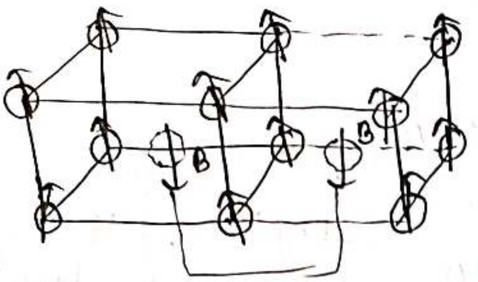
20/03/25

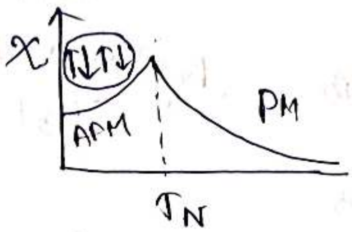


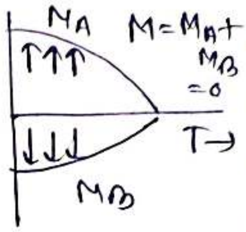
A Sublattice and B Sublattice.

$$M = M_A + M_B \approx 0$$

Stagged Magnetization $= |M_A - M_B|$

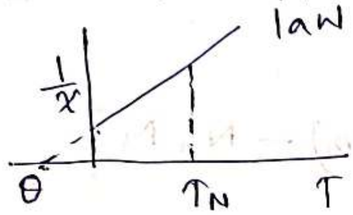
Order parameter





$T > T_N$

$$\chi = \frac{C}{T+\theta}$$ · Curie Weiss law



$$H_A = H - N_{ii} M_A - N_{AB} M_B$$
$$H_B = H - N_{AB} M_A - N_{ii} M_B$$

N_{AB} = Internal molecular field co-efficient for n.n. interaction

N_{AA} or N_{BB} or N_{ii} = Internal molecular field co-efficient for n.n.n interaction.

$$M_A = \frac{Ng^2\mu_B^2 J(J+1)}{6k_B T}\{H - N_{ii} M_A - N_{AB} M_B\}$$ $M = M_A + M_B$

$$M_B = \frac{Ng^2\mu_B^2 J(J+1)}{6k_B T}(H - N_{AB} M_A - N_{ii} M_B)$$ $\chi = \frac{C}{T+\theta_N}$

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

$$M_A = \frac{N}{2} g\mu_B J B_J(x_A)$$ $C = \frac{Ng^2\mu_B^2 J(J+1)}{3k_B}$

$$M_B = \frac{N}{2} g\mu_B J B_J(x_B)$$ $\theta_N = \frac{C}{2}(N_{ii} + N_{AB})$

Case-II : $T < T_N$

Below T_N, both the sublattice possess a spontaneous magnetization.

$H = 0$

$$M_A = \frac{C}{2T}(-N_{ii} M_A - N_{AB} M_B)$$

$$M_B = \frac{C}{2T}(-N_{AB} M_A - N_{ii} M_B)$$

$$M_A\left[1+\frac{C}{2T_N}N_{ii}\right]+M_B\left(\frac{C}{2T_N}N_{AB}\right)=0$$
$$M_A\left(\frac{C}{2T_N}N_{AB}\right)+M_B\left[1+\frac{C}{2T_N}N_{ii}\right]=0$$

$$\begin{vmatrix} x & y \\ y & x \end{vmatrix}=0 \qquad x = 1+\frac{C}{2T_N}N_{ii}$$
$$y = \frac{C}{2T_N}N_{AB}$$

$$x^2-y^2=0$$
$$(x-y)(x+y)=0$$

$x=y$ valid soln

$x=-y$ ✗ opposite magnetization.

So take negative also as opposite.

$$x=y$$
$$\Rightarrow 1+\frac{C}{2T_N}N_{ii}=\frac{C}{2T_N}N_{AB}$$
$$\Rightarrow \frac{C}{2T_N}(N_{AB}-N_{ii})=1$$
$$\boxed{T_N=\frac{C}{2}(N_{AB}-N_{ii})}$$
$$\theta=\frac{C}{2}(N_{ii}+N_{AB})$$
$$\frac{T_N}{\theta}=\frac{N_{AB}-N_{ii}}{N_{AB}+N_{ii}}$$

if $N_{ii}=0$

$$\boxed{T_N=\theta}$$

If consider ~~Nor~~ Next Nearest Neighbour int.

