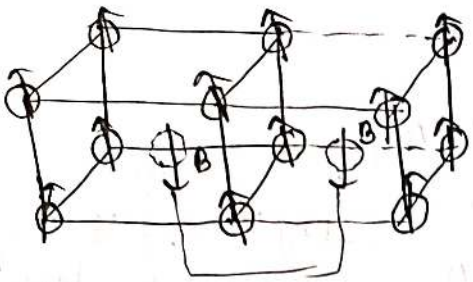
20/03/25

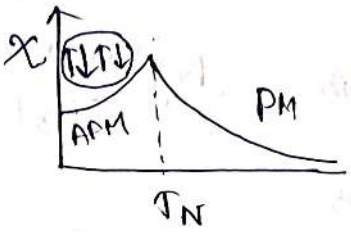


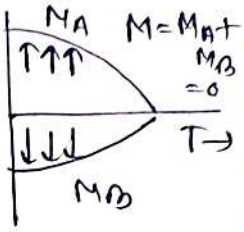
A Sublattice and B Sublattice.

$M = M_A + M_B \gtrless 0$

Stagged Magnetization $= |M_A - M_B|$

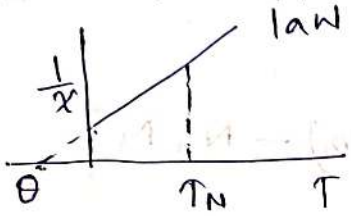
order parameter





$T > T_N$

$\chi = \frac{C}{T+\theta}$ · 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. inter-action

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

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

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

$M = M_A + M_B$

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

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

$M_A = \frac{N}{2} g \mu_B J B_J(x_A)$

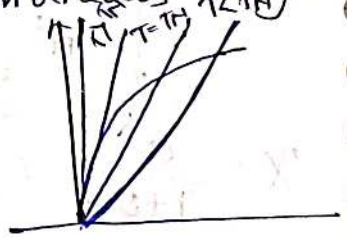
$M_B = \frac{N}{2} g \mu_B J B_J(x_B)$

$C = \frac{N g^2 \mu_B^2 J(J+1)}{3 K_B}$

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

Case-II : $T < T_N$

Below T_N, both the Sublattice posses a spontaneous magnetization.



$H = 0$

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

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

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

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

$$\begin{vmatrix} x & y \\ y & x \end{vmatrix}=0$$

$$x=1+\frac{C}{2T_N}N_{ii}$$

$$y=1\,\frac{C}{2T_N}N_{AB}$$

$$x^2-y^2=0$$

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

$x=y$ valid soln

$x=-y$ ✗ opposite Magnetization. So take negative cho ab 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 Next Nearest Neighbour int.

$T_N<\theta$

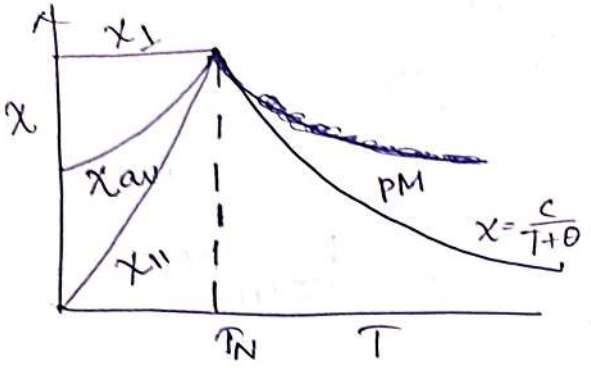
if $N_{ii}>0$

T_N increases if AFM, AB int (N_{AB}) because stronger but decreases with increasing AA or BB.

