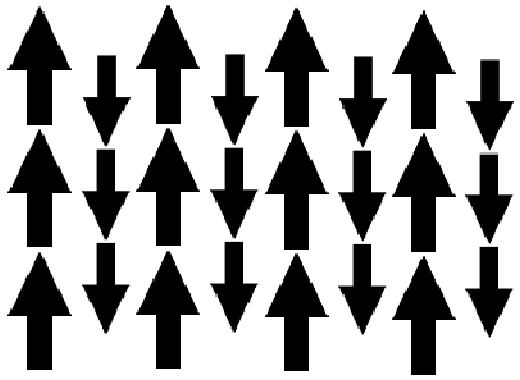
# 18PYB101J-Electromagnetic Theory, Quantum Mechanics, Waves and Optics

## Module 2 Lecture-7

Ferrimagnetic materials: Basic ideas, Ferrites- Explanations of regular spinel and inverse spinel structures

## Ferrimagnetic Materials (Ferrites)

Ferrimagnetic materials are also called as Ferrites. Ferrites are the modified structures of iron with no carbon and are composed of two or more sets of different transition metals. These materials have anti parallel magnetic moments of different magnitudes, giving rise to large magnetic moment in the presence of external magnetic field.



Materials are only ferrimagnetic below their corresponding Curie temperature. Ferrimagnetic materials are magnetic in the absence of an applied magnetic field and are made up of two different ions.

Below the Curie temperature the atoms of each ion are aligned anti-parallel with different momentums causing a spontaneous magnetism; the material is ferrimagnetic. Above the Curie temperature the material is paramagnetic as the atoms lose their ordered magnetic moments as the material undergoes a phase transition.

**Properties**

➢The susceptibility ($\chi$) is very large and positive. It is represented by,

$$\chi = C / (T \pm \theta),$$

C=Curie Constant

$\theta$ =Curie temperature

Below Curie temperature, they behave as ferrimagnetic materials.

- Mechanically, they have pure iron character. They have low tensile strength and are brittle and soft.
- In these, all valence electrons are tied up by ironic bonding and they are bad conductors with high resistivity of $10^{11}$ Ω m.
- Ferrites are manufactured by powder metallurgical process by mixing, compacting and then sintering at high temperatures followed by age hardening in magnetic fields.
- They are soft magnetic materials and so they have low eddy current losses and hysteresis losses.

## Structure of Ferrites

- The general chemical formula of a ferrite molecule is $M^{2+}Fe_2^{3+}O_4^{2-}$, where $M^{2+}$ represents a divalent metal ion such as $Zn^{2+}$, $Fe^{2+}$, $Mg^{2+}$, $Mn^{2+}$, $Cd^{2+}$ etc.,
- Ferrites crystallize in the form of a cubic structure. Each corner of a ferrite unit cell consists of a ferrite molecule
- Therefore, in a ferrite unit cell there are eight molecules. Therefore in a ferrite unit cell, there are eight divalent metal ions, 16 ferric ions and 32 Oxygen ions.
- If only the oxygen ions in ferrite crystal are considered, it is found that they constitute a close packed face centered cubic structure.
- In these arrangement it is found that for every four $O^{2-}$ ions there are 2 octahedral sites (surrounded by 6 $O^{2-}$ ions) and one tetrahedral site (surrounded by4 $O^{2-}$ ions).

➢The metal ions are distributed over these tetrahedral sites (A sites) and octahedral sites (B sites). Thus in ferrites the number of octahedral sites is twice the number of tetrahedral sites.

➢Normally there are two types of structures in ferrites.

- ➢Regular spinel and
- ➢Inverse spinel

**i) Regular spinel structure**

➢In this type, each divalent metal ion occupies 1 tetrahedral site and each trivalent metal ion occupies 1 octahedral site. Totally in an unit cell, there will be 8 tetrahedral (8 A) sites and 16 octahedral (16B) sites.

➢Hence, the sites A and B combined to form a regular spinel ferrite structures as shown in Fig.

➢The schematic representation of zinc ferrite molecule as shown in Fig.

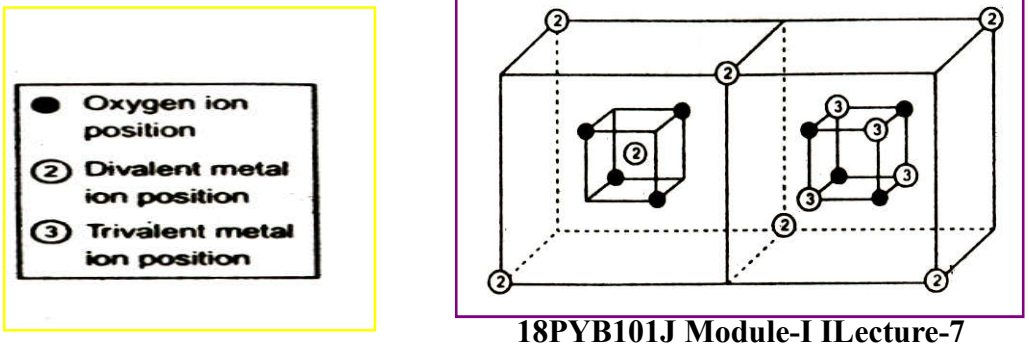
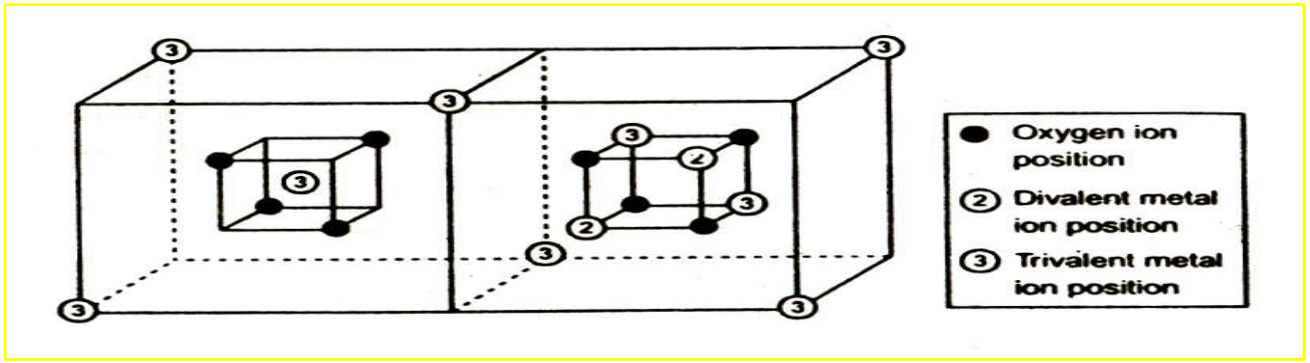