$T_N < \theta$

is $N_{ii} > 0$

If AFM, AB int (N_{AB}) because stronger

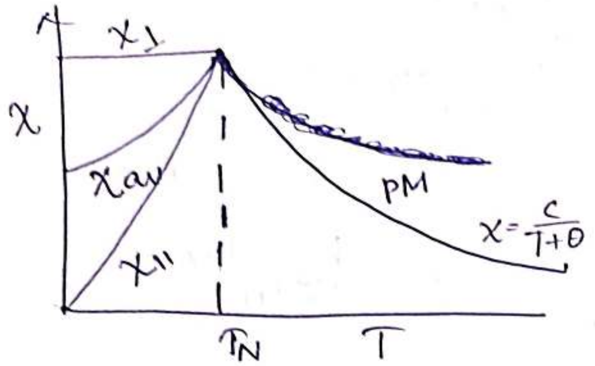
T_N increases with increasing AA or BB.

but decreases

Material	T_N (K)	θ(K)	J
MnF_2	67	−80	5/2
MnO	116	−510	5/2
CoO	292	−330	3/2
FeO	116	−610	2
Cr_2O_3	307	−485	3/2
α-Fe_2O_3	950	−2000	5/2

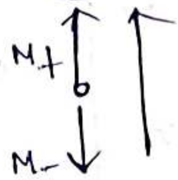
It is seen that $T_N < \theta$

AFM



powder sample → χ_{av}

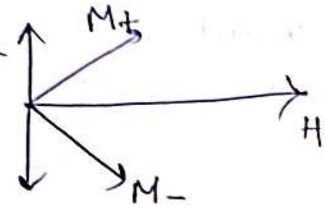
$$\chi_{avg} = \frac{1}{3}\chi_{\parallel} + \frac{2}{3}\chi_\perp$$



Small Magnetic field

$H_{\parallel}$ → Magnetisation for M_+ & M_- sublattice all are at saturated state.

$H_\perp$ →

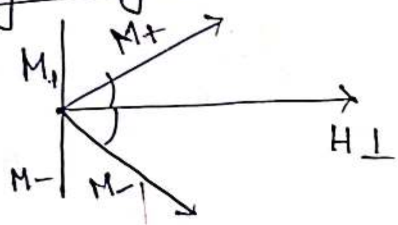


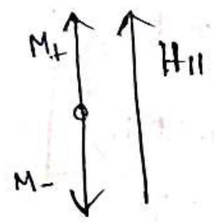
χ ~~$H_\perp$ ~~ ~~per~~

$\chi_\perp$ remain const till $T = T_N$

Strong Magnetic field

$H_\perp$

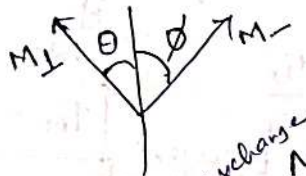


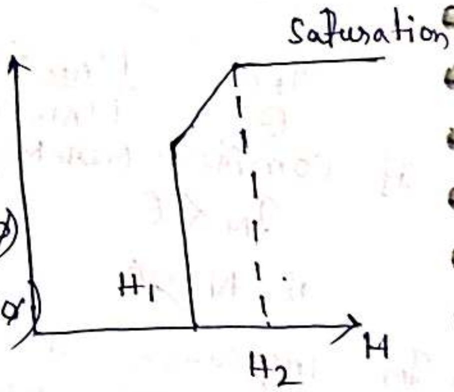


at M_+ making angle θ M_- making angle ϕ

AFM → $\theta = 0$
$\phi = \pi$

Spin - flop transition $\theta = \phi$

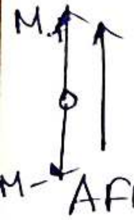




Total Energy:

$$E = -MB\cos\theta - MB\cos\phi + AM^2\cos(\theta+\phi) - \frac{1}{2}\Delta(\cos^2\theta + \cos^2\phi)$$

zeeman zeeman exchange anisotrophy



AFM, $\theta = 0$, $\phi = \pi$

$$E_{AFM} = -MB + MB - AM^2 - \Delta$$
$$= -AM^2 - \Delta$$

This is independent of field.

In the spin flop state $\theta = \phi$

$$E_{AFM} = -2MB\cos\theta + AM^2\cos 2\theta - \Delta\cos^2\theta$$

Minimum Energy Configuration $\frac{\partial E}{\partial \theta} = 0$

$+2MB\sin\theta \mp 2AM^2\sin 2\theta + 2\Delta\cos\theta\sin\theta = 0$ $\qquad \Delta\cos^2\theta$ is small

