Magnetism

All materials exhibit magnetism though of different nature

$$\vec{B} = \mu_0 (\vec{H} + \vec{M})$$
$$= \mu_0 H (1 + \chi)$$
$$= \mu H$$
$$= \mu_0 \mu_r H$$

so $\boxed{\mu_r = 1 + \chi}$ in general χ & μ are tensor

but for isotropic medium χ & μ are scalers

magnetisms in solid arises due to orbital & spin motion of $\bar{e}$s as well as spins of nuclei.

Classification of magnetism

1) Diamagnetism
2) Paramagnetism
3) ferromagnetism
4) Antiferromagnetism
5) ferrimagnetism

1) Diamagnetism : Those substance, which when placed in a magnetic field are feebly magnetized in a direction opp. to that of mag. field.

e.g. Gold, diamond, water, bismith, copper etc.

⇒ Diamagnetism is very weak effect and is observed in solids which donot contain any permanent magnetic moments.

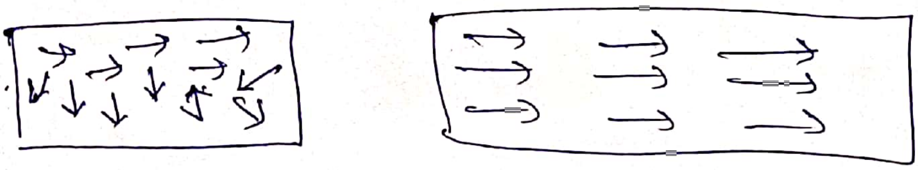
⇒ The magnetic moment is always directed opp. to applied mag. field.

⇒ χ is −ve.

2) Paramagnetism : Those substance, which when placed in a mag. field are feebly magnetized in the direction of mag. field.

e.g. Sodium, Cromium, Aluminium, Platinium Oxygen etc.

- Paramagnetism is also weak effect.
- The magnetic moments are aligned in the direction of field.
- On absence of mag. field the moments usually point in random directions & thus produce no magnetization. But in presence of a mag. field these moments ~~[illegible]~~ tent to line up in the dir. of field & have net magnetization.
- χ is +ve.
- The direction of magnetization is || to the applied field.



[w/out field] [with field]

3) Ferromagnetism : Those substance, which when placed in a mag. field are strongly magnetised in the direction of field.

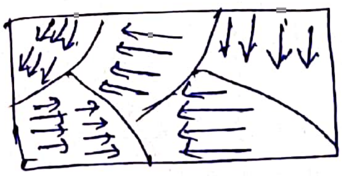
Ferromagnetic substances are attracted by the magnet and can also be magnetized.

e.g. Iron, Nickel, Cobalt, & their alloys etc.

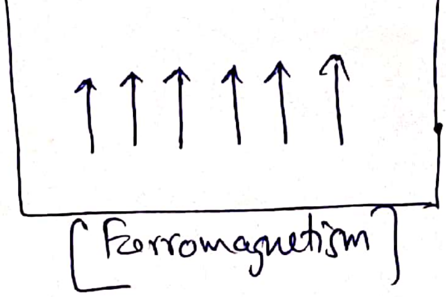
- Ferromagnetism is very strong effect and arises when the adjacent magnetic moments align themselves in the same direction.
- ferromagnetic materials consists of spontaneously magnetized regions called domains which are randomly oriented in absense of applied mag. field.
- spontaneous magnetization vanishes above critical temp called curie temp.

& χ is not constt but vary with field.

- Spontaneous magnetization of the specimen is determined by the vector sum of mag. moments. of the individual domain

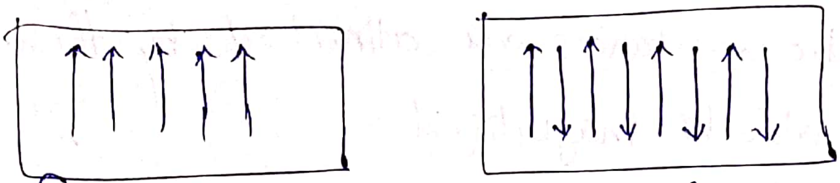


[Ferromagnetic domain]



[Ferromagnetism]

4) Anti Ferromagnetism : In this the adjacent moments are equal and opposite to each other and hence complete cancellation of moments take place.



