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## Research Article

# CoFe<sub>2</sub>O<sub>4</sub> Magnetic Nanoparticles using Sol-Gel Method

P. Rajamani,

Department of physics, Immaculate college for women, cuddalore 607006, Tamilnadu.

P. Balakrishnan,

Department of Physics, Bwda Arts and science College, Kolliyankunam.

Pravinamary,

Department of Zoology, St. Joseph's College of Arts and Science (Autonomous) Cuddalore -607001.

M. Marshal Arunkumar

Department of Physics, Idhaya Arts and Science College for Women, Pondicherry, Tamil Nadu, India.

S.Udhayan

Department of Physics, Adhi College of engineering and technology, Sankarapuram, kanchipuram district - 631605.

(Corresponding author: rmani499gmail.com)

## Abstract

In this work, the sol-gel method was used to produce and characterize soft CoFe<sub>2</sub>O<sub>4</sub> magnetic nanoparticles. FT-IR, SEM, XRD, and other techniques were used to characterize the produced nanoparticles. The samples' cubic structure was verified by XRD, and their mean crystallite sizes were 28.41 nm and 14.64 nm, respectively. SEM and EDAX spectra were used to examine the produced particles' morphology and quantitative analysis. The existence of functional groups was investigated using the FTIR. Lastly, a vibrating sample magnetometer (VSM) was used to study the powders' magnetic characteristics at room temperature based on hysteresis loop observations. According to this analysis, when the degree of Fe substitution increases, the saturation magnetization values rise and the coercive field of CoFe<sub>2</sub>O<sub>4</sub> nanoparticles falls.

**Keywords:** *Actinidia chinensis; Actinidia deliciosa; Pseudomonas syringae* pv. *Actinidiae*; quality

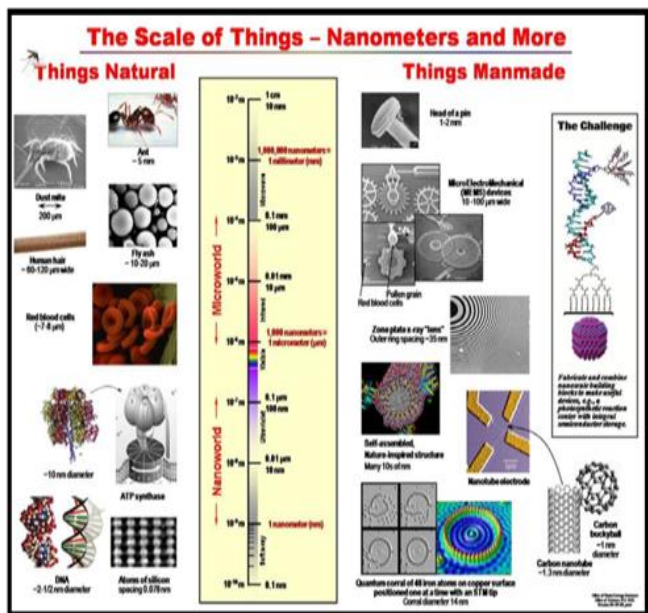
## Introduction

### *Nanotechnology: Introduction and Significance*

Nobel laureate Richard P. Feynman initially discussed nanotechnology in his well-known 1959 talk at the California Institute of Technology titled "There's Plenty of Room at the Bottom" (Feynman et al., 1960). Over the next 25 years, there have been groundbreaking advancements in biology, chemistry, and physics. Feynman's theories of influencing and modifying matter at incredibly small scales, including molecules and atoms, or the nanoscale, have been validated by these advancements (Bharat et al., 2004). The material's surface area significantly expands as particle size decreases, and more atoms are found on the particle's surface (Whatmore et al., 1995).

These two phenomena are further illustrated by the scale of things-nanomaterials in Figure 1.1. An electron with a charge of  $e$  rotating at a speed of  $v$  is equal to a current loop. It functions similarly to a magnetic dipole with an **orbital magnetic moment of  $\mu_l = nev$** . **The spin magnetic moment  $\mu_s$  is created as the electron rotates around itself.**

Figure: Scale of Things-Nanometers and More



The various characteristics of the various ferritin types are listed in Table. The type of magnetism generated in various solids affects the susceptibility's magnitude and sign.

