**자성재료특강** **중간시험** **November 12, 2008**

1. (10pts) Calculate the magnetic induction $B$ (in Tesla) and magnetization $M$ (in Oe) of a paramagnetic material with the relative permeability $\mu_r$ = 1.001 under an applied field strength $H$ of $5.0\times10^5$ A/m.

Where $\mu_0 = 4\times10^{-7}$ henry/m, 1 henry · A = 1 Wb. 1 Tesla = 1 Wb/m$^2$

$$1 \text{ henry/m} = 1 \text{ Wb/(A}\cdot\text{m)} = 1 \text{ Tesla}\cdot\text{m}^2\text{/(A}\cdot\text{m)} = 1\ \frac{Tesla}{A/m}$$

2. (25pts) Answer the following questions.

(a) (5pts) Prove the relative permeability $\mu_r$ is given by

$\mu_r = 1 + \chi$ (susceptibility) in SI, and $\mu_r = 1 + 4\pi\chi$ in cgs.

(b) (10pts) Draw and explain $\chi(T)$ and $M(T)$ curves over all temperature region for normal diamagnets, normal paramagnets, antiferromagnets, ferromagnets, and ferrimagnets, respectively.

(c) (5pts) Some paramagnetic materials exhibit temperature-independent susceptibility. Explain the theory describing this behavior briefly.

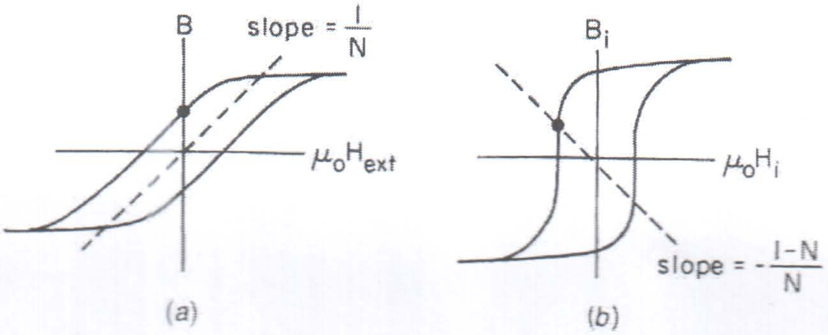
(c) (5pts) Superconductors exhibit a perfect diamagnetism. Represent the susceptibility $\chi$ and relative permeability $\mu_r$ for superconductors in SI and cgs units, respectively.

3. (20pts) 다음의 질문에 답하시오.

(a) (10pts) 어떤 강자성체 시편의 자기이력곡선을 측정하는 경우, 가해준 자장 ($\mu_0\boldsymbol{H}_a$: SI unit expression)의 함수로 자속밀도를 그리면 시편의 형상(shape)에 따라 자기이력곡선이 다르게 나타난다. 형상에 따라 달라지는 그림 2.9(a)를 실제 시편에 가해진 자장($\mu_0\boldsymbol{H}_i$: true or internal field)으로 환산하여 그림 2.9(b)와 같이 형상과 무관한 이력곡선을 얻을 수 있다. 그림 2.9(a)와 (b)에서 점선으로 나타낸 deagnetizing field $H_d$ 와 각 자장이 나타내는 직선의 기울기가 1/N 및 - (1-N)/N이 됨을 보이라. N은 반자장계수 (demagnetizing factor)이다.

(b) (5pts) 그림2.9(a)에 나타낸 apparent remanence $B_r$ 값이 그림2.9(b)에서는 2 사분면의 $B_i$-$H_i$ curve (demagnetization curve)와 $H_d$ vs $\mu_0H_i$ 직선의 교차점으로 나타남을 증명하라.

(c) (5pts) At a field strength of $H_{ext}$ = 80 kA/m, the magnetic induction $B$ of a spherical sample is 1 Tesla. Calculate the internal (or true) magnetic field $H_i$ of this sample.



(a) (b)

**Figure 2.9** Schematic representation of demagnetization effect on $B$-$H_{appl}$ loops ($a$) and on $B$–$H_i$ loops ($b$). The dashed lines rotated into the vertical axis in each case relate one loop to the other.

4. (30pts) Answer the following questions.

(a) (5pts) According to the classical Langevin theory, magnetization $M$ for paramagnetic materials is given by $M = NmL(a)$,

$$\text{Langevin function, } L(a) = \coth a - \frac{1}{a} \text{ and } a = \frac{\mu_o m H}{kT}$$

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

where, $N$ is the number of atomic magnetic moment ($m$) per unit volume, $k$ is Boltzmann constant, $T$ is absolute temperature, and $H$ is applied field strength. Using the Langevin function, derive the Curie law : $\chi = \frac{C}{T}$ , $C = \frac{N\mu_o m^2}{3k}$.