[Ferromagnetism] (Antiferromagnetism)

- In absence of an external field, the neighbouring magnetic moments cancel out each other and the material as a whole exhibits no magnetization.
- When field is applied a small magnetization appears in the direction of field which increases further with temp.
- The $\vec{M}$ becomes max. at a critical temp. T_N called Neel temp. which is analogous to curie temp. in Paramag.

e.g MnO, MnF_2

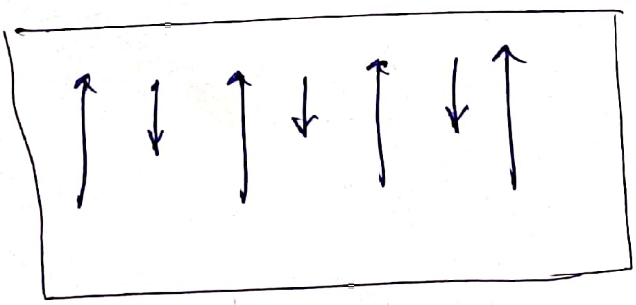
5) <u>ferrimagnetism</u> : A ferrimagnetic material is identical to an antiferromagnetic material except that the opp. mag. moments of nbr.ing sublattices have unequal magnitudes. OR

opp. mag. moments of two sets of atoms in the sublattice are different in magnitude give rise to a large net magnetization.

OR

Adjacent mag. moments unequal & not cancellation take place.

- It is also spontaneous magnetization & also exhibit the phenomenon of hysteresis like ferromagnetism.



Ferrimagnetism.

Langevanis theory

$$\boxed{\chi_{dia} = -\frac{N\mu_0 Z e^2}{6m}\langle r^2\rangle}$$

→ classical

→ quantum

N = no. of atoms / unit vol. of solid

Z = no. of ēs in each atom

m = ēnic mass

$\langle r^2\rangle$ = Avg. radius of ē from field axis

OR

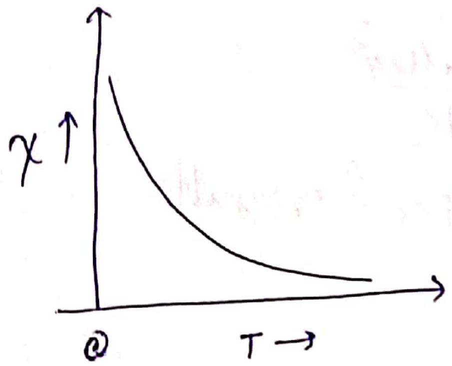
mean square distance of ēs relative to nucleus.

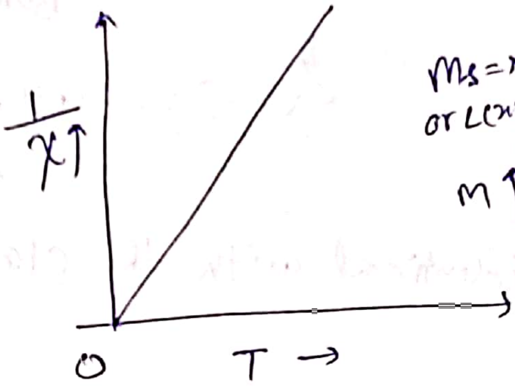
- χ_{dia} is independent of temp.

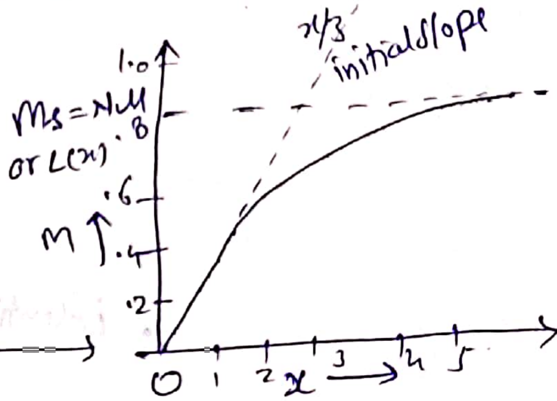
$$\boxed{\chi_{para} = \frac{\mu_0 M}{B} = \frac{\mu_0 N\mu^2}{3KT} = \frac{C}{T}} \rightarrow \text{curie law}$$

where $C = \dfrac{\mu_0 N\mu^2}{3K}$ is constt called curie constt.