$\cancel{\sin\theta(2MB \mp 2AM^2\cos\theta + 2\Delta(\cos\theta)) = 0}$

$2MB\sin\theta - 2AM^2\sin 2\theta = 0$

$\Rightarrow 2\sin\theta\,(MB - 2AM^2\cos\theta) = 0$

$\sin\theta = 0$, $\theta = 0$ | $B - 2AM\cos\theta = 0$

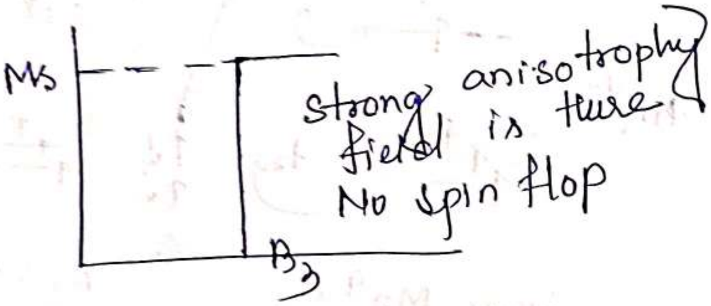
$\cos\theta = \frac{B}{2AM}$

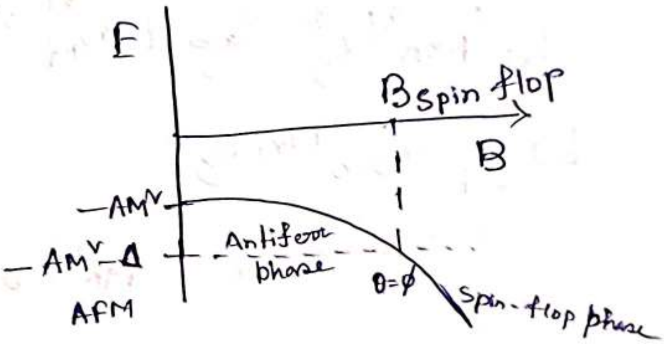
$\theta = \cos^{-1}\left(\frac{B}{2AM}\right)$ $\qquad \sin\theta =$

$$E = -2MB\,\cancel{\cos\theta}\cdot\frac{B}{2AM} + 2AM^2\cdot 2\sqrt{1-\frac{B}{2AM}}\;\; \frac{2\times B^2}{4A^2M^2} - AM^2$$

$$E = -\frac{B^2}{A} + \frac{B^2}{2A} - AM^2$$

$$E = -\frac{B^2}{2A} - AM^2$$





Direct Exchange:

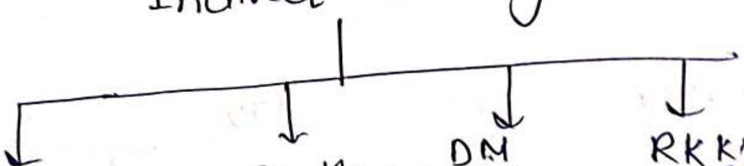
$H_{ex} = -2J\,\vec{S_i}\cdot\vec{S_j}$

FM

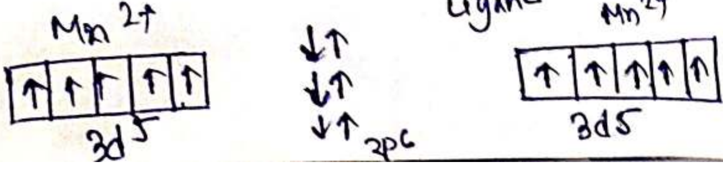
AFM

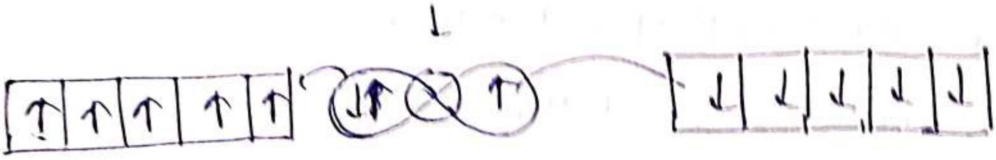
Ferri

Indirect Exchange



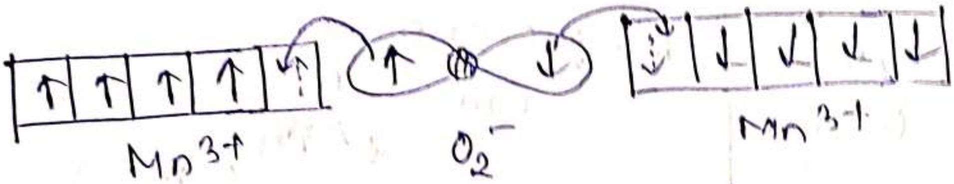
$MnO \rightarrow$ $\quad Mn^{2+} - O^{2-} - Mn^{2+}$ $\quad$ far apart, No direct exch.





AFM superexchange.

