

19

October • Tuesday

WK 43 (292-073)

October - 2021

M	T	W	T	F	S	S	M	T	W	T	F	S	S
					1	2	3	4	5	6	7	8	9
11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31							

## Paramagnetic System.

$$dU = Tds + Bdm$$

Paramagnetism:  $M = \text{Magnetization}$ .

$$m = \frac{M}{V} = \text{magnetic moment}$$

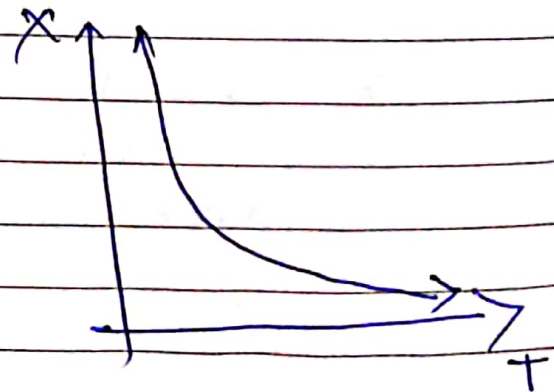
$$B = \mu_0 (H + m) \approx \mu_0 H$$

$\mu_0 = \text{vacuum permeability}$ .

$$\chi = \lim_{H \rightarrow 0} \frac{dM}{dH} = \frac{\mu_0 M}{B}$$

$$\chi \propto \frac{1}{T}$$

Curie's Law.



$$\left( \frac{\partial \chi}{\partial T} \right)_B < 0$$

~~10/2~~

2021

# Thermodynamics of magnetic system.

$P \quad V \quad T$

$B = \text{Magnetic Induction / Flux}$

$B \quad M \quad T$

$M = \text{Magnetization}$

$$(1) \quad dU = TdS + B dM$$

$$(2) \quad U = U(S, M)$$

$$(3) \quad H = U - MB$$

$$dH = TdS - MdB \Rightarrow H = H(S, B)$$

$$(4) \quad F = U - TS$$

$$\Rightarrow dF = -SdT + BdM \Rightarrow F = F(T, M)$$

$$4. \Rightarrow G = U - TS - MB$$

$$\Rightarrow dG = -SdT - MdB \Rightarrow G = G(B, T)$$

From (1)

$$\Rightarrow T = \left( \frac{\partial U}{\partial S} \right)_M$$

$$B = \left( \frac{\partial U}{\partial M} \right)_S$$

Maxwell Relations

$$\left( \frac{\partial T}{\partial M} \right)_S = \left( \frac{\partial B}{\partial S} \right)_M$$



17

October • Sunday

WK 42 (290-075)

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M	T	W	T	F	S	S	M	T	W	T	F	S
					1	2	3	4	5	6	7	8
11	12	13	14	15	16	17	18	19	20	21	22	23
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Heat Capacity

$$C_M = T \left( \frac{\partial S}{\partial T} \right)_M = - T \left( \frac{\partial^2 F}{\partial T^2} \right)_M$$

9

$$C_B = T \left( \frac{\partial S}{\partial T} \right)_B = - T \left( \frac{\partial^2 G}{\partial T^2} \right)_B$$

Magnetic Susceptibility

10

$$\chi_T = \left( \frac{\partial M}{\partial B} \right)_T = - \left( \frac{\partial^2 G}{\partial B^2} \right)_T$$

12

$$\chi_S = \left( \frac{\partial M}{\partial B} \right)_S = - \left( \frac{\partial^2 H}{\partial B^2} \right)_S$$

1

2

$$\alpha_B = \left( \frac{\partial M}{\partial T} \right)_B = \left( \frac{\partial^2 G}{\partial T \partial B} \right)$$

3

4

Show

$$\frac{C_B}{C_M} = \frac{\chi_T}{\chi_S}$$

5

6

$$\chi_T (C_B - C_M) = T \alpha_B^2$$

$$C_B (\chi_T - \chi_S) = T \alpha_B^2$$

2021

Adiabatic Demagnetization.

Liquid Helium boiling ~~point~~

for Temp  $< 4^{\circ}\text{K}$   $\sim 0.7^{\circ}\text{K}$

$$dQ = dU - B dM$$

$$\Rightarrow T dS = dU - B dM.$$

Maxwell's

$$\Rightarrow \left( \frac{\partial S}{\partial B} \right)_T = \left( \frac{\partial M}{\partial T} \right)_B \quad \left( \frac{\partial T}{\partial B} \right)_S = - \left( \frac{\partial M}{\partial S} \right)_B$$

G

H

$$\left( \frac{\partial T}{\partial B} \right)_S = - \left( \frac{\partial M}{\partial S} \right)_B = - \frac{\left( \frac{\partial M}{\partial T} \right)_B}{\left( \frac{\partial S}{\partial T} \right)_B} = - \frac{T}{C_B} \left( \frac{\partial M}{\partial T} \right)_B$$

Integrating we have

$$T_f = T_i = \Delta T = - \int_{B_i}^{B_f} \frac{T}{C_B} \left( \frac{\partial M}{\partial T} \right)_B dB$$



$$\left(\frac{\partial T}{\partial B}\right)_S = - \frac{T}{C_B} \left(\frac{\partial M}{\partial T}\right)_B$$

For Paramagnetic  $M \sim B$

$$\approx \odot \propto \sqrt{B}$$

$$\approx \frac{C}{T} \sqrt{B}$$

Curie's law

$$\chi \sim \frac{1}{T}$$

$$\Rightarrow \left(\frac{\partial M}{\partial T}\right)_B = - \frac{C \sqrt{B}}{T^2}$$

$$\Rightarrow \left(\frac{\partial T}{\partial B}\right)_S = + \frac{T}{C_B} \frac{C \sqrt{B}}{T^2}$$

$$\Rightarrow \int_{T_i}^{T_f} T dT = \int_{B_0}^0 \left(\frac{C \sqrt{B}}{C_B}\right) B dB$$

$$\Rightarrow (T_f^2 - T_i^2) = - \left(\frac{C \sqrt{B}}{C_B}\right) B_0^2$$

$$\Rightarrow \underbrace{(T_f - T_i)}_{\Delta T} = - \left(\frac{C \sqrt{B}}{C_B}\right) \frac{B_0^2}{2 T_{av}}$$

$$T_{av} = \frac{T_f + T_i}{2}$$