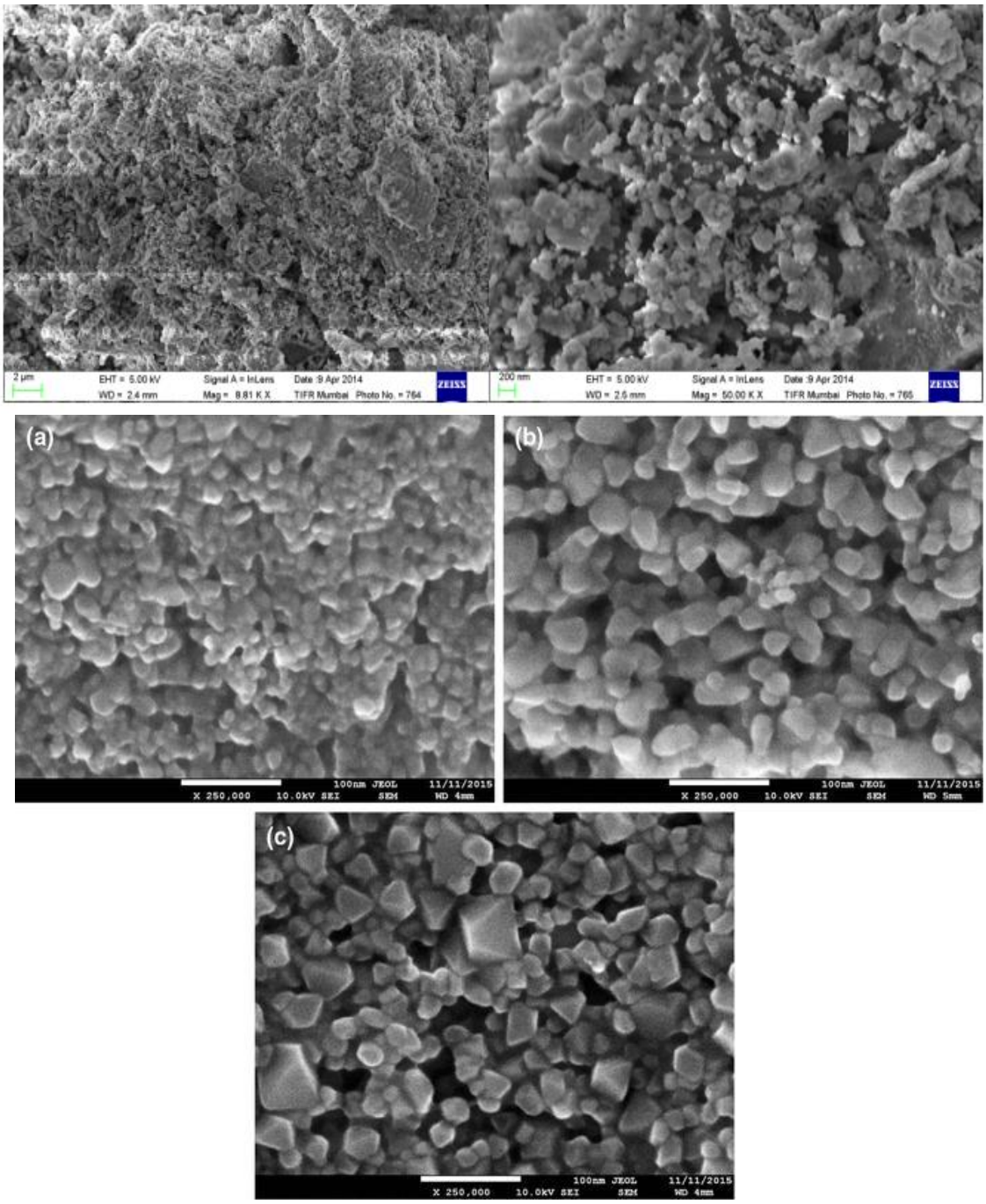



***Figure 4.2a. Scanning electron microscopic image of zinc ferrite nanoparticles at different magnifications (Yadav, Raghvendra & Havlica, et Al, (2016)***

Above images show the zinc ferrite nanoparticles at different magnification. From the SEM micrograph it is clear that mostly the particles are mostly spherical in nature. The particle size is nonuniform. Average particle size is of the order of 20 nm which agrees with the XRD data.