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
$\alpha-Fe_2O_3$	950	−2000	5/2

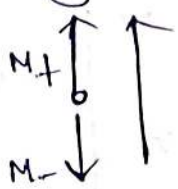
It is seen that $T_N<\theta$

AFM



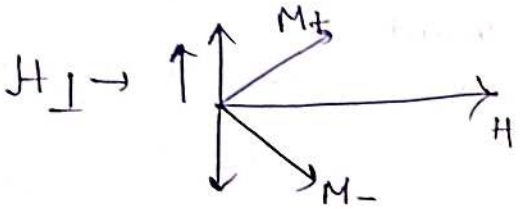
powder sample → χ_{av}

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



Small Magnetic field

$H_\perp \rightarrow$

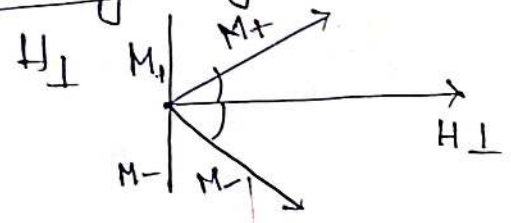


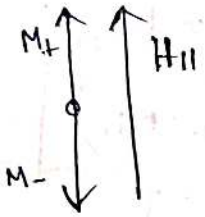
$H_\parallel \rightarrow$ Magnetisation for M_+ & M_- sublattice all are at Saturated state.

~~$\chi_\parallel$~~ ~~remain~~ Comt till $T = T_N$

$\chi_\perp$ remain

Strong Magnetic field

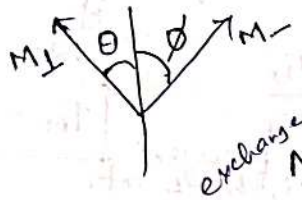




at M_+ making angle θ
M_- making angle ϕ

AFM → $\theta = 0$
$\phi = \pi$

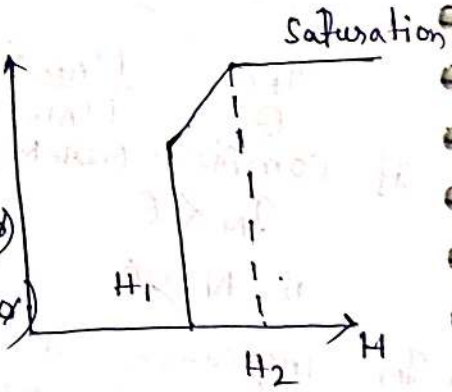
Spin - flop transition $\theta = \phi$



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

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

Thus is independent of field.

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

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

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

$+2MB\sin\theta \mp 2AM^2\sin 2\theta + 2\Delta\cos\theta\sin\theta = 0$ $\quad \Delta\cos\theta \approx$ Small

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

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

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

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

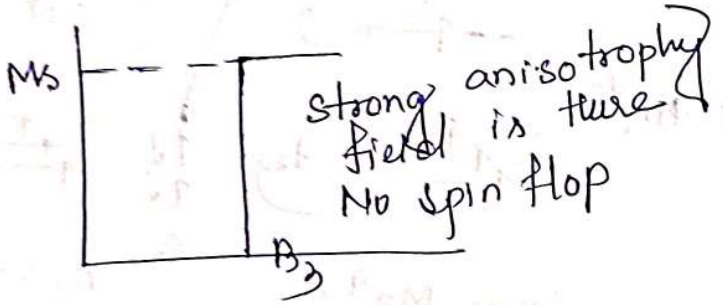
$\theta = 0$ | $\cos\theta = \frac{B}{2AM}$

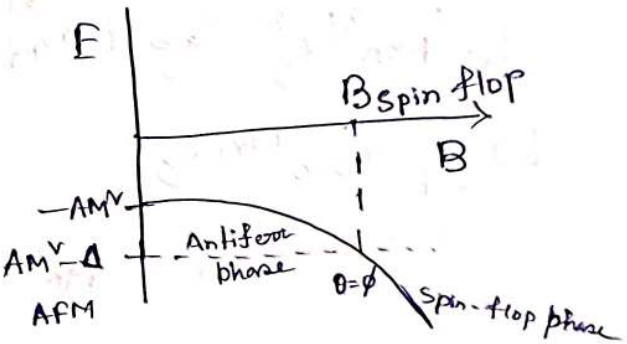
$\theta = \cos^{-1}\left(\frac{B}{2AM}\right)$ $\quad \sin\theta =$