- χ_{para} is temp. dependent.
- curie law holds good for $\dfrac{\mu B}{KT} << 1$
- when $\dfrac{\mu B}{KT} >> 1$ then $\boxed{M = N\mu = M_s} \rightarrow$ saturation magnetization







when $L(x)$ = Langevin function

& $x = \dfrac{\mu B}{KT}$

For $x << 1$, $\boxed{M \cong \dfrac{N\mu^2 B}{3KT}}$

for $x >> 1$, $\boxed{M = N\mu = M_s}$

μ = permanent mag. moment.

Langvin's Classical theory

Quantum Theory

$$\boxed{\chi_{para} = \frac{\mu_0 N \mu_{eff}^2}{3KT} = \frac{C}{T}}$$ → curie law

where $\mu_{eff}^2 = g_J^2 J(J+1)\mu_B^2$
gives effective no. of
Bohr's magneton

& $C = \frac{\mu_0 N \mu_{eff}^2}{3K}$

- identical with the classical result.

- $x = \frac{gJ\mu_B B}{KT}$

$M = NgJ\mu_B B_J(x)$	$x << 1$
$M = NgJ\mu_B$	$x >> 1$

Weiss's theory of Ferromagnetism / Assumptions

- A specimen of ferromagnetic material contains a no. of small regions called domains which are spontaneously magnetized. The magnitude of spont. magnetization of the specimen as a whole is determined by the vector-sum of the magnetic moments of individual domains.
- The spont. magnetization of each domain is due to the presence of an exchange field B_E which tends to produce all alignment of atomic dipoles. &

$$B_E = \alpha M$$

, α is constt. called Weiss's field constt & is indep. of temp.

$$\frac{M(T)}{M_s(0)} = \frac{x K T}{\alpha N g^2 J^2 \mu_B^2} \rightarrow (A)$$

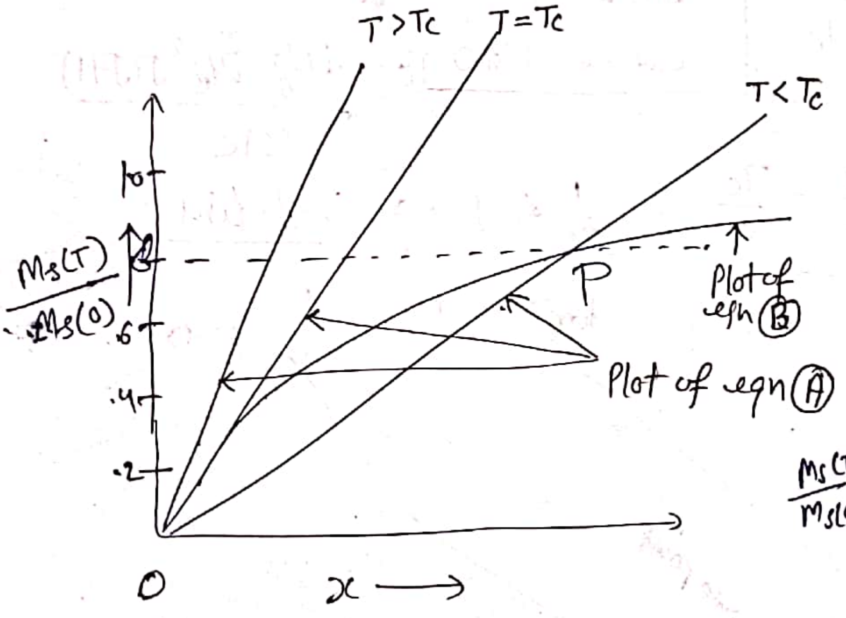
$$\frac{M(T)}{M_s(0)} = B_J(x) \rightarrow (B)$$