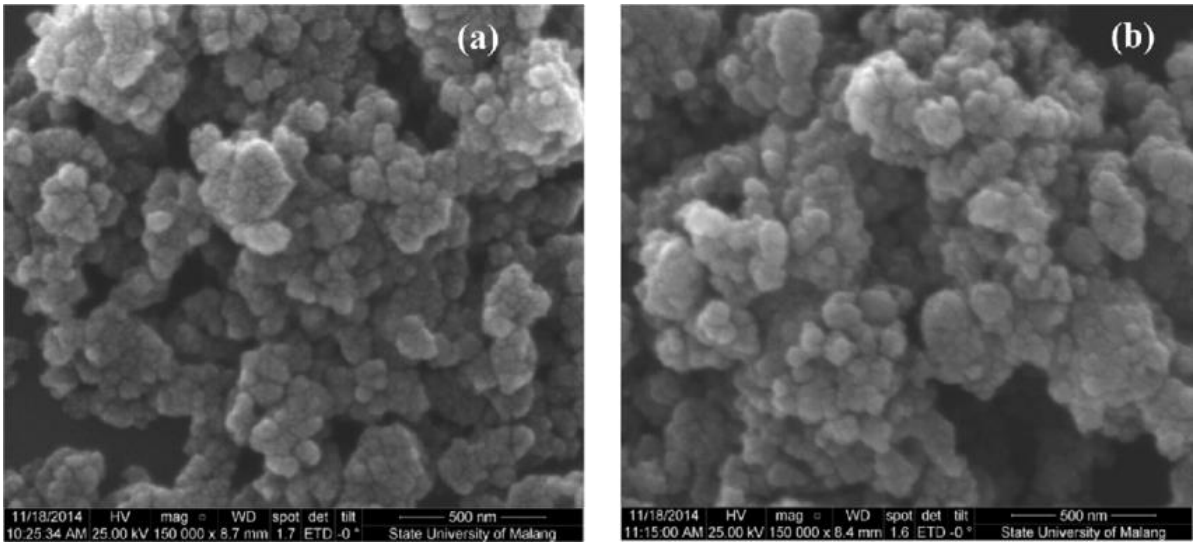



***Figure 4.2b Typical SEM images for cobalt ferrite after annealing at 600°C (Purnama, Budi & Rahmawati, et Al., 2015)***

Figure4.2b shows the SEM image of the cobalt ferrite nanoparticles with a 150,000× magnification at annealing time periods of 2 and 11 h. The particle distribution is indicated by a small circle, which is the typical observational expectation for cobalt ferrite nanoparticles. With an annealing time of 11 h,itseems that the small particles diffuse relative to the other particles to create bigger particle.

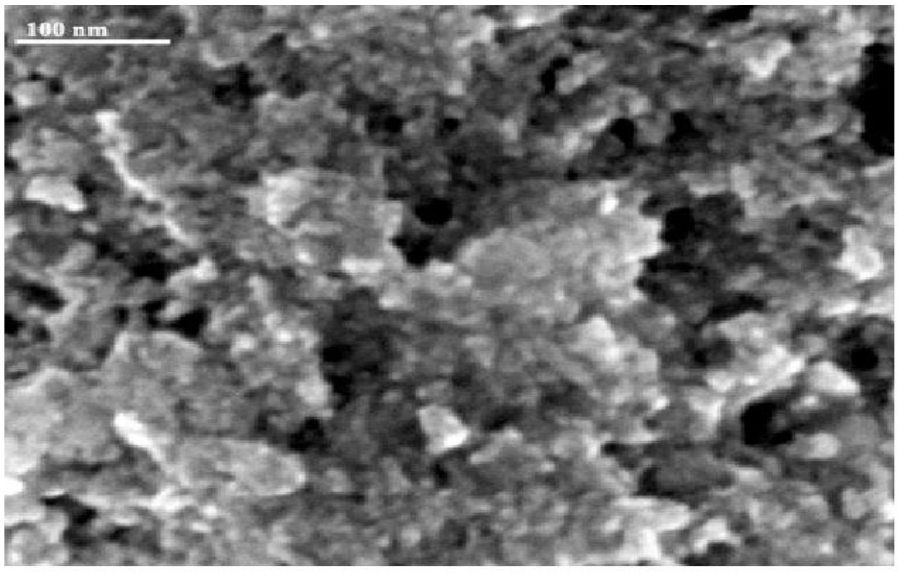



***Figure 4.2c. SEM image for manganese ferrite nanoparticles (Bellusci, Mariangela & Aliotta, et Al. , 2012).***

Figure 4.2c, clearly shows the SEM image of the manganese ferrite particle that agglomeration phenomena. However, the composite materials remain in a dimensional range applicable in biomedical field.

## 4.3 Vibrating sample magnetometer (VSM) Analysis

The magnetic characteristics of the produced samples were subjected to magnetic analysis using VSM (15k Oe).figure 4.3 depicts the resulting magnetic hysteresis. This hysteresis loop was used to investigate the relationship between respective magnetic characteristics measurements. The magnetization of zinc ferrite at 15k Oe was correlated to the crystallite size and inversion parameter. The magnetic measurements exhibited that the zinc ferrite nanoparticles synthesized at 40 °C were superparamagnetic with the maximum magnetization of 7.3 emu/g at 1k Oe.