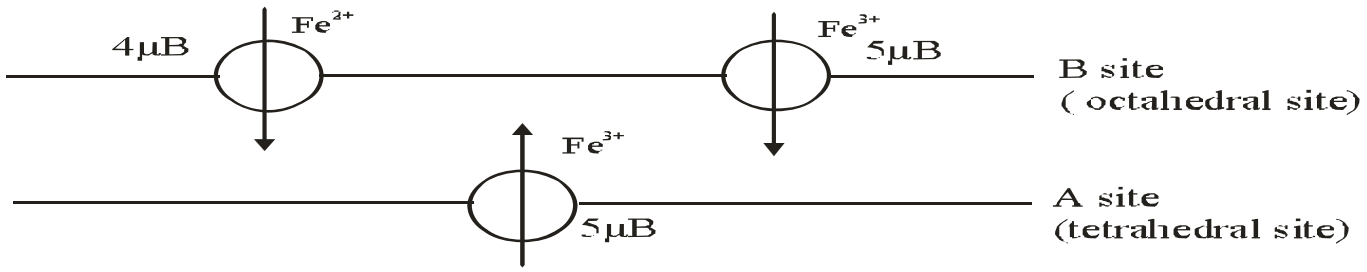

**Fig. Regular spinel structure**

## Inverse spinel structure

In this type half of the B sites (8sites) are occupied by divalent metal ions and the remaining half of the B sites (8 sites) and all the A sites are occupied by the trivalent metal ions, as shown in Fig.

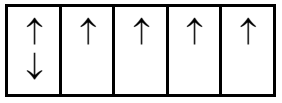
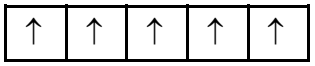



- The schematic representation of a ferrous ferrite molecule is shown in Fig.



- The anti parallel alignment of a ferrous ferrite molecule in inverse spinel structure is explained by the calculation of its magnetic moment. In a ferrous ferrite molecule, there are one ferrous ion and 2 ferric ions.
- When the Fe atom is ionized to form the $Fe^{2+}$ ions, there are 4 unpaired 3d electrons left after the loss of two 4s electrons.
- When the Fe atom is ionized to form the $Fe^{3+}$ ions, there are 5 unpaired 3d electrons left after the loss of two 4s electrons and one 3d electron. It is shown in the following electronic configuration

**Table 3d electronic configuration of $Fe^{2+}$ and $Fe^{3+}$**

| Ion | No. of electrons | 3d electronic configuration | Ionic magnetic moment |
|---|---|---|---|
| $Fe^{2+}$ | 24 |  | $4\mu_B$ |
| $Fe^{3+}$ | 23 |  | $5\mu_B$ |

❖ Since each unpaired 3d electron has a magnetic moment of one μB, the $Fe^{2+}$ ion has a moment of 4μB, and $Fe^{3+}$ ion has a moment of 5μB.

❖ If parallel alignments of ferrous and ferric ions are considered, the total dipole moment = 4 + (2×5)=14 μB. This observed value doesn't coincide with the experimental value.

❖ Consider anti parallel alignment of ferrous and ferric ions in inverse spinel structure.

❖ If one ferrous ion and one ferric ion are in one direction and another ferric ion is in opposite direction then the dipole moment is, {[(5×1) + 4] – (5×1)} = 4μB

❖ This observed value is in good agreement with the experimental value and hence this confirms the anti parallel alignment of dipoles in ferrites.

## ➢Applications of Ferrites

➢ Ferrite is used in radio receivers to increase the sensitivity and selectivity of the receiver.

➢ Ferrites are used as cores in audio and TV transformers.

- ❖ Ferrites are used in digital computers and data processing circuits. Ferrites are used to produce low frequency ultra sonic waves by magnetostriction principle.
- ❖ Ferrites are widely used in non-reciprocal microwave devices. Examples for non-reciprocal microwave devices are Gyrator, Isolator and Circulator.
- ❖ Ferrites are also used in power limiting and harmonic gyration devices.
- ❖Ferrites can also be used in the design of ferromagnetic amplifiers of microwave signals.
- ❖ Ferrite core can be used as a bitable element.
- ❖The rectangular shape ferrite cores can be used as a magnetic shift register.
- ❖Hard ferrites are used to make permanent magnets.
- ❖ The permanent magnets (hard ferrites) are used in instruments like galvanometers, ammeter, voltmeter, flex meters, speedometers, wattmeter, compasses and recorders.

Thank you