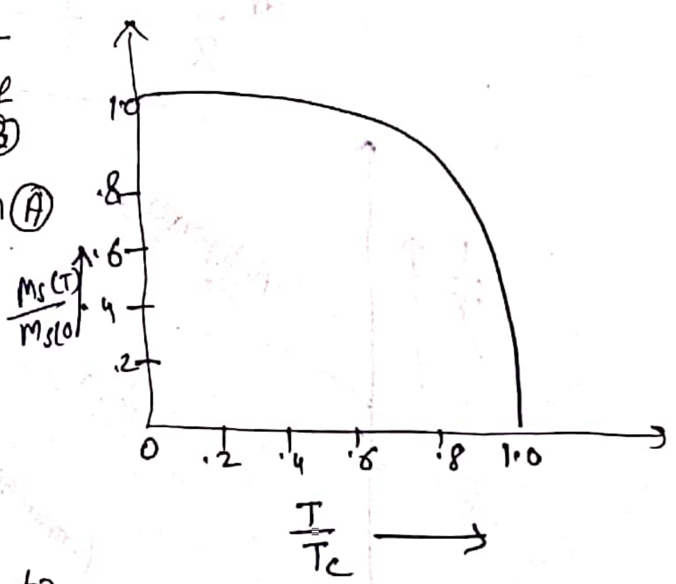
where

$$x = \frac{g J \mu_B \alpha M}{KT}$$

$$M(T) = \frac{x K T}{g J \mu_B \alpha}$$

$$\& \ M_s(0) = N g J \mu_B$$





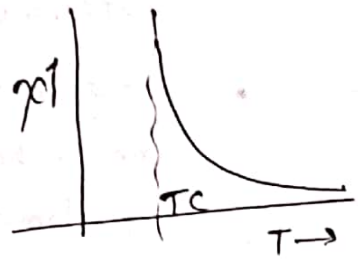
Note
$T \geq T_c$. no spont. magnetization
$T < T_c$ spont. magnetization

T_c -P, -F

At T_c [$\because T=T_c$] $\boxed{T_c = \frac{N \mu_J^2 \alpha}{3K}}$ $\rightarrow \chi << 1$

• shows T_c is proportional to weiss's constt. α.

Below T_c [$T<T_c$] $\boxed{\frac{M_s(T)}{M_s(0)} = \frac{T}{T_c}\left(\frac{J+1}{3J}\right) x}$



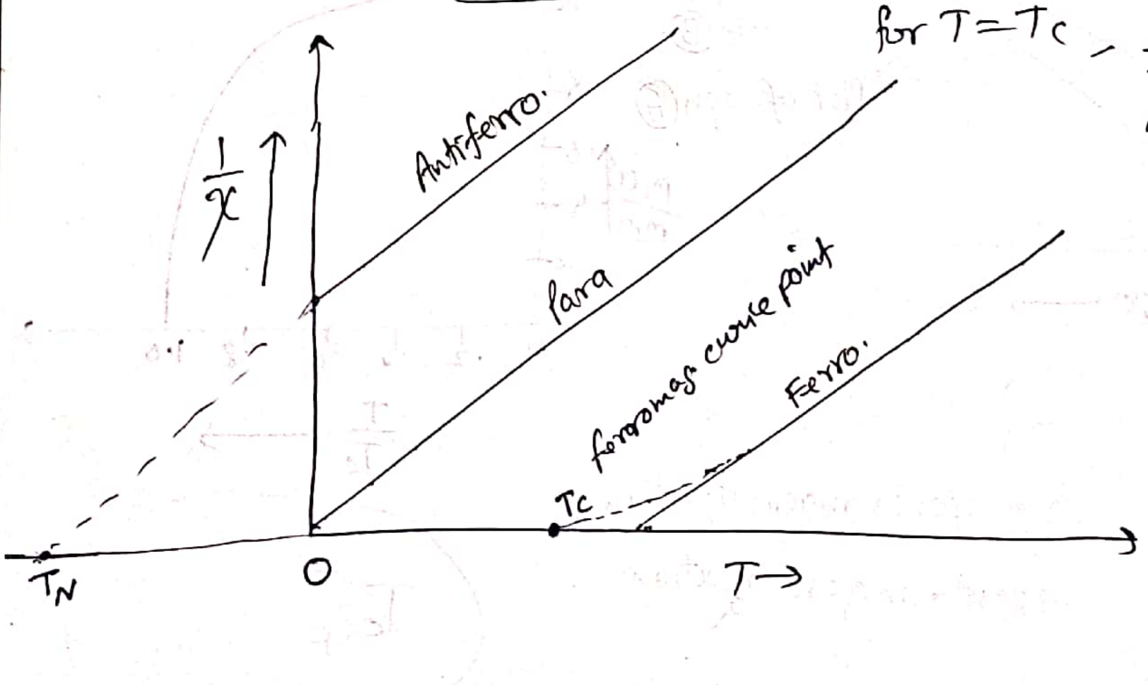
Above T_c [$T>T_c$] · The magnetization occurs only when mag.field is applied. There is no spont. magnetization. This region is known as paramagnetic region.

