ENGINEERING PHYSICS

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Langevin theory of paramagnetism and Weiss molecular field

Class #50

- *Langevin theory of paramagnetism*
- *Weiss molecular field*
- *Curie- Weiss Law*
- *Curie temperature*

Langevin theory of paramagnetism and Weiss molecular field

- ***Suggested Reading***

1. ***Quantum Physics of Atoms Nuclei and Molecules, Robert Eisberg, Robert Resnick, Wiley, 2nd edition, Ch 14, 2006.***
2. ***Learning material provided by the department***

- ***Reference Videos***

1. ***https://nptel.ac.in/courses/115/105/115105099***
2. ***Lecture video No. 49***

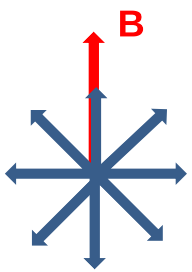
Quantum theory of paramagnetism - Langevin function

- ***Average Magnetization***

$$M = Ng\mu_B j\left[\frac{2j+1}{2j}coth\left(\frac{(2j+1)a}{2j}\right) - \frac{1}{2j}coth\left(\frac{a}{2j}\right)\right]$$

- ***In the limit of large j, Brillouin function reduces to classical Langevin function***

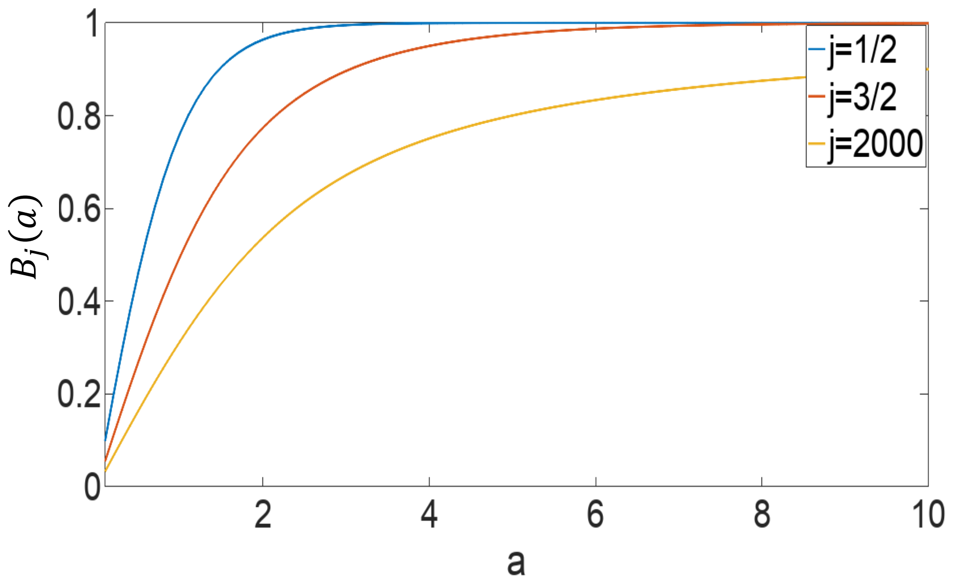
$$L(a) = coth(a) - \frac{1}{a}$$



- ***Classical theory of paramagnetism***
- ***Interaction between individual spin system is negligible***

Quantum theory of paramagnetism- Brillouin function

- *At $x=0$, Brillouin function is 0 and at $x=\infty$, it is 1.*
- *Behaviour of the function in between depends on the value of j*
- *Large j represents classical Langevin function*



Brillouin function for various j values

Quantum theory of paramagnetism - Langevin function

- *In the limit of large j, Brillouin function reduces to classical Langevin function*

$$L(a) = coth(a) - \frac{1}{a}$$

- *L(a) can be expressed in series,*

$$L(a) = \frac{a}{3} - \frac{a^3}{45} + \frac{2a^5}{945} - \ldots.$$

- *For small values of a the function then converges to a /3.*
- *Reduces to Curie's theory of paramagnetism*

Quantum theory of paramagnetism - Langevin function

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- *When all the dipoles are aligned, magnetization is saturated M_s*

$$M = M_s L(a) = M_s\{coth(a) - \frac{1}{a}\}$$

- *Since,* $L(a) = \frac{a}{3}$ $\Rightarrow \frac{M}{M_s} = L(a) = \frac{a}{3}$

- *Now substituting for* $a = \frac{\mu B}{3k_B T}$

- *Paramagnetic susceptibility is given by*

$$\chi = \frac{Ng^2\mu_o\mu_B^2}{3k_B T} = \frac{C}{T} \Rightarrow \chi \,\alpha\, \frac{1}{T}$$