Table: Properties of different types of ferrites

<i>Magnetism</i>	<i>Susceptibility</i>	<i>Atomic / Magnetic Behaviour</i>	<i>Example / Susceptibility</i>
Diamagnetism	Small & negative.	<p>Atoms have no magnetic moment</p>	<p>Au <math>-2.74 \times 10^{-6}</math></p> <p>Cu <math>-0.77 \times 10^{-6}</math></p>
Paramagnetism	Small & positive.	<p>Atoms have randomly oriented magnetic moments</p>	<p><math>\beta</math>-Sn <math>0.19 \times 10^{-6}</math></p> <p>Pt <math>21.04 \times 10^{-6}</math></p> <p>Mn <math>66.10 \times 10^{-6}</math></p>
Ferromagnetism	Large & positive, function of applied field, microstructure dependent.	<p>Atoms have parallel aligned magnetic moments</p>	<p>Fe <math>\sim 100,000</math></p>
Antiferromagnetism	Small & positive.	<p>Atoms have mixed parallel and anti-parallel aligned magnetic moments</p>	<p>Cr <math>3.6 \times 10^{-6}</math></p>
Ferrimagnetism	Large & positive, function of applied field, microstructure dependent	<p>Atoms have anti-parallel aligned magnetic moments</p>	<p>Ba ferrite <math>\sim 3</math></p>

Ferrites' high permeabilities, low power losses, and enormous resistivities have made them crucial for high frequency soft magnetic applications. According to Slick et al. (1980), Mn

ferrites are necessary components for higher-frequency (up to MHz) devices like transformers and inductors.

**Preparation of Nanomaterial's**

The primary distinction between conventional and nanotechnology is that the former typically favors a "top-down" approach, while the latter prefers a "bottom-up" approach. Chemical synthesis is an example of the "bottom-up" strategy in this context, while crushing and milling are methods that could be categorized as "top-down" procedures (Whatmore et al., 2012).

Different methods for synthesis of Nanoparticles.

Nanoparticles can be produced by a variety of methods. These include combustion synthesis,

Plasma synthesis method

Chemical vapour deposition

Solvothermal Method

Microwave Method

Dimensionality Method (1D, 2D, 3D)

Sol-gel method and Sol-gel Synthesis

The different classification of metal containing nanoparticles by the shape is shown in Fig

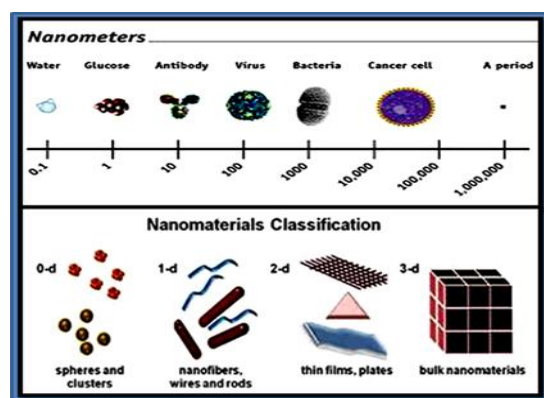


Fig: classifications of metal containing nanoparticles by the shape

### Sol-gel method

The sol-gel process creates a concentrated suspension of a metallic hydroxide or oxide (sol), which is then dehydrated by solvent extraction or evaporation to produce a semi-rigid mass (gel). Grain size, particle morphology, porosity, compositional homogeneity, and other required structural characteristics can be tailored using this approach, which is done in solution. For the best control of grain size and microstructure to maintain high reliability, the particles must be uniformly distributed (Shah and Ahmad, 2010).

This gellated substance can be heated under regulated conditions to yield a variety of pure and mixed oxides. The hydrolysis and polymerization reactions of precursors, which are

often inorganic metal salts or metal organic compounds like metal alkoxide, result in a colloidal suspension, or sol, in a conventional sol-gel procedure. Numerous factors, including pH, reaction temperature and duration, reagent concentration, catalyst type and concentration, H<sub>2</sub>O/M<sup>+</sup> molar ratio, aging temperature and duration, and drying, are associated with the features and attributes of a specific sol-gel network and impact the rate of hydrolysis and condensation reactions.