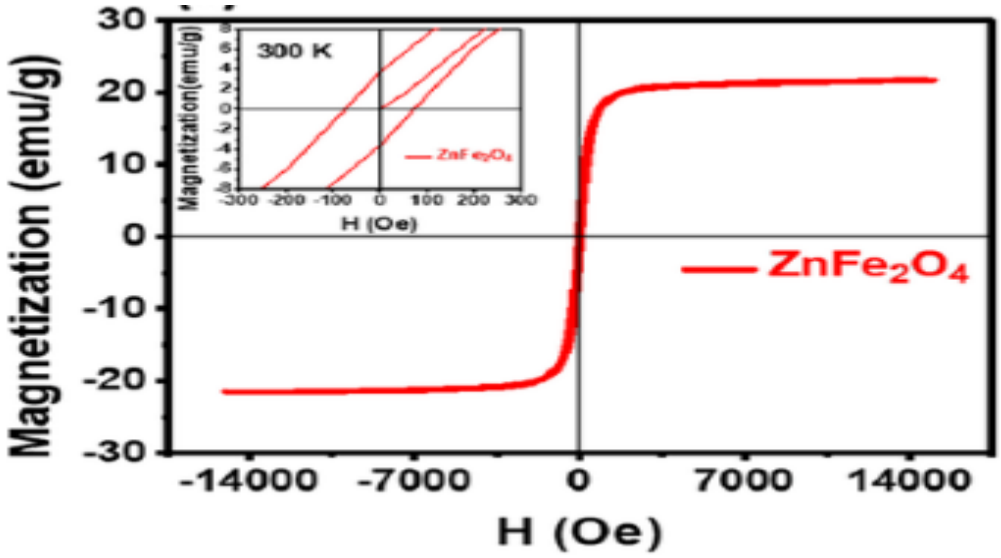



***Figure 4.3 a) Vibrating sample magnetometer (VSM) analysis graph of nanoparticles $ZnFe_2O_4$ (Patil, 2023)***

The magnetic properties of the $ZnFe_2O_4$ nanoparticles were studied by utilizing pulsed field hysteresis loop tracing method at room temperature. The M-H plot for the $ZnFe_2O_4$ nanoparticles is appeared in figure 4.3a. These prepared zinc ferrite nanoparticles display the superparamagnetic nature which can be described by hysteresis curve with the magnetic parameters as moderate saturation magnetization, lower remanence magnetization and unimportant coercivity esteem. This proposes the prepared zinc ferrite catalyst show magnetic character, which demonstrates that no magnetization remained when the applied attractive field is expelled. Taking points of interest of these magnetic properties, the catalyst ought to almost certainly effectively separate from reaction mixture by applying an outside guest magnetic field.

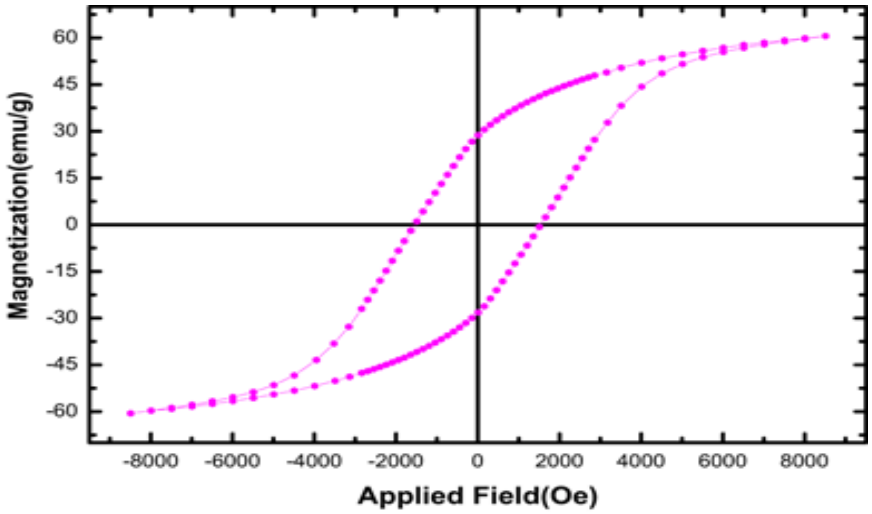



***Figure 4.3 b) VSM curve of cobalt ferrite nano particle (Talebi R. , 2017)***

Figure 4.3b shows the M–H loop taken at room temperature with a maximum applied field of ±2 T. From the hysteresis loop both saturation magnetization (Ms) and coercivity values (Hc) were extracted. Coercivity, Hc of 1409 Oe with the corresponding saturation magnetization, Ms of 52.6 emug−1 was obtained which indicates the ferromagnetism of the nanoparticles.