$\boxed{\chi = \frac{C}{T-T_c}}$ where $C = \frac{\mu_0 T_c}{\alpha}$ 4

$\rightarrow$ curie weiss's law $T_c = \frac{\alpha N g^2 \mu_B^2 J(J+1)}{3K}$

or $\boxed{\frac{1}{\chi} = \frac{T}{C} - \frac{T_c}{C}}$ $\frac{1}{\chi}$ & $T \rightarrow$ st. line

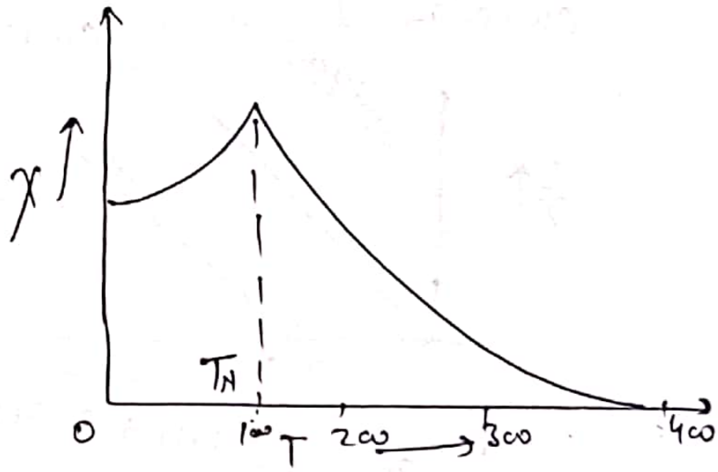
for $T=T_c$, $\frac{1}{\chi} = 0$



$$\boxed{\chi = \frac{C}{T - T_c}}$$ → Curie Weiss's law

- χ has singularity at $T = T_c$
- Below this temp. (T_c) ∃ spontaneous magnetization
- $T_c \begin{cases} F \to P \\ M_{spt.} \end{cases}$

Antiferromagnetism



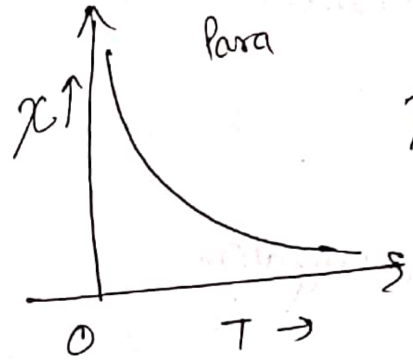
$$\boxed{\chi = \frac{C}{T + T_N}}$$

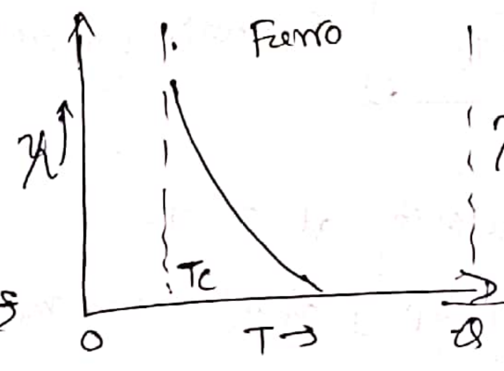
$T_c = T_N =$ Neel temp.

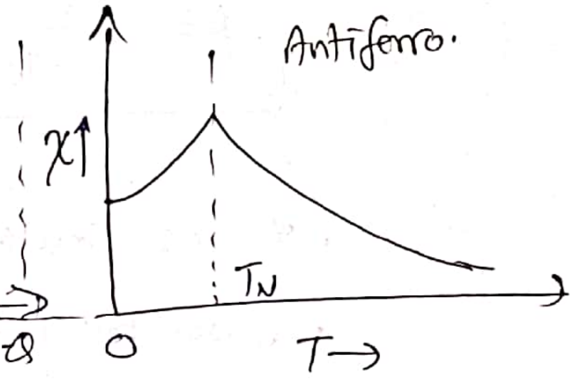
$C = 2\mu_0 C_A$ = const.

- The critical temp. at which χ is max. called Neel temp.

$$\boxed{T_c \begin{cases} AF \to P \\ M_{spt.} \end{cases}}$$







$\chi = \frac{C}{T}$ (Curie-law)

$\chi = \frac{C}{T - T_C}$ $(T > T_C)$ (Curie-Weiss law)

$\chi = \frac{C}{T + \theta}$ $(T > T_N)$ $= \frac{C}{T + T_N}$

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}$$

$g = 2$ if net angular momentum of dipole is due to electron

$= 1$ if due to orbital motion.

$$\mu_B = \frac{e\hbar}{2m} \quad \text{(Bohr's magneton)}$$

$$= 9.27 \times 10^{-24}\ J/T$$