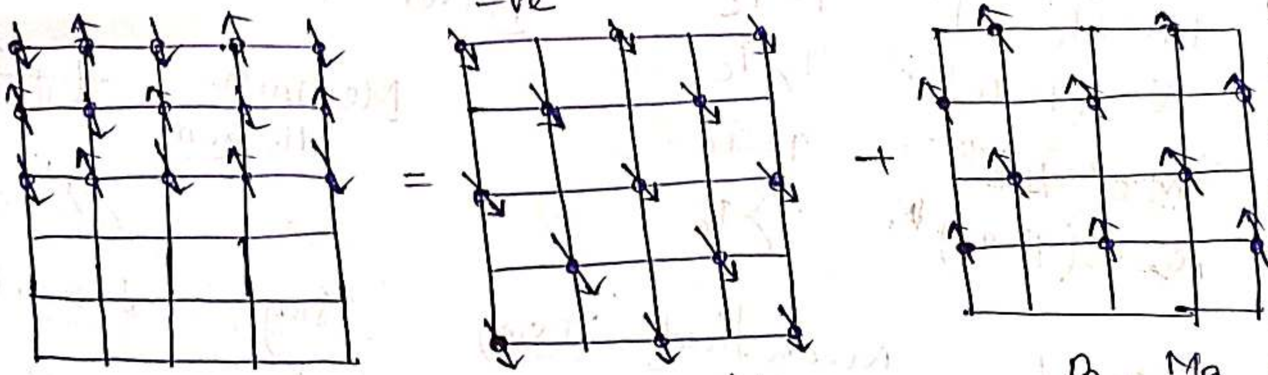
Antiferromagnetism

13/03/25

In 1936 Neel showed theoretically that if exchange integral J_{ij} = −ve, there a state of lowest energy is obtained where the spin of neighbouring atoms have opposite orientation. Such materials are known as antiferromagnetic materials.

$$\hat{H}_{spin} = -2 \underbrace{J_{ij}}_{-ve} \vec{S}_i \cdot \vec{S}_j$$



A M_A B M_B

Two interpenetrating sublattice A & B

$M = M_A + M_B$

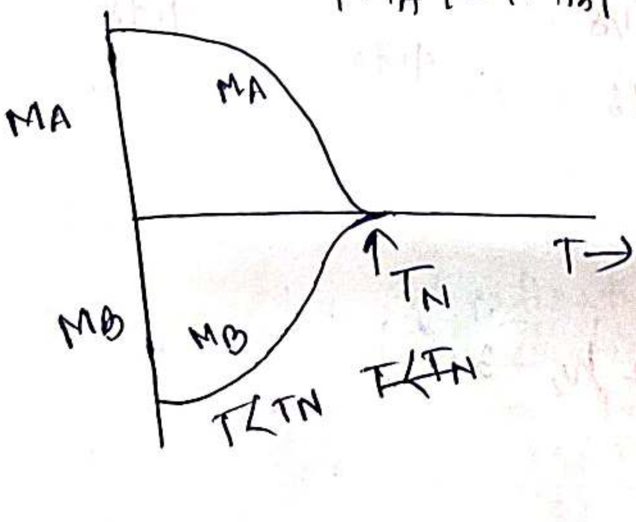
≈ 0 $|M_A| = |M_B|$

nearest neighbour interaction is AFM

next " " " is FM

M_A = A-sublattice magnetization

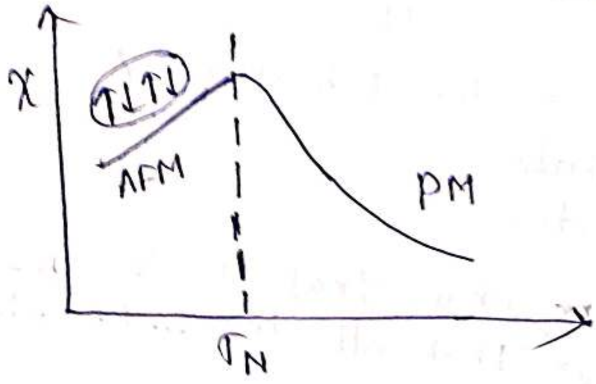
M_B = B-sublattice "

