Unit-IV Ferromagnetism

A magnetic materials can be distincted into five Categories - Diamagnetic, Paramagnetic, Ferromagnetic, Antiferromagnetic & ferrimagnetic materials.

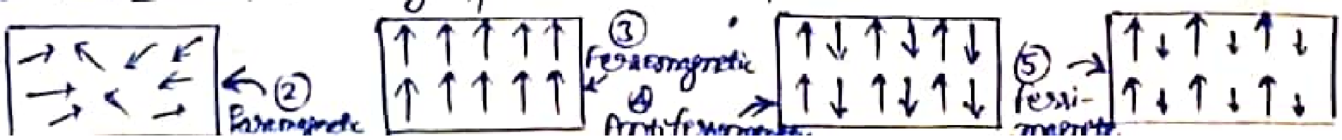
(1) Diamagnetic :- Those material which donot have permanent dipoles, consequently magnetic effects are very small. $B \approx 0$, susceptibility χ is negative, Always temp independent
Example - organtic material, benzene, naphtalene,
Alkali earth - Bi, Cu, Au, Ag.

(2) Paramagnetic :- Those material which possess permanent dipoles in the absence of magnetic field and dipoles are are randomly oriented so that net magnetisation is zero, susceptibility χ is positive and small. Example - Alkali metals Na, Ti, Al, Rare earth actinide elements

(3) Ferromagnetic :- Those material which posses spontaneous magnetisation even in the absence of magnetic field All magnetic dipoles are arranged parallel to one another, susceptibility χ is very large and positive
Example - Fe, Co, Ni, Gd & Dy.

(4) Antiferromagnetic :- Magnetic dipoles are arranged antiparallel to one another so that net magnetisation is zero. Example - MnO, MnS, FeO, χ - small, positive

(5) Ferrimagnetic :- Magnetic dipoles are arranged antiparallel to one another but the magnetic moments in one direction have large magnitude compare to other so net magnetisation is not zero. χ - large, positive Example Fe_2O_3, $NiFe_2O_4$, $CuFe_2O_4$.



Ferromagnetism :-

- Those materials which have spontaneous magnetization even in the absence of magnetic field are called ferromagnet and property of material are called ferromagnetism.
- It exhibits hysteresis curve (B-H curve) 

- only five elements (Fe, Co, Ni, Gd and Dy) are ferromagneti and rest are alloys and insulating compounds.
- Ferromagnetism arises because of cooperative alignment of permanent atomic dipoles which may be supposed to be caused by the mean molecular field.

Weiss theory of ferromagnetism (Weiss molecular field theory :-

Langevin theory failed to explain the concept of ferromagnetism so Weiss modified the Langevin theory in 1907 and introduced a concept of internal molecular field. The weiss theory of ferromagnetism is based on the following two assumptions

(1) A ferromagnetic specimen of macroscopic dimension Contains a number of small regions (which are called domain) are spontaneously magnetized.

(2) There exist a molecular magnetic field within each domain and field tends to produce a parallel alignment of individual localized atomic moments

Weiss observed that internal molecular field should be proportional to the magnetization M.