A modified sol-gel process was used to manufacture nickel oxide, and Wu et al. (2007) produced spherical NiO nanoparticles. In this work, spherical nanoparticles were created by influencing a few parameters during the synthesis of nanosized NiO materials. Likewise, the sol-gel approach was used to create numerous other metal oxides, such as SnO<sub>2</sub> (Aziz et al., 2013) and TiO<sub>2</sub> nanoparticles (Hema et al., 2013).

### Sol-gel Synthesis

Mix the salt and water to create a homogenous solution, then treat it with the appropriate reagent and heat it through to turn it into a sol.

### Applications of Nanotechnology

The goal of Understanding Nanotechnology is to give concise, understandable explanations of the uses of nanotechnology.

#### Food

From the production of food to its packaging, nanotechnology is influencing many facets of food science. Businesses are creating nanoparticles that will alter food's flavor as well as its safety and health advantages delivers.

#### Medicine

Customized nanoparticles the size of molecules is being created by researchers to deliver medications to illness cells in your body. When this technique is developed, it should significantly lessen the harm that chemotherapy

And other treatments cause to a patient's healthy cells.

#### Electronics

Some solutions for enhancing the functionality of electronics devices while lowering their weight and power consumption can be found in nanotechnology.

## Fuel Cells

Nanotechnology is being utilized to enhance the efficiency of fuel cell membranes that separate hydrogen ions from other gases, such as oxygen, and to lower the cost of the catalyst used in fuel cells to manufacture hydrogen ions from fuel, such as methanol.

## Solar Cells

Businesses have created nanotech solar cells, which are much less expensive to produce than traditional solar cells.

## Batteries

Businesses have created nanotech solar cells, which are much less expensive to produce than traditional solar cells.

## Chemical Sensors

Sensors can detect minuscule amounts of chemical vapors because to nanotechnology. Nanotechnology-based sensors can employ a variety of sensing elements, including palladium nanoparticles, zinc oxide nanowires, and carbon nanotubes. The annealing temperatures had a significant impact on the coercivity of ferrite powder, which was directly correlated with the size variation of cobalt ferrite particles.

## Introduction of Magnetic materials

Humans have long been captivated by magnetism. Lodestone, a type of magnetite with the chemical formula  $\text{Fe}_3\text{O}_4$ , is where magnetism was initially discovered (Anantharaman et al., 1981). An internal molecular field proportionate to the average magnetization that spontaneously aligns the electronic micro magnets in magnetic materials is the basis of Weiss's theory of magnetism. In 1890, D. U. Bois measured the saturation magnetization of magnetite (Du Bois et al., 1890). The magnetic properties were studied by Pierre Weiss (Weiss et al., 1907). Therefore, the vector sum of the individual spin and orbital magnetic moments of the outer-shell electrons is the atom's net magnetic moment. (Jeyadevan et al., 2003).

## Classification of magnetic materials

Current ideas state that the orbital and spin motions of electrons as well as the spin of nuclei are what cause magnetism in solids. To create a net non-zero magnetic moment, several of these magnetic moments may align themselves in various orientations. Therefore, the quantity of

unpaired valence electrons in solid atoms and the relative orientations of the nearby magnetic moments determine the type of magnetization that is generated.

The magnetism in solids has been classified into the following categories, which shown in Fig