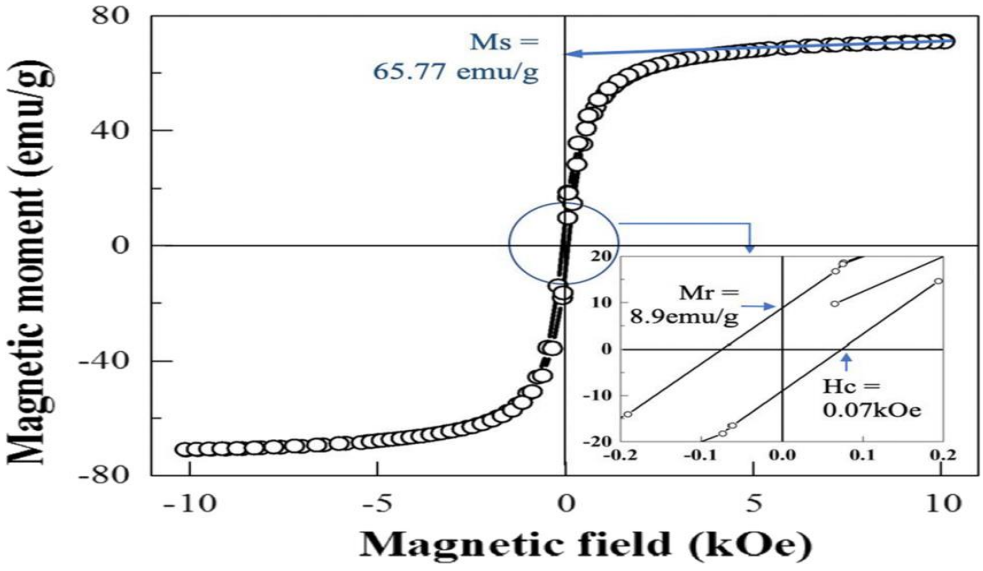



***Figure 4.3c. VSM curve of manganese ferrite nano particle (Gao, 2021).***

Hysteresis loop for the sample recorded at room temperature pointing the ferromagnetic nature of manganese ferrite. Inset shows minor hysteresis loop at maximum hyperthermia field of 300 Oe used for theoretical estimation of hysteresis losses

## 4.4 Fourier Transform Infrared Spectroscopy (FTIS) Analysis

The spectroscopy analysis shows the fingerprint of the organic compound in ferrites. The various bands are used to determine the characteristic functional groups and bonds present in organic compound. Additionally, the results of various spectroscopy confirm that the substitutions and their doping percentage level are responsible for frequency band shift in infrared absorption spectrum.

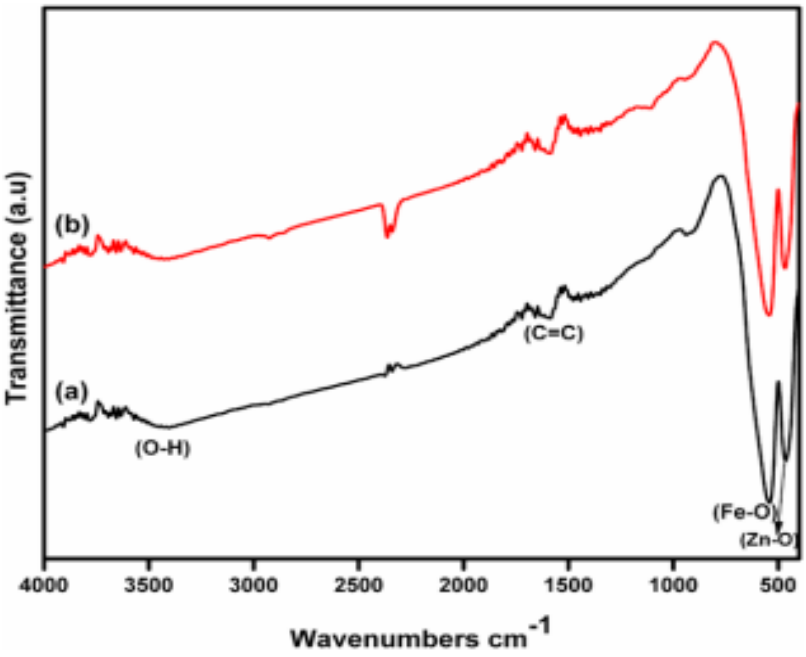



***FIGURE 4.4a: FTIR spectrum of (a) sample-a and (b) sample-b of zinc ferrite nanoparticles (Rameshbabu, R. & Ramesh, et AL., 2013)***

Figure 4.4a shows regular spinel $ZnFe_2O_4$ structure in the annealed zinc ferrite sample is further supported by FT-IR spectrum. The broad band absorption peak at 3433 cm−1 (bending mode of H2O) indicated the presence of water molecules on the surface of $ZnFe_2O_4$ nanoparticles. The very weak band observed at 1640 cm−1 was related to stretching vibration of C=C, presence of EA on surface of the $ZnFe_2O_4$ nanoparticles. The strong peaks appearing at 542 cm−1 and 467 cm−1 represent tetrahedral and octahedral modes of $ZnFe_2O_4$; this was assigned to Fe–O vibration and Zn–O vibration, respectively.