$$H_m \propto M \quad \text{or} \quad H_m = \lambda M \quad ----(1)$$

Where λ is Weiss molecular field constant

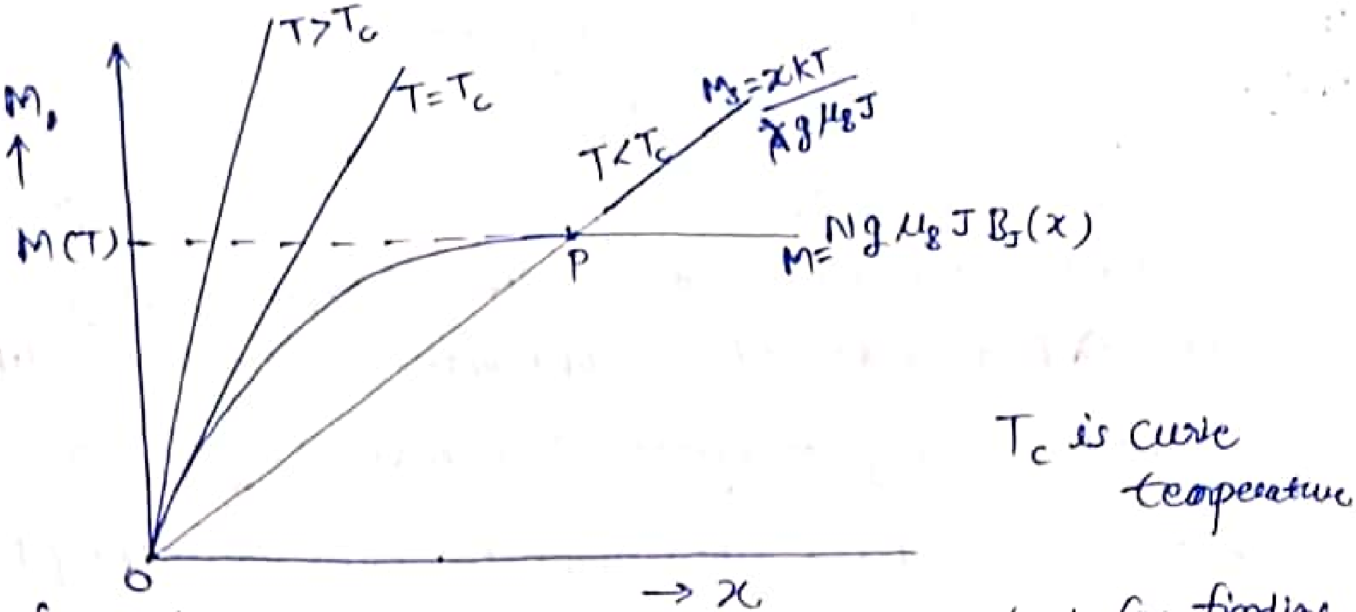


fig - Schematic representation of the method for finding the spontaneous magnetisation at temperature T.

Both M by eq(3) & eq(6) satisfy to each other so the condition of spontaneous magnetisation are determined by the graph between M & x with respect to eq (3) & eq(6). The value of M_s is obtained from the intersection point P of two curves.

for $M_s = \frac{xkT}{\lambda g \mu_B J}$ represents a straight line and slope of line proportional to T.

From graph ① for $T < T_c$ we obtain a non-vanishing value of M although the external magnetic field is zero ($H = 0$) Hence it is spontaneous magnetization (M_s)

② for $T = T_c$ the slope of the straight line is equal to the tangent of curve at the origin O.

(3) for $T \geq T_c$ the spontaneous magnetization vanishes and material becomes paramagnetic.

for spontaneous magnetisation occurs it is necessary that the slope of the straight line at origin should be less than the curve slope. so that $x \ll 1$ near the origin so the net effective magnetic field is given by

$$H_e = H + H_m$$

or $$H_e = H + \lambda M \qquad \text{--------(2)}$$

Where H is external applied field, M is magnetization and λM provides the cooperative effect of dipoles

Quantum theory of ferromagnetization used by Weiss

Let us consider a ferromagnetic solid containing N atoms per unit volume, each with magnetic moment μ_B and a total angular momentum quantum number J ($\because J = L + S$)

Ferromagnetism may as well be regarded as paramagnetism with a molecular field that produces self-ordering.

According to Langevin theory for paramagnetic solids, the magnetization is written as

$$M = N g J \mu_B B_J(x) \qquad \text{--------(3)}$$

where $x = \frac{gJ\mu_B H}{KT}$ and $B_J(x)$ is the Brillouin function ------(4)

which can be defined by

$$B_J(x) = \frac{2J+1}{2J} \coth\left[\frac{(2J+1)x}{2J}\right] - \frac{1}{2J}\coth\left(\frac{x}{2J}\right) \qquad \text{----(5)}$$

For ~~an~~ ferromagnetic materials, according to Weiss field theory we should replace H by $(H + H_m)$ then we get

$$x = \frac{gJ\mu_B(H + H_m)}{KT} = \frac{gJ\mu_B(H + \lambda M)}{KT} \qquad \text{---(5)(a)}$$

In the absence of magnetic field $H = 0$ the magnetization is spontaneous magnetization M_s so

$$x = \frac{gJ\mu_B \lambda M_s}{KT} \quad \text{or} \quad M_s = \frac{xKT}{\lambda g J \mu_B} \qquad \text{---(6)}$$