$E = -2MB\cos\theta\cdot\frac{B}{2AM} + 2AM^2\cdot\left(\frac{B}{2AM}\right)^2 - AM^2$

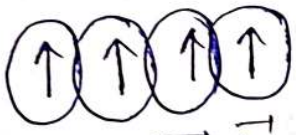
$E = -\frac{B^2}{A} + \frac{B^2}{2A} - AM^2$

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





Direct Exchange:



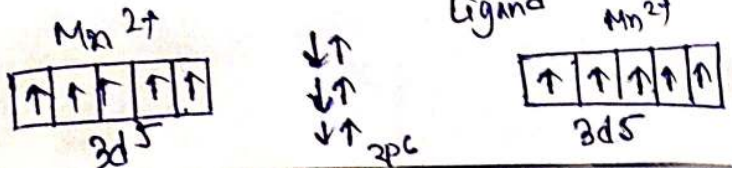
$H_{ex} = -2J\vec{S_i}\cdot\vec{S_j}$

Indirect Exchange

- Superexchange
- Double exchange
- DM inter
- RKKY int

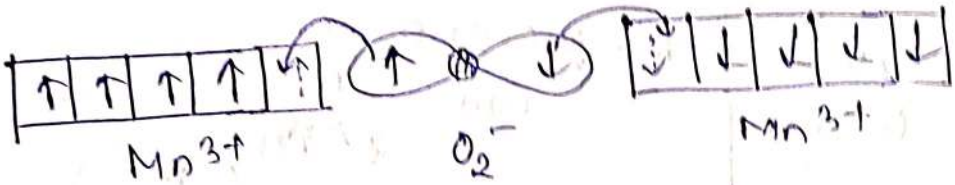
FM
AFM
FErri

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



AFM Superexchange.

Mn^{3+}



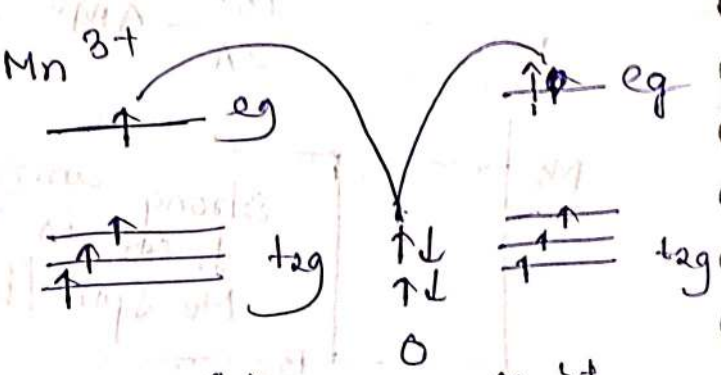
Superexchange
AFM interaction.

Double Exchange:

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

$La_{0.7} Sr_{0.3} Mn O_3$

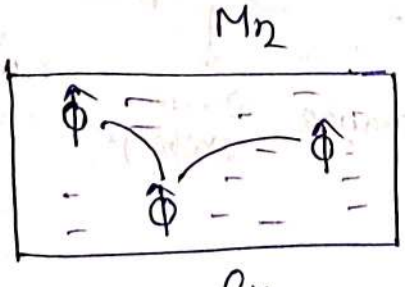
$Mn^{3+} - O - Mn^{4+}$



CMR material.
DE interaction

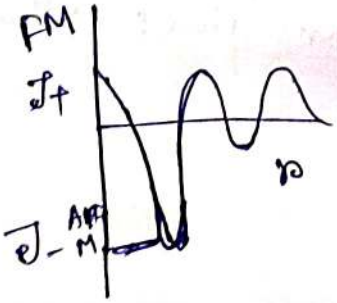
e^- hoping can take place

RKKY



communicate conduction electron via 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)