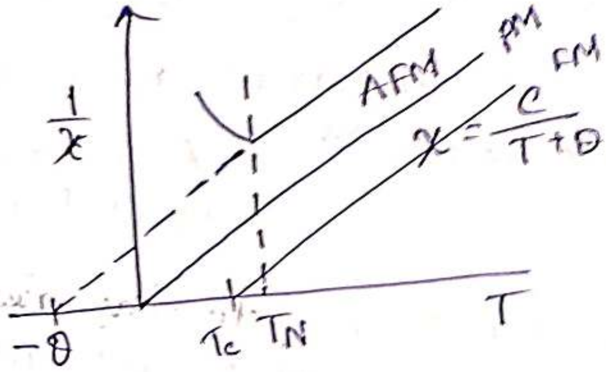


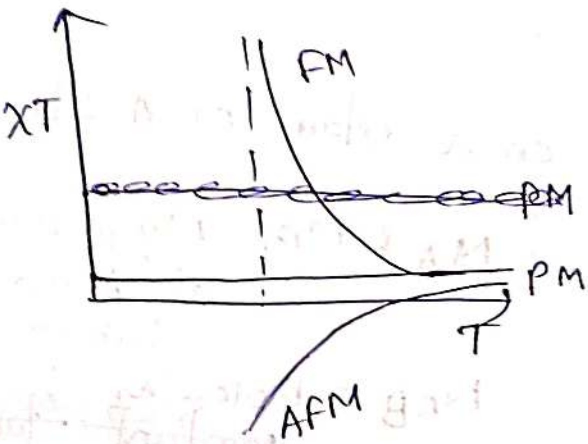
T_N = Neel temperature

$M = M_A + M_B = 0$

$|M_A - M_B|$ = Staggered Magnetization is used as order parameter.







$\chi = \frac{C}{T}$

$\chi = \frac{C}{T-\theta}$

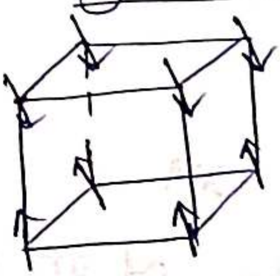
$\chi T - \chi\theta = C$

$\theta = 0$ PM
$\theta > 0$ FM
$\theta < 0$ AFM

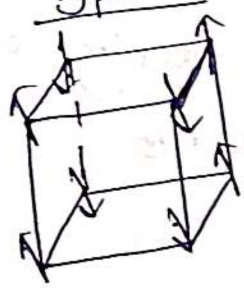
Types of AFM

Cubic Crystal

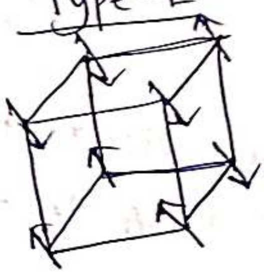
Type A



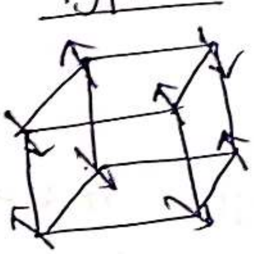
Type-C



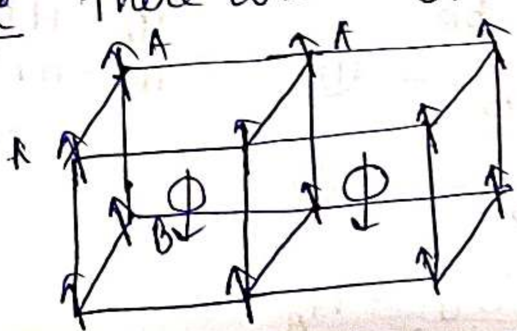
Type-E

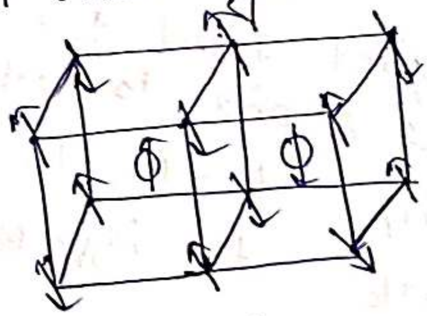


Type-G

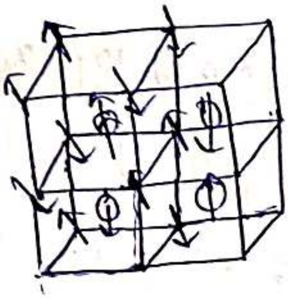


Bcc there are 3-types of AFM ordering





B Sublattice.



Wiess molecular field theory for AFM

Consider magnetic materials with two sublattices A & B

Bcc lattice $\quad A \to$ corner points

$\quad\quad\quad\quad\quad B \to$ Bcc position

An atom at A-site has nearest neighbours that all lie on B-sites & next nearest neighbour that all lie on A-sites.

$$H_{M_+} = -\lambda M_-$$

$$H_{M_-} = -\lambda M_+$$

The molecular field H_{mA} acting on a atom at A-site

$$H_{mA} = -N_{AA}M_A - N_{AB}M_B$$

M_A & M_B = Magnetizations of A and B Sublattice

N_{AB} = Molecular field constant for the Nearest Neighbour Interaction.