(b) (5pts) Derive Curie-Weiss law by using the molecular (or Weiss) field from Curie law.

(c) (5pts) According to quantum theory, temperature and field dependence of magnetization for a ferromagnet is given by Brillouin function, $B_J(x)$.

$$B_J(x) = \frac{M}{M_o} = \frac{2J+1}{2J} coth\left(\frac{2J+1}{2J}\right)x - \frac{1}{2J}\coth\frac{x}{2J}, \; x = \frac{gJ\mu_B\mu_o H}{kT}$$

Show that Brillouin function $B_J(x)$ reduces to the Langevin function $L(x)$, with $x = \mu_0 mH/kT$, in the limit $J$ approaches infinity.

(d) (5pts) If $J = \frac{1}{2}$(one spin /atom), show that $\frac{M}{M_o} = B_J(x) = \tanh x$, $x = \frac{\mu_B\mu_o H}{kT}$

and thus $\frac{M_s}{M_o} = \tanh(\frac{\mu_B\mu_o \alpha M_s}{kT})$ in the absence of a magnetic field.

(e) (5pts) Explain the temperature dependence of the spontaneous magnetization, $M_s$ (which is measured by saturation magnetization) for a ferromagnet of $J = \frac{1}{2}$ in the absence of a magnetic field using the Brillouin function.

(f) (5pts) Explain briefly in what aspect the above quantum theory is inappropriate for the explanation of ferromagnetism of 3d transition metals. If there is a theory explaining ferromagnetism in 3d transition metals, explain that briefly.

5. (15pts) (a) (10pts) Magnetic ion들의 magnetic moment는 spin의 moment에만 의존한다고 가정할 때 조성이 80% $NiO \cdot Fe_2O_3$ + 20%$ZnO \cdot Fe_2O_3$)인 Ni-Zn ferrite의 molecule당 net magnetic moment를 Bohr magneton($\mu_B$)을 단위로 계산하라. 여기서 magnetic ion들의 spin-only moment는 $Ni^{2+}$ 의 경우 $2\mu_B$, $Fe^{3+}$의 경우 $5\mu_B$, $Zn^{2+}$ 의 경우 $0\mu_B$ 이다.

(b) (5pts) 아래의 그림에 나타낸 바와 같이 spinel ferrite에 Zn의 치환량을 증가시킬 때, 처음에는 molecule당 net magnetic moment가 직선적으로 증가하나 일정량에 이르면 최댓값을 보이고, 치환량이 더욱 증가하면 그 값이 감소하는 이유를 설명하라.

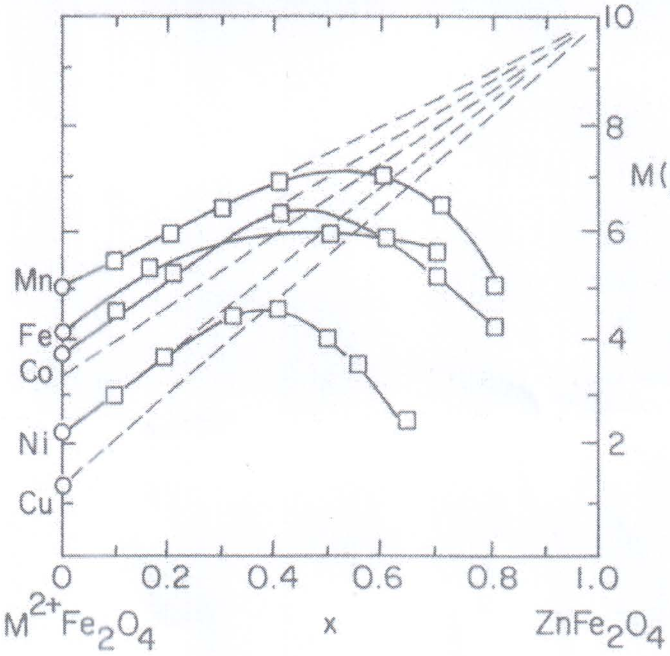


**Figure 4.7** Magnetic moments in transition metal–zinc ferrites as $T$ = Cu, Ni, Co, and so on are substituted for divalent iron (Guillaud 1951, Gorter, 1954).