Careful observation on the FTIR spectra shown in Fig. 4.4b shows an absorption peak at 592 cm-1 corresponding to intrinsic stretching vibrations of metal at the tetrahedral site, whereas the v2-lowest band, observed in the range of 400–300 cm-, is due to the octahedral–metal stretching (S., 2015). $Co^{2+}$ ions usually occupy octahedral-site, while Fe3+ ions has the tendency to occupy both octahedral and tetrahedral sites. Further observations shows strong absortions peaks at 3414 and 1617 cm-1 wavelengths.

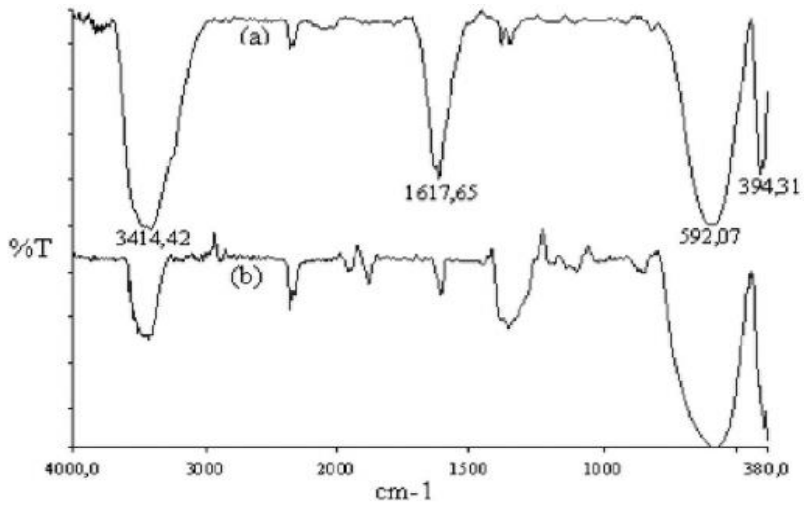



***Figure 4.4b FTIR spectra of cobalt ferrite nanoparticles calcined at (a) 600°C and (b) 900°C (Yakubu, Abubakar & Abbas, et Al. , 2015)***