$H = 0$

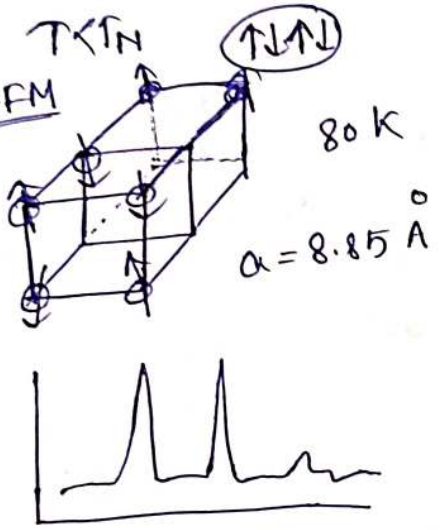
$$M_A = \frac{C}{2T}[-N_{ii} M_A - N_{AB} M_B]$$

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

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

$T < T_N$

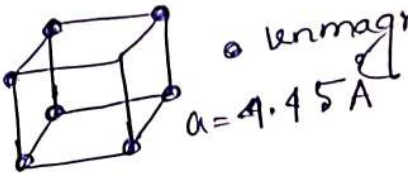
AFM



Neutron diffraction. NPD

Spin structure

$T > T_N$

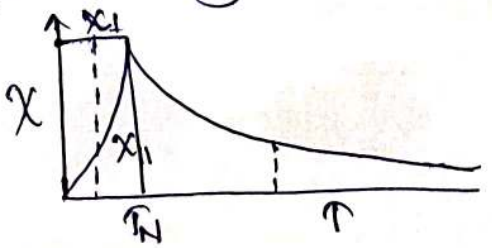


~~Neutron~~ x-ray diffraction

XRD. NPD

Lattice structure.

Problem → 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 $T = 2T_N$



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

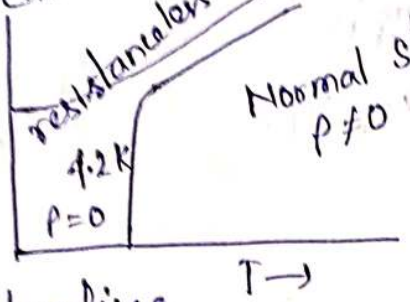
$T_N = \theta$ ~~$= \frac{C}{2} N_{AB}$~~

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

Superconductivity

1908 Kamerling onnes — He-gas → boiling point
Liq. H → 4.2 K

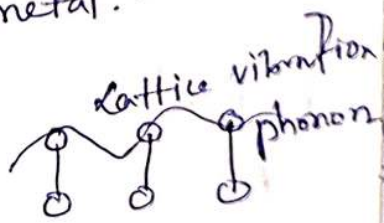
1911 → He discovered superconductivity state in Hg



Hg

1931 → Noble pize for study of low temp properties of metal.

Superconducting state or resistanceless state.



$$\rho = \rho_0 + A\left(\frac{T}{\theta_D}\right)^4 \int_0^{\theta/T} \frac{x^5\,dx}{(e^x-1)(1-e^{-x})} + \rho_{mag}$$

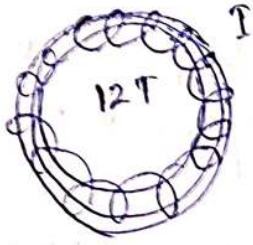
ρ_0 → Impurity scattering
$A\left(\frac{T}{\theta_D}\right)^4$ → e-phonon scattering term
$\int_0^{\theta/T} \frac{x^5\,dx}{(e^x-1)(1-e^{-x})}$ → Bloch-Grueisen Integral
ρ_{mag} → (Magnetic scattering term)

1957 → BCS Theorem (cooper)
Borden
Schreiffer
(Transistor)

Borden
Britain
Schokley
Transistor P-N-P
1947

MRT → Superconducting Magnet

TO KOMOK



1) High field magnet
2) SMES
3) Magnetic levitation
High speed train running 400 - 500 KM/hours
4) Superconducting switches
5) Jaephin tunneling - SQUID

Meissner-Oschenfield Effect:

expansion of Magnetic flux line.