Diamagnetism

Para magnetism

Ferromagnetism

Antiferromagnetism

Ferrimagnetism

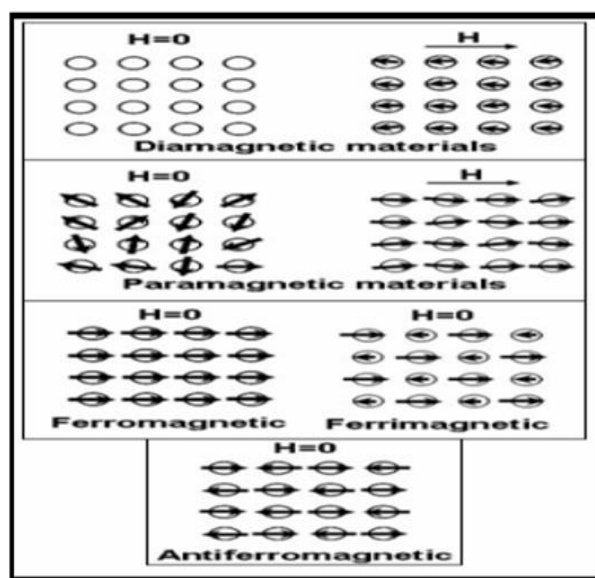


Fig: Direction of magnetic field

## Hysteresis loop

A hysteresis loop is a plot of the fluctuation of magnetization with applied magnetic field. Magnetic materials are described by the hysteresis loop. With the aid of the hysteresis loop, a number of characteristics, including coercivity, remanence, and saturation magnetization, can be determined. Magnetic domains grow in the crystal's easy direction when a magnetic field is applied to a sample. Following the application of a specific magnetic field, domains.

To align the domain with the direction of the applied magnetic field, begin rotating away from the easy axis. A saturation magnetization ( $M_s$ ) is attained when every domain is perfectly aligned. The curve does not return to its initial course when the applied magnetic field is decreased to zero. A residual magnetization

known as remanence, or remanent magnetization  $M_r$ , is kept at zero magnetic fields, meaning that the material is still magnetized even when no magnetic field is supplied.

Coercivity is the process of applying an external magnetic field to reduce this accessible residual magnetization to zero. Saturation magnetization will be attained in the negative direction following the application of a strong magnetic field in the opposite direction. The complete hysteresis loop is depicted if the applied field is then reduced and applied once more in a positive direction. The M-H loop's squareness is shown by the ratio of remanence to magnetization saturation ( $M_r/M_s$ ).

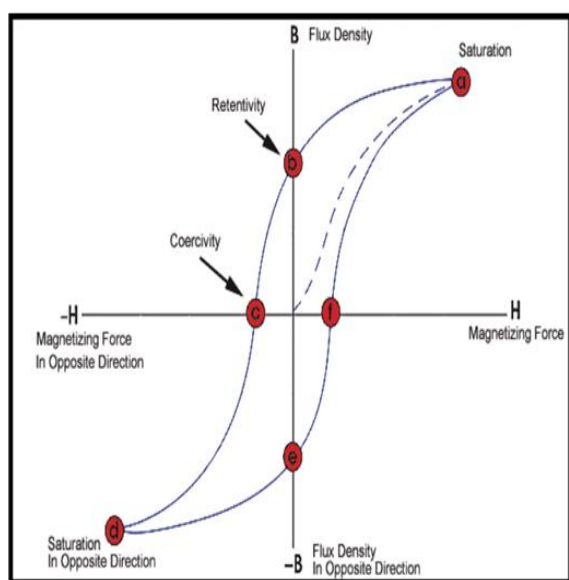


Fig: Hysteresis loops of ferromagnetic materials

### Ferrites

According to Cornell et al. (1996), ferrites are typically non-conductive ferrimagnetic ceramic compounds with the general formula  $MeFe_2O_4$ , where Me stands for one or more divalent transition metals. Compared to ferromagnetic materials like transition metals, ferrimagnetic iron oxides naturally have a weaker magnetic response (Smith et al., 1956).

Depending upon crystal structure they are classified as

Ferrosipinel  $MeFe_2O_4$

Garnets  $Me_3Fe_5O_{12}$

Orthoferrites  $MeFeO_3$

Hexagonal (Magnetoplumbite)  
 $MeFe_{12}O_{19}$

### Cobalt based cubic spinel oxides

The mixed valent metal oxides that make up cobalt-based cubic spinel oxides have the general formula  $AB_2O_4$ , where A and B stand for divalent and trivalent cations, respectively.