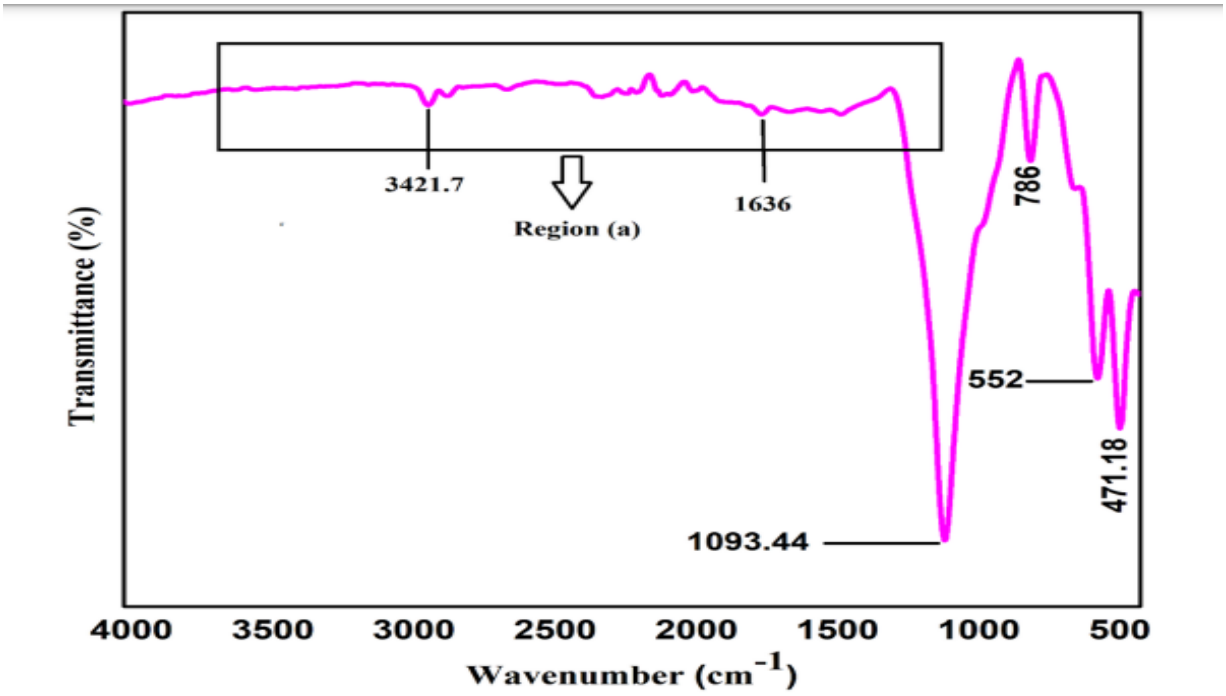



***Figure 4.4c. FTIR spectra of manganese ferrite nanoparticles (Ahmad, 2022).***

For the determination of chemical and structural changes, Fourier transform infra-red (FTIR) of the sample was performed. Figure 4.4c shows FTIR spectra of the synthesized sample. Many small peaks can be seen in the range 3600-1200 cm-1 labelled as region (a). The peak at 471.18 cm-1 show stretching vibrations of intrinsic metal oxygen at octahedral sites while the peak at 552 cm-1 represents the stretching vibrations of metal oxides at the tetrahedral and octahedral positions (Ahmad, 2022)..FTIR analysis also confirmed the formation of ferrite nanoparticles (manganese ferrite)

### 4.5. Thermal analysis

The thermal analysis results reveal that the substitutions and their doping percentage level can affect the associated water content and hence changes the preparation condition of ferrites.

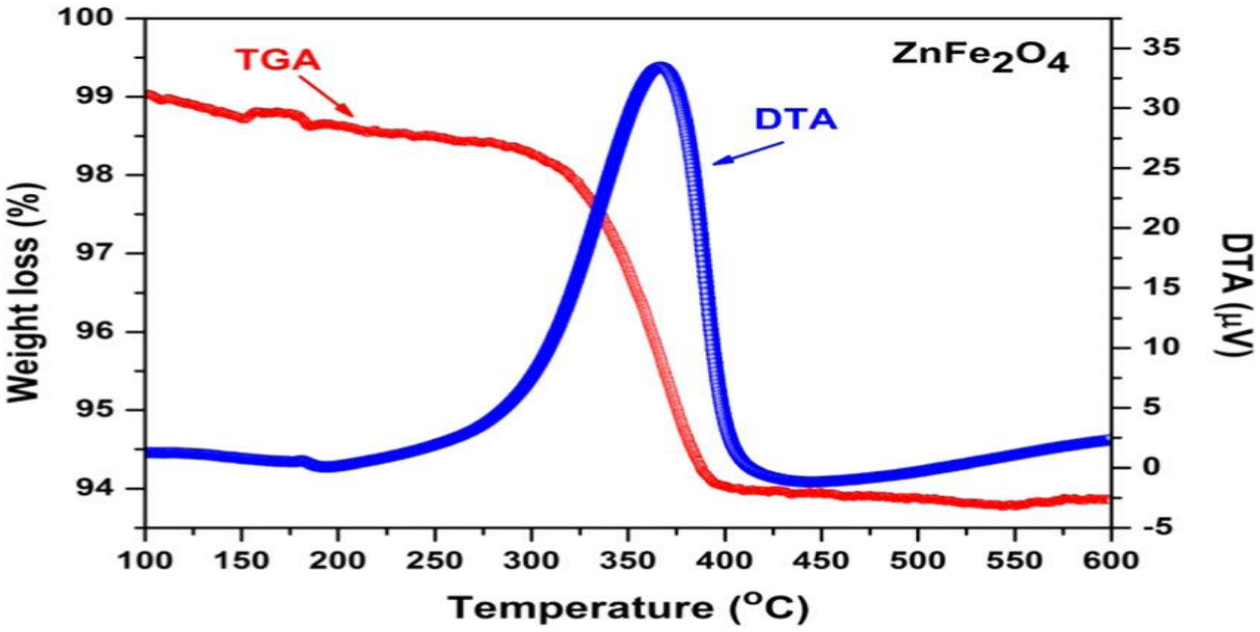



*Figure 4.5a: TGA-DTA curve of zinc ferrite nanoparticles (Borade, Ravikumar & Somvanshi,et Al, 2020).*