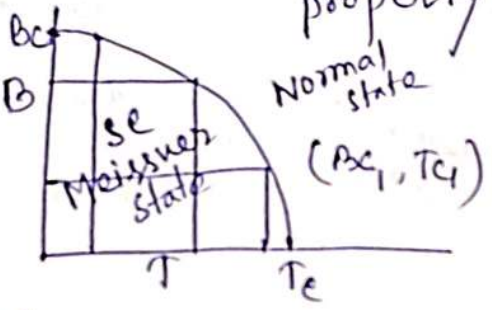
i) $\rho = 0$ ii) $B = 0$ These two properties are independent.

$E = \rho J$ $\rho = 0 \Rightarrow E = 0$ $E = 0$ sc property is a special property where $B = 0$

$\vec{\nabla} \times \vec{E} = 0$

$-\frac{\partial B}{\partial t} = 0$

$B = \text{const}$



Hg = 4.2 K
B = 0

Element	T_c (K)
Al	1.2
Cd	0.5
Ga	1.1
In	3.4
Pb	7.2
Nb	9.3
Tc	8.2
Sn	3.7
V	3.3
Nb_3Ge	23
Nb_3Sn	18.1
Nb_3Al	17.5
$Nb_3Al_{0.8}Ge_{0.2}$	20.1

Low T_c Material → Type-I superconductor

1987 · Bednorty and Mueller → High T_c Superconductor
Type-II Superconductor.

High T_c Material	T_c (K)
$(CaBa)_2CuO_4$	38 K
$YBa_2Cu_3O_{7-\delta}$	90K
$Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$	110K
$Tl_2Ba_2Ca_2Cu_3O_{10+\delta}$	130K
H_2S (155 GPa)	200 K
Lanthanum hydride (170 GPa)	250K

C-H-S (267 GPa) – 270K

$B = 0$ $\quad \vec{B} = \mu_0(\vec{H} + \vec{M}) = \mu_0 \vec{H}\left(1 + \frac{M}{H}\right) = \mu_0 H(1+\chi)$

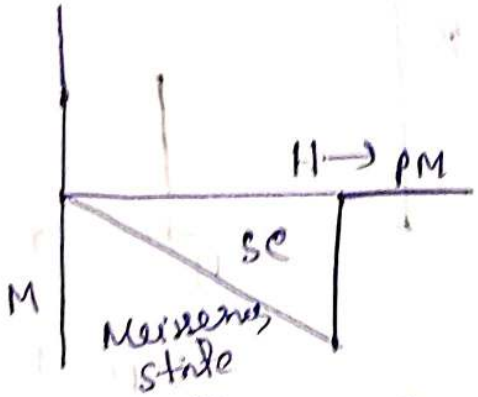
$= \mu H = \mu_0 \mu_r H$

$0 = H + M$

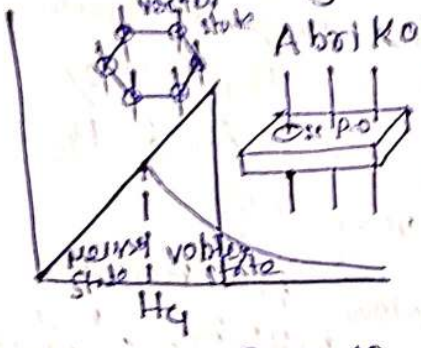
$M = -H$

$\chi = \frac{M}{H} = -1$ $\qquad \chi = -10^{-5}$

Perfect diamagnet



Type - I SC



Type - II