Mn 3+



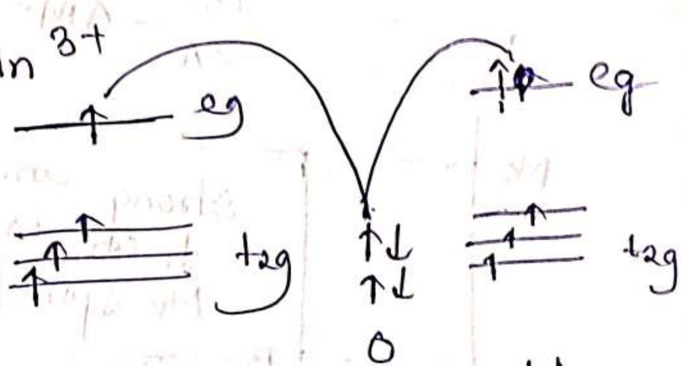
Superexchange
AFM interaction.

Double Exchange:

$La^{3+}Mn^{3+}O_3^{2-}$, $La_{0.7}^{3+}Sr_{0.3}^{2+}Mn^{3+}Mn^{4+}O_3^{2-}$

$La_{0.7}Sr_{0.3}MnO_3$

$Mn^{3+}-O-Mn^{4+}$

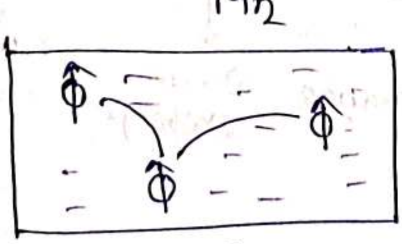


CMR material.
DE interaction

become Mn^{4+}

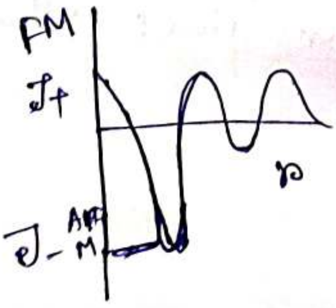
e^- - hoping can take place

RKKY



communicate via conduction electron
cu have lots of conduction e^-.

CuMn, AgMn



$J(r) \propto \frac{\cos k_F r}{r^3}$

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The critical temparature can be found by approaching from the high temp side $T > T_N$

$$M_A = \frac{C}{2T}(H - N_{ii}M_A - N_{AB}M_B)$$

$$M_B = \frac{C}{2T}(H - N_{AB}M_A - N_{ii}M_B)$$

In the vicinity of T_N (saturation effects are unimportant)

$H = 0$

$$M_A = \frac{C}{2T}[-N_{ii}M_A - N_{AB}M_B]$$

$$M_B = \frac{C}{2T}[-N_{AB}M_A - N_{ii}M_B]$$

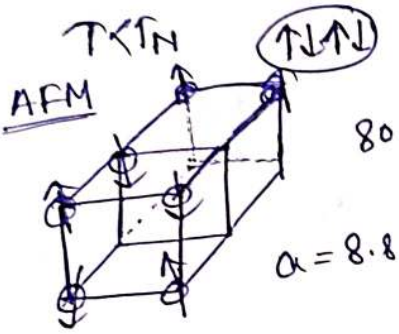
For Non zero values of M_A and M_B the determinant of M_A & M_B must be zero.

$T > T_N$ (↗↙↖↘)

300 K

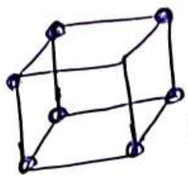
$T < T_N$ (↑↓↑↓)

AFM



80 K

$a = 8.85$ Å



• unmagnetized MnO

$a = 4.45$ Å

Neutron diffraction, NPD

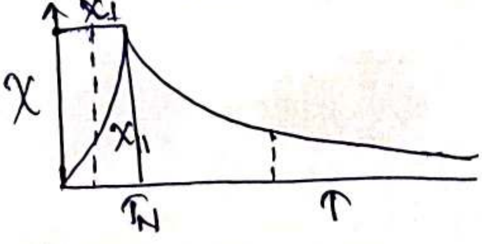
Spin structure

x-ray ~~Neutron~~ diffraction

XRD, NPD

Lattice structure.

<u>Problem</u> → Consider an AFM material which has susceptibility χ_0 at its Neel temp. T_N. Assuming that the exchange interaction between nearest neighbour A & B ions are much larger than those A-A and B-B pairs. calculate the values of susceptibilities which would be measured under the application of fields perpendicular to the magnetization direction at $T = 0$, $T = T_N/2$ and $T = 2T_N$



$N_{AB} \gg N_{ii}$ $\quad \chi = \frac{C}{T+\theta} = \frac{C}{T+T_N}$

$T_N = \theta$

at $T = 2T_N$ $\quad \chi = \frac{C}{3T_N}$.