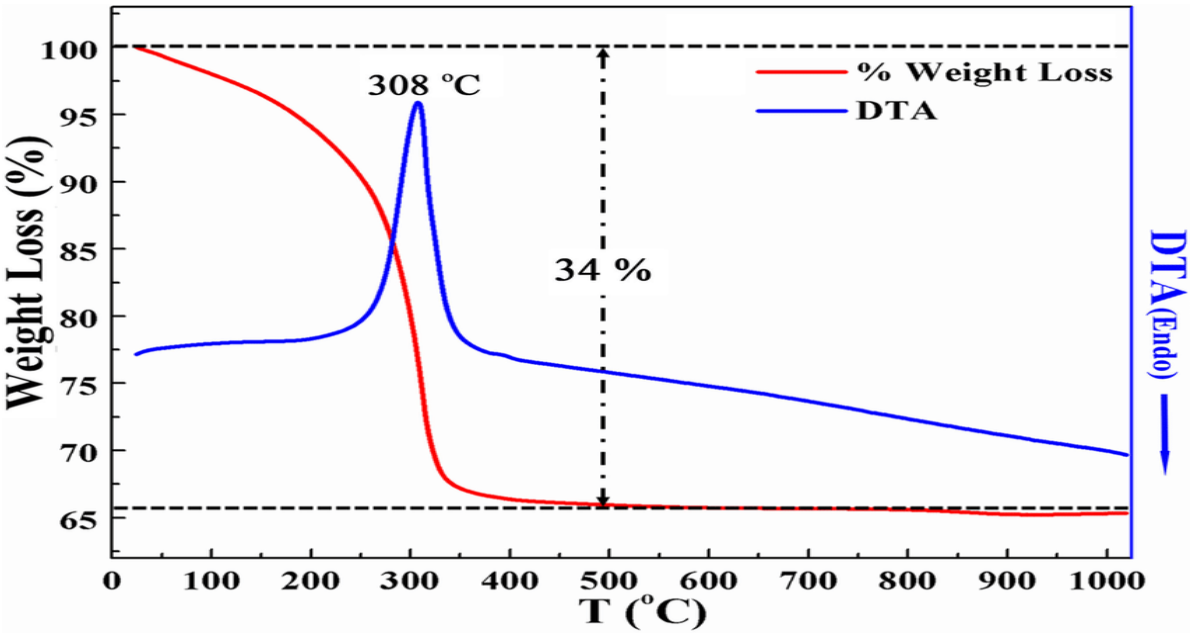



*Figure 4.5b TGA-DTA curve of cobalt ferrite nano particle (Hussain, Akhlaq & Naeem, et Al., 2018).*

In the above figure 4.5a Thermal examination of as readied zinc ferrite nanoparticles was done to explore the development of the spinel ferrite stage. It is recorded in the temperature scope of 30°C − 800°C in nitrogen environment at a warming rate of 5°C min−1. The TGA-DTA plot for zinc ferrite nanoparticles as readied powder is appeared in figure 4.5a. The nearness of exothermic tops at 368°C in DTA bend demonstrates the response of glycine with nitrates, disintegration of glycine and the expulsion of nitrates pursued by arrangement of ferrite stage. It is seen from gelation strategy that above 350°C the organics are evacuated totally.

The TGA bend displayed the absolute weight reduction of 6%. Also, it is seen from TGA bend that there is no noteworthy weight reduction after temperature 575°C which can be ascribed to ferrite stage development. Accordingly, we have picked the temperature 600°C as a sintering temperature for prepared zinc ferrite nanoparticles.

The TGA and DTA curves of as-prepared sample is shown in Figure 4.5b. TGA curve showed 34% of total weight loss in the temperature range from 25 to 500 °C. The weight loss from 25 to 180 °C is due to the dehydration of absorbed moisture. The weight loss above this temperature up to 500 °C is due to the removal of crystal water, surfactant. No remarkable weight loss was observed from 500 to 1000 °C. DTA curve of the sample showed a sharp exothermic peak centered at 308 °C, which is corresponding to crystallization of ferrite (Hussain, Akhlaq & Naeem, et Al., 2018). No other peaks were observed.

