Quadrant II – Transcript and Related Materials

Programme: Bachelor of Science (Third Year)

Subject: Physics

Paper Code: PYD103

Paper Title: Solid State Physics

Unit 4: Magnetic Properties of Matter

Module Name: Weiss's Theory of Ferromagnetism & Ferromagnetic Domains

Module No: 32

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Notes

Ferromagnetism :

Like Paramagnetism, Ferromagnetism is also associated to the presence of permanent magnetic dipole moments (originated due to partially field **3d/4f** subshell).

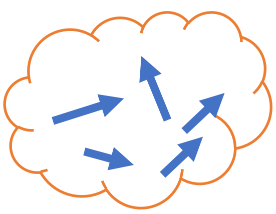
But unlike Paramagnetism the magnetic dipole moments of adjacent atoms in ferromagnetic material are align in a particular direction even in the absence of external magnetic field.

Therefore, a Ferromagnetic material as a spontaneous magnetic moment even in zero external magnetic field.

Paramagnetism

B=0

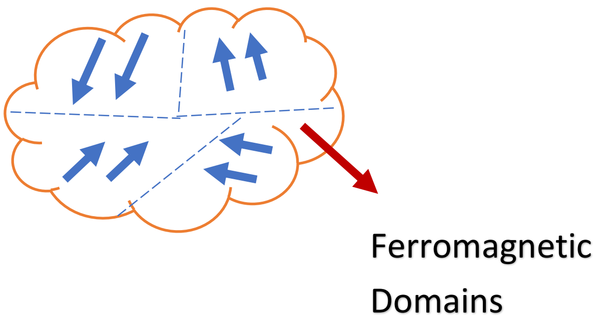
M=0



Ferrromagnetism

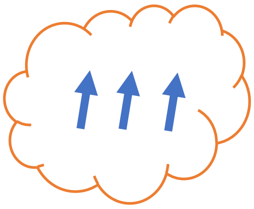
B=0

M$\neq$0



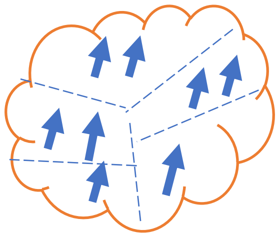
B≠0

M≠0



B≠0

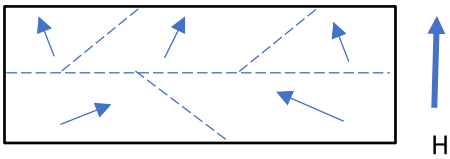
M≠0



Eg Fe, Co, Ni, Gd, CrO_2.

Ferromagnetic Domains :

A Ferromagnetic material is composed of small regions, within each of which the local magnetization is saturated.



However, the direction of magnetization of different domain may be random.

Weiss theory on Ferromagnetism:

Weiss proposed that the spontaneous magnetism of each domain is due to presence of an " exchange field" $(\boldsymbol{B_E})$, which tends to orient the magnetic moments parallel to each other.

However , the orientation effect of exchange field is opposed by thermal agitation and at elevated temperature the order is destroyed.

$\boldsymbol{B_E \alpha M}$

$\boldsymbol{B_E = \lambda M}$ ....(1)

Where λ = Weiss constant

In presence of external magnetic **(B)**, the effective field experience by atomic magnetic dipole moments is

$\boldsymbol{B_{eff} = B + \lambda M}$ ....(2)

For normal field and ordinary temperatures.

$$M = \frac{N g_J^2 \mu_B^2 J(J+1)(B+\lambda M)}{3k_B T}$$

$$M = \frac{N g_J^2 \mu_B^2 J(J+1)B}{3k_B T} + \frac{N g_J^2 \mu_B^2 J(J+1)\lambda M}{3k_B T}$$

$$M - \frac{N g_J^2 \mu_B^2 J(J+1)\lambda M}{3k_B T} = \frac{N g_J^2 \mu_B^2 J(J+1)B}{3k_B T}$$

$$M\left[1 - \frac{N g_J^2 \mu_B^2 J(J+1)\lambda}{3k_B T}\right] = \frac{N g_J^2 \mu_B^2 J(J+1)B}{3k_B T}$$

$$M = \frac{\frac{Ng_J{}^2\mu_B{}^2J(J+1)B}{3k_BT}}{\left[1-\frac{Ng_J{}^2\mu_B{}^2J(J+1)\lambda}{3k_BT}\right]} = \frac{\frac{Ng_J{}^2\mu_B{}^2J(J+1)B}{3k_BT}}{\frac{1}{T}\left\{T-\frac{Ng_J{}^2\mu_B{}^2J(J+1)\lambda}{3k_B}\right\}} = \frac{\frac{Ng_J{}^2\mu_B{}^2J(J+1)B}{3k_B}}{\left[T-\frac{Ng_J{}^2\mu_B{}^2J(J+1)\lambda}{3k_B}\right]}$$

$\chi_{Ferromagnetism} = \frac{M}{H} = \frac{C}{T-T_C}$ ⟹ Currie-Weiss Law of Ferromagnetism