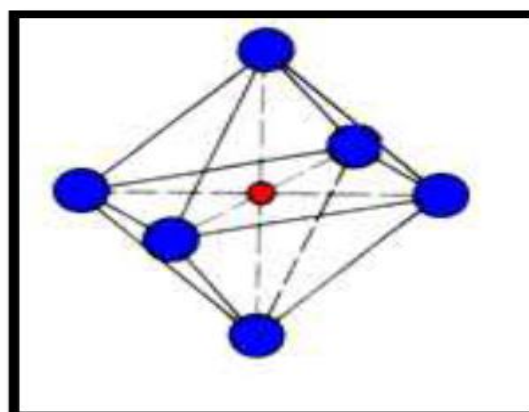
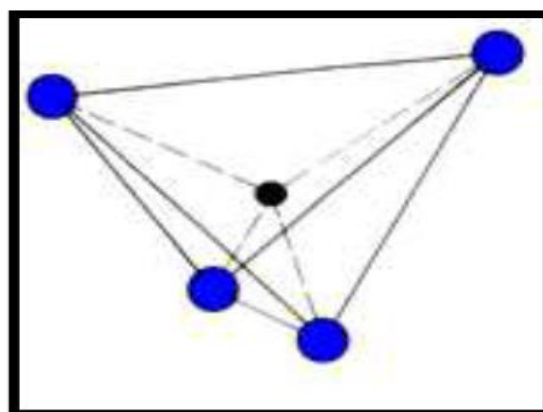
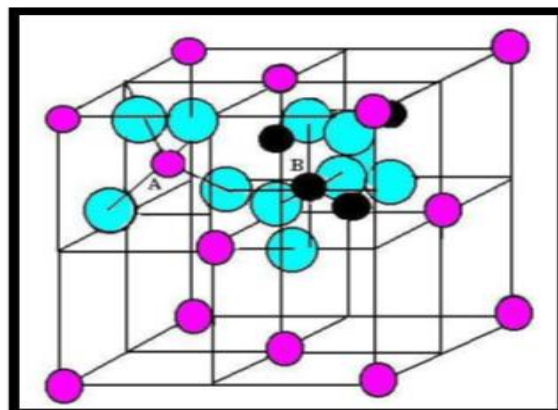


Fig: General Spinel Structure and structures of tetrahedral A-site and octahedral B-site

### Cobalt ferrite

Because of its moderate magnetism and high coercivity, cobalt ferrite is classified as a hard magnet. It has been employed in many different applications because of its strong magnetic coercivity value and good physical and chemical stability. The structure of cobalt ferrite ( $CoFe_2O_4$ )

is neither spinel nor inverse spinel. Its spinel structure is partially inverse  $[\text{Co}_{2+}\text{Fe}_{1-3+}] (\text{Co}_{1-2+}\text{Fe}_{1-3+})\text{O}_4$ , and it has a modest magnetism of 50 emu/g and a coercivity of 1000 Oe.

### Structure of cobalt ferrite

Displays the  $\text{CoFe}_2\text{O}_4$  structure. Due to their possible uses in high density magnetic recording, magnetic nanoparticles have been the subject of extensive investigation. Cobalt ferrite ( $\text{CoFe}_2\text{O}_4$ ) is one of the many ferrite materials that has been extensively researched because to its exceptional mechanical hardness and chemical stability (Mordock et al., 1992).

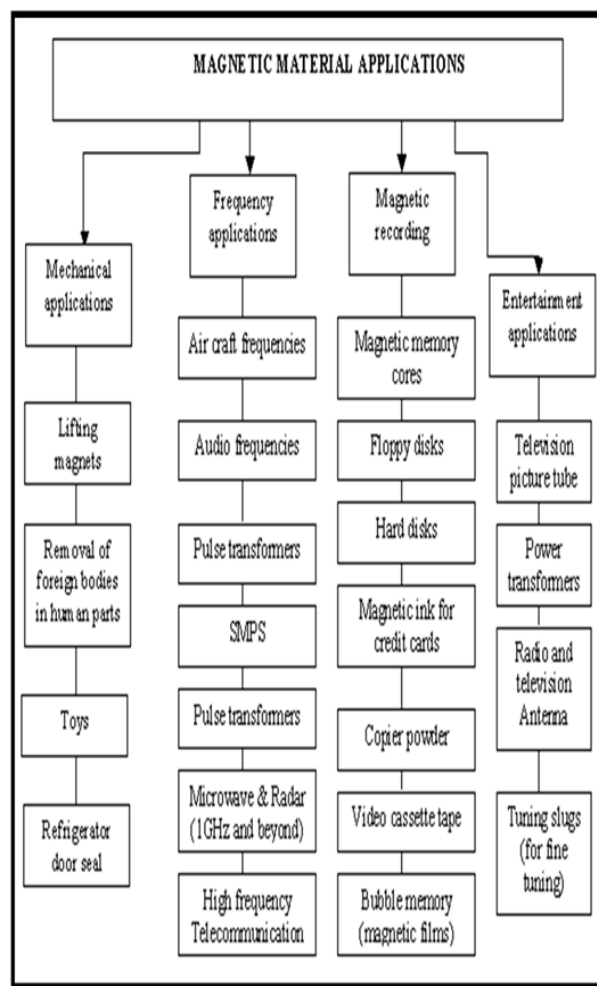
### Structure of $\text{CoFe}_2\text{O}_4$