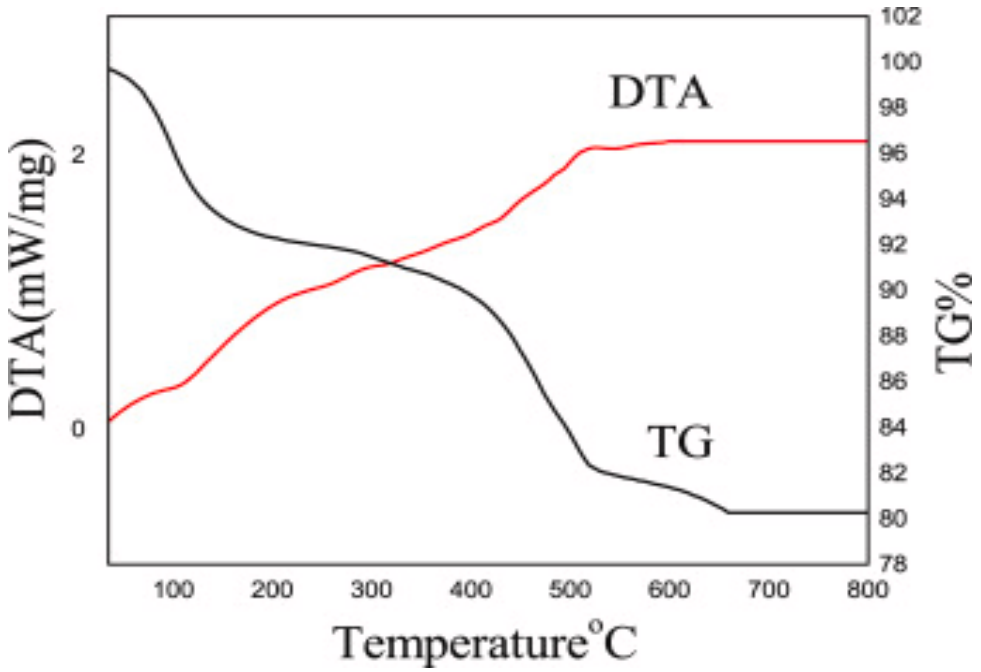



***Figure 4.5c TGA-DTA curve of MANGANESE ferrite nanoparticles (Abisha D,and Gibin S.R, et Al., 2023).***

In the above figure 4.5c during the analysis, the first weight loss of about 8 % was observed between 70 °C and 325 °C. This weight loss can be attributed to the emission of water molecules from the sample. The second weight loss of around 10 % occurred between 325 °C and 500 °C, which was attributed to the decomposition of organic templates present in the sample. Furthermore, the third weight loss of roughly 2 % was observed in the temperature between 500 °C and 670 °C, which can be attributed to a phase transition within the sample (P. Sivagurunathan, 2016) .

The DTA curve shows a minor endothermic peak around 125 °C, indicating the occurrence of dehydration. Additionally, an exothermic peak at 540 °C was observed which suggests the decomposition of nitrates present in the sample (P. Sivagurunathan, 2016)

# CHAPTER FIVE

# CONCLUSION AND RECOMMANDATION

## 5.1 Conclusion

In this study the main focus of the present work is to review synthesize nano magnetic particles of different ferrite ($AFe_2O_4$, A=Zn,Co,Mn). The ferrite nanoparticles were effectively prepared by sol-gel, hydrothermal and chemical co-precipitation technique. XRD analysis revealed the high purity and single phase of the zinc ferrite sample, average crystallite sizes are 21 nm and 27 nm for the zinc samples annealed in air atmosphere at 300 °C and 600 °C.and the calculated crystallite size was found to be 14.33 nm for cobalt,27nm for zinc ferriete and 23.53 nm for manganese ferrite.

The SEM micrograph comparison revealed that the morphology, microstructure development, and grain size is greatly dependent on substitutions and their doping percentage level.

The addition of zinc oxide (ZnO) can influence the magnetic and electrical properties of the ferrite material. prepared zinc ferrite nanoparticles display the superparamagnetic nature which can be described by hysteresis curve from VSM result. Ms of 52.6 emug−1 of cobalt ferrite was obtained which indicates the ferromagnetism of the nanoparticles and Hysteresis loop for the sample recorded at room temperature pointing the ferromagnetic nature of manganese ferrite.

Generally we review the ferrite nano particle such zinc,cobalt,manganese ferrite based on this review we know the property of the those ferrite so other ferrite material like Mg,Cu,Fe ferrite material can be study and review as the same way.therefore if we know the ferrite material property we can simply modifiy or doping to develop required application.

## 5.2 Recommandation

This study provides understandings into the synthesis, thermal property, structural characteristics, and optical properties of ferrite materials, zinc ferrite ($ZnFe_2O_4$). Based on the findings of this study, the following recommendations are proposed:

- Investigate the integration of zinc,cobalt and manganese ferrite with other materials, such as graphene, nanomaterials, or metamaterials, to create hybrid materials with enhanced properties**.** it can be suggested that high unique magnetic, electrical, and optical properties Zinc ferrite is explored for its potential use in energy storage devices such as batteries and supercapacitors due to its high electrical conductivity and magnetic properties.
- Explore the development of new synthesis methods and techniques for zinc ferrite, including the use of machine learning and artificial intelligence to optimize its properties
- Finally, Cyclic voltametric analysis, Electron paramagnetic resonance (EPR) spectroscopy, Energy dispersive X-ray analysis (EDAX) and liquidity coverage ratio (LCR), dielectric behaviour,frequency and proportion of highly liquid assets are not included in this study. Therefore, this will be considered in future studies to further enhance the understanding of the ferrite material

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