Where **C**= $\frac{Ng_J{}^2\mu_B{}^2J(J+1)\mu_o}{3k_B}$ ⟹ curries constant

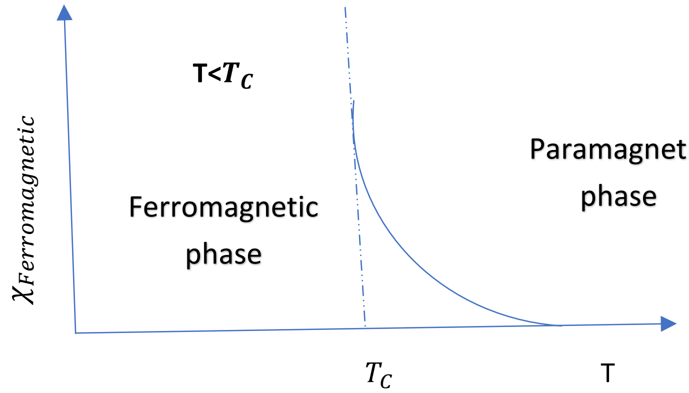
$T_C = \frac{Ng_J{}^2\mu_B{}^2J(J+1)\lambda}{3k_B}$ ⟹ Curies temperature

T_C values for

Fe = 1043 K

Co = 1403 K

Ni = 631 K



Above T_C the spontaneous magnetization vanishes. T_C separates the disordered paramagnetic phase at T>T_C from the ordered Ferromagnetic phase at $T < T_C$.

Temperature dependence of spontaneous magnetization ($T < T_C$)

Magnetization :-

$$M = Ng_J\mu_B \frac{\sum_{m_J=-j}^{+J} (-m_J)\, e^{\frac{-m_J g_J \mu_B . B}{k_BT}}}{\sum_{m_J=-j}^{+J} e^{\frac{-m_J g_J \mu_B . B}{k_BT}}} \quad \text{..........(1)}$$

We consider

J = ½ i.e L= 0 , S= ½ , g_J=2, m_J= - ½, ½

$$M = N2\mu_B \frac{\left[-\left(-\frac{1}{2}\right) e^{\frac{-\left(-\frac{1}{2}\right)2\mu_B . B}{k_BT}} - \left(\frac{1}{2}\right) e^{\frac{-\left(\frac{1}{2}\right)2\mu_B . B}{k_BT}}\right]}{e^{\frac{-\left(-\frac{1}{2}\right)2\mu_B . B}{k_BT}} + e^{\frac{-\left(\frac{1}{2}\right)2\mu_B . B}{k_BT}}}$$

$$M = N\mu_B \frac{\left[e^{\frac{\mu_B . B}{k_BT}} - e^{\frac{-\mu_B . B}{k_BT}}\right]}{e^{\frac{\mu_B . B}{k_BT}} + e^{\frac{-\mu_B . B}{k_BT}}}$$

$$M = N\mu_B tan\, h\left(\frac{\mu_B . B}{k_BT}\right) \quad \text{........(2)}$$

In case of Ferromagnetic material the equation (2) in absence of external field.

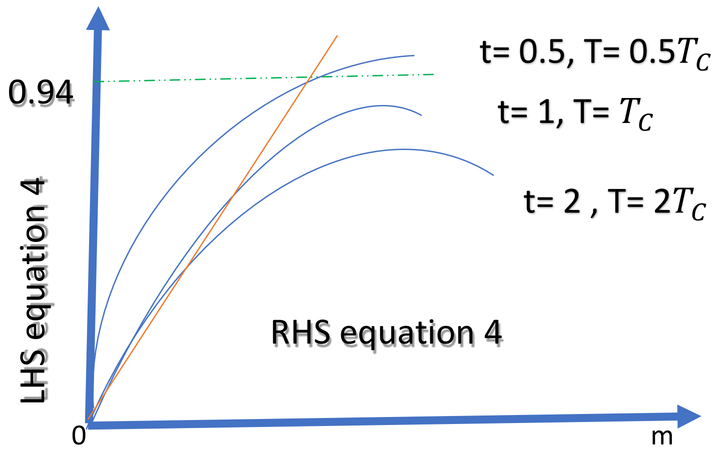
$$M = N\mu_B \tan h\left(\frac{\mu_B.\lambda M}{k_B T}\right) \quad ......(3)$$

Set $m = \frac{M}{N\mu_B}$ & $t = \frac{k_B T}{N{\mu_B}^2 \lambda} = \frac{T}{T_C}$

Reduced magnetization

$$m = \tan h\left(\frac{m}{t}\right) \quad ....(4)$$

From the graphical solution of equation (4)



Plot of LHS of equation 4 v/s m

I. The curve for $t = 2$ provided a solution at $m = o$, $(M = 0)$ which is expected in the paramagnetic phase.

II. The curve for $t = 1$ is tangent to the straight line m at origin. This temperature makes the on set of Ferromagnetic phase.

III. The curve for $t = 0.5$ provide a solution at $m = 0.94$ when t tends to **0** then solution moves up to $m = 1$.

As $t \rightarrow 0$, $T \rightarrow 0K$, $m = 1$

Saturated magnetization at $T = 0K$

$$M_S(0) = N\mu_B$$

For T << T_C

$$Tan\, h\left(\frac{\mu_B.\lambda M}{k_B T}\right) \approx 1\text{-}2\, e^{\left\{-2\frac{\mu_B.\lambda M}{k_B T}\right\}}$$

$$\approx 1\text{-}2\, e^{\left\{-2\frac{{\mu_B}^2 \lambda N}{k_B T}\right\}} \quad ....(5)$$