Their high value makes them ideal for use in torque sensors, ferrofluids, high density magnetic storage materials, magneto-mechanical systems, and medical diagnostics.

### Applications of magnetic materials

As compacted powders in permanent magnets, surface-functionalized particles in biomedical applications, particle arrays in magnetic storage media, and ferrofluids in solutions (Pankhurst et al., 2003 Berry et al., 2003 Ross et al., 2001 and Weller et al., 2000). The sections that follow have covered a few of the uses unique to hard magnetic materials.

There are numerous ways to classify magnetic materials. They can be categorized first by market,



### Magnetic properties in cobalt ferrite

The effectiveness of its practical application depends on the capacity to manage crystal size within the super-paramagnetic and single domain constraints by manipulating the composition and structure of  $\text{CoFe}_2\text{O}_4$  (Wang Hai et al., 2011).

Cobalt ferrite has a strong coercivity, moderate magnetization, a considerable magnetic anisotropy, and is a hard magnetic material. Cobalt ferrite's excellent physical and chemical durability makes it appropriate for a variety of applications, including high-density digital recording disks and audio and videotape (Tang DP et al., 2007).

The effective uniaxial anisotropy of  $\text{CoFe}_2\text{O}_4$  nanoparticles is suggested by a system of non-interacting single domain particles. Additionally, the annealing temperatures had a significant impact on the coercivity of ferrite powder, which was directly linked to the change in the sizes of the cobalt ferrite particles.

Figure Applications of magnetic materials

### Experimental Detail

## Materials

Magnetite nanoparticles were prepared using analytical-grade cobalt nitrate ( $\text{Co}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ ) and ferric nitrate ( $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ), which were acquired from Finar Chemicals Corporation. No additional purification was required before using the reagents.

### Synthesis of $\text{CoFe}_2\text{O}_4$ magnetic nanoparticles:

The following procedure was used to create almost monodisperse  $\text{CoFe}_2\text{O}_4$  with super paramagnetic behavior at room temperature: Typical synthesis involves mixing cobalt nitrate ( $\text{Co}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ ) and ferric nitrate ( $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ) in 2-Methoxyethonal with continuous magnetic stirring for a few minutes. In order to keep the pH of the precursor solution at 10.3,  $\text{NH}_3$  was then introduced.

The solution was supplemented with a 1:1 molar ratio of ethylene glycol and acetic acid. Following constant stirring The transparent sol was fully transformed into a gel after 4 hours at  $80^\circ\text{C}$ . After drying, the gel was ground into powders. The powder was then annealed in a furnace using air for two hours at  $700^\circ\text{C}$ . Ultimately, as the flow chart below illustrates, magnetic nanoparticles of various sizes were created.