N_{AA} = " For Next Nearest Neighbour Int.

The molecular field H_{mB} acting on the atom B-site

$$H_{mB} = -N_{BA}M_A - N_{BB}M_B$$

$$N_{AA} = N_{BB} = N_{ii}$$

$$H + \lambda M$$

$$N_{BA} = N_{AB}$$

If H applied field the; the field H_A and H_B at an atom on the A and B lattice would be

$H_A = H + H_{mA}$

$H_B = H + H_{mB}$

$$H_A = H - N_{ii}M_A - N_{AB}M_B \quad \text{—— (1)}$$

$$H_B = H - N_{AB}M_A - N_{ii}M_B \quad \text{—— (2)}$$

$$M_A = Ng\mu_B J\, B_J(x_A) \qquad x_A = \frac{Jg\mu_B}{k_BT}H_A$$

$$M_B = \frac{N}{2}g\mu_B J\, B_J(x_B) \qquad x_B = \frac{Jg\mu_B}{k_BT}H_B$$

$$B_J(x_A) = \frac{2J+1}{2J}\coth\frac{2J+1}{2J}x_A - \frac{1}{2J}\coth\left(\frac{x_A}{2J}\right)$$

Case - 1 : Behaviour above T_N · $T > T_N$

$$B_J(x) \to \frac{3J+1}{3J} x$$

$x \to$ small $\quad M_A = \frac{N}{2} g \mu_B J \cdot \frac{J+1}{3J} \cdot \frac{J g \mu_B}{K_B T} H_A$

$$= \frac{N g^2 \mu_B^2 J(J+1)}{6 K_B T} H_A = \frac{N g^2 \mu_B^2 J(J+1)}{6 K_B T} \cdot \left\{ H - N_{ii} M_A - N_{AB} M_B \right\}$$

$$M_B = \frac{N g^2 \mu_B^2 J(J+1)}{6 K_B T} H_B = \frac{N g^2 \mu_B^2 J(J+1)}{6 K_B T} \cdot \left\{ H - N_{AB} M_A - N_{ii} M_B \right\}$$

$M = M_A + M_B$

$$M = \frac{N g^2 \mu_B^2}{6 K_B T} J(J+1) \left[2H - N_{AB}(M_A + M_B) - N_{ii} M \right]$$

$$M \left[1 + (N_{AB} + N_{ii}) \frac{N g^2 \mu_B^2}{6 K_B T} J(J+1) \right] = \frac{N g^2 \mu_B^2}{6 K_B T} J(J+1) \cdot 2H$$

$$\chi = \frac{M}{H} = \frac{\frac{N g^2 \mu_B^2 \cdot J(J+1)}{3 K_B T}}{1 + (N_{AB} + N_{ii}) \frac{N g^2 \mu_B^2 J(J+1)}{6 K_B T}}$$

$$\chi = \frac{\frac{C}{T}}{1 + \frac{(N_{AB} + N_{ii})}{2} \cdot \frac{C}{T}}$$

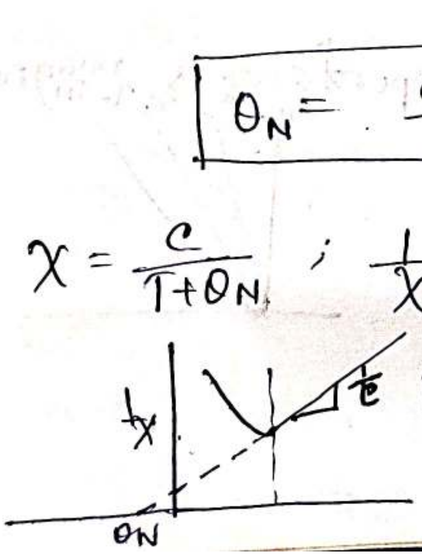
$$\chi = \frac{C/T}{1 + \frac{C}{2T}(N_{AB} + N_{ii})}$$

$$\chi = \frac{C}{T + \frac{C}{2}(N_{AB} + N_{ii})}$$

$\chi = \frac{C}{T + \theta}$ → Curie Weiss law for the AFM in the PM.

$$\boxed{\theta_N = \frac{C}{2}(N_{ii} + N_{AB})} \qquad C = \frac{N g^2 \mu_B^2 J(J+1)}{3 K_B}$$

$$\chi = \frac{C}{T + \theta_N} \; ; \; \frac{1}{\chi} = \frac{T}{C} + \frac{\theta_N}{C}$$



$|T_N| \simeq \theta_N$