Curie's law

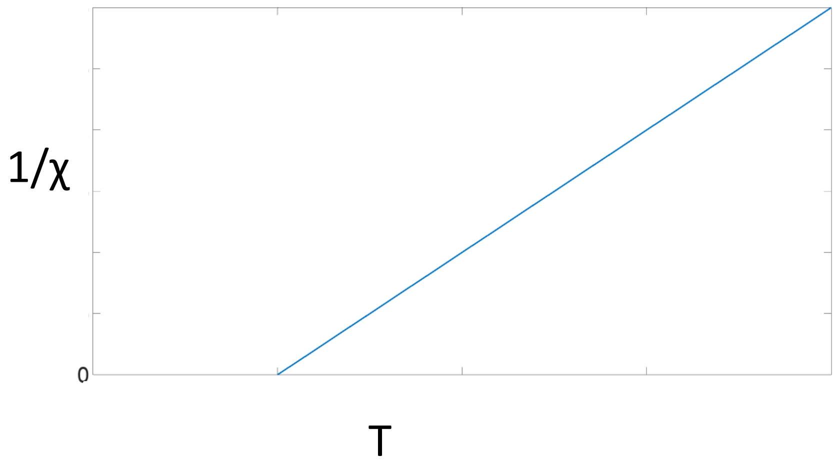
where C is the Curie constant

Weiss molecular field

- *Inverse of susceptibility exhibits positive temperature intercept for some materials*
- *Effect of neighboring dipoles*
- *Weiss proposed that there exists an internal field (H_i)*

$$H_i = \lambda M$$

Variation of inverse of magnetic susceptibility with temperature



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Weiss molecular field

- *Total field is given by* $H_T = H + H_i$
- *Magnetic susceptibility is given by*

$$\chi = M/H_T = \frac{M}{H+\lambda M} = \frac{C}{T}$$

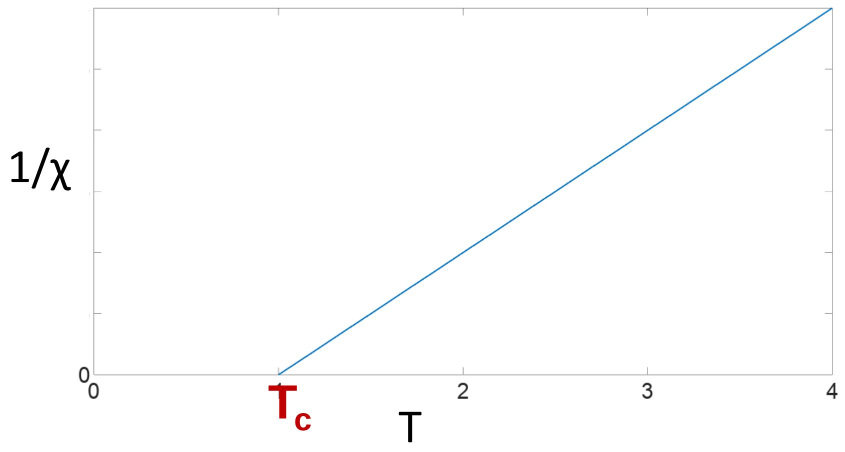
- *Curie- Weiss law* $\chi = \frac{C}{T - T_c}$

$$MT = C(H + \lambda M)$$

$$M(T - C\lambda) = CH$$

$$\frac{M}{H} = \frac{C}{T - C\lambda}$$

Variation of inverse of magnetic susceptibility with temperature



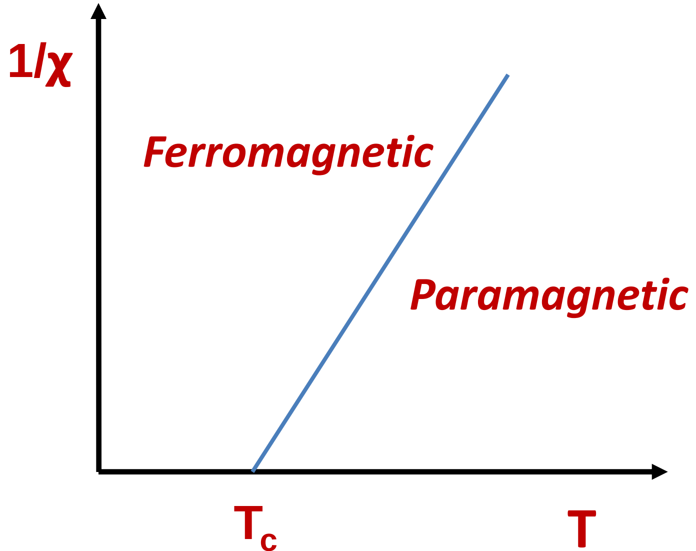
Curie- Weiss Law

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

- *T_C is the Curie temperature given as* $T_C = C\lambda$

  Note that susceptibility has a singularity at T_C

- *At $T \leq T_c$, there exists spontaneous magnetization*
- *Curie-Weiss law describes the observed susceptibility variation in the paramagnetic region fairly well*



Curie temperatures

Below T_C, materials exhibit ferromagnetic behaviour

Element	T_C (°C)
Gadolinium	19
Nickel	358
Iron	770
Cobalt	1100
Ni-Cr alloy	-196
YNi_3	-238

The concepts related to Langevin function and Weiss molecular field that are true are……

1. In the limit of total angular momentum quantum number j → 0, Brillouin function becomes classical Langevin function
2. Plot of inverse of paramagnetic susceptibility v/s temperature is a straight line passing through the origin
3. There exists an internal field in magnetic materials that is dependent on the magnetization
4. Below Curie- temperature, material possess spontaneous magnetization
5. All materials have same Curie temperature

THANK YOU

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