### Flow chart for the Sol-Gel method to prepare $\text{CoFe}_2\text{O}_4$ Magnetic Nanoparticles

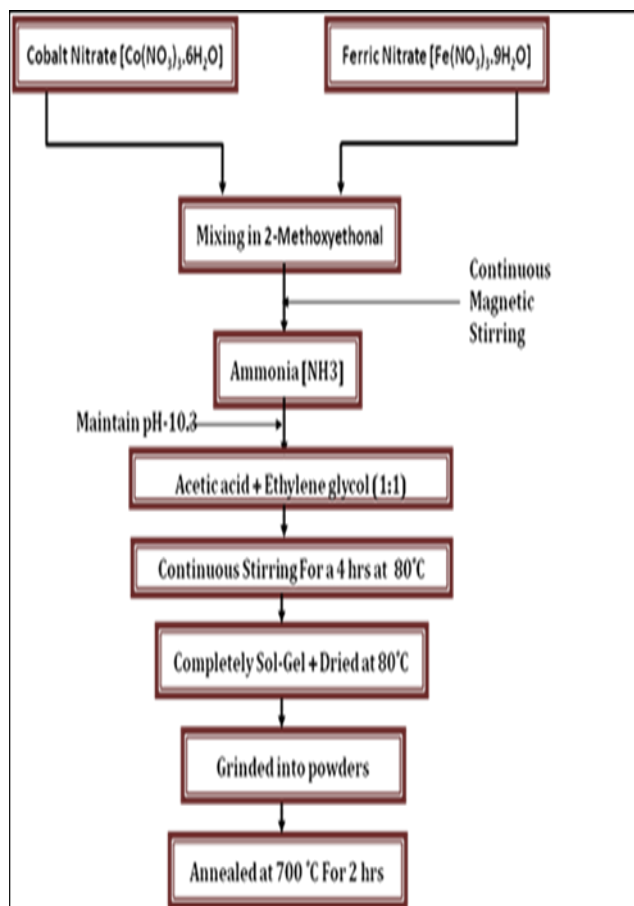


Fig: XRD pattern of  $\text{CoFe}_2\text{O}_4$  at  $700^\circ\text{C}$  annealing temperature: (A) 99+1%, (B) 9 8+2%

## Result and Discussion

### A.XRD:

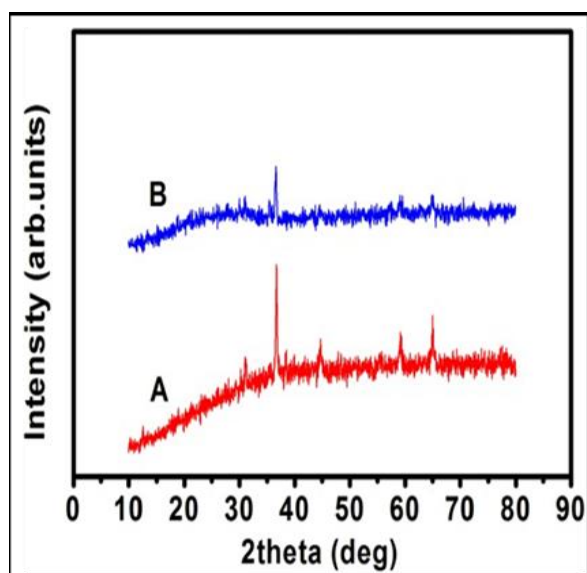
The XRD patterns of the  $\text{CoFe}_2\text{O}_4$  nanocrystals produced at  $700^\circ\text{C}$  are displayed in Figure (1). The cubic structure of  $\text{CoFe}_2\text{O}_4$  [JCPDS card No: 22-1086] is consistent with the structure of the synthesized material. The cubic  $\text{CoFe}_2\text{O}_4$  [Fd3m,  $a=8.391\text{\AA}$ ] is the index for the crystalline peaks (2 2 0), (3 1 1), (2 2 2), (4 0 0), and (5 3 1). Using the Debye-Scherrer formula, the nanoparticles' crystallite size is determined

$$D = K\lambda / \beta \cos \theta$$

Where  $\theta$  is the Bragg angle,  $\beta$  is the line broadening at half the maximum intensity (FWHM),  $\lambda$  is the X-ray wavelength, and  $K$  is the dimensionless form factor. The  $\text{CoFe}_2\text{O}_4$  nanoparticles produced at  $700^\circ\text{C}$  have mean crystallite diameters of 14.64 nm and 28.41 nm, respectively.

### B.SEM

The surface morphology of  $\text{CoFe}_2\text{O}_4$  powder made by varying the molar ratio of  $\text{CoFe}_2\text{O}_4$  is displayed in Figure (2). The cobalt



ferrites that are calcined at 700°C for two hours have the characteristic octahedral shape. A small number of particles with different morphologies are also present in the calcined powder, as indicated by the reed circle in the photos, and these belong to the unreacted phase CoFe<sub>2</sub>O<sub>4</sub>

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