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APPENDIX

Scaling Theory

A.1 Generalized Homogeneous Functions

We shall see in the next section , A.2 , that the scaling theory states not that thermodynamic potentials are homogeneous of the form

$$f(\lambda x, \lambda y) = \lambda^{n} f(x, y)$$

but rather that they are of somewhat more general form

$$f(\lambda^{a} x, \lambda^{b} y) = \lambda f(x,y) \qquad \text{(A.1)}$$

where a and b are arbitrary numbers. Functions $f(x,y)$ that satisfy equations of the form of Eq. (A.1) are sometimes called generalized homogeneous functions.

A.2 Scaling Theory (82)

To be specific , let us assume that we have a system for which the appropriate free energy is a function of two independent thermodynamic variables (e.g., $E(s,M)$. $A(T,M)$, $G(T,H)$. At the critical point of the system , these variables have the values T_c , H_c , M_c , and so on. We introduce the relative variables

$$h = \frac{H - H_c}{H_c}$$

$$t = \frac{T - T_c}{T_c} \qquad (A.2)$$

$$n = \frac{M - M_c}{M_c}$$

we denote the free energy by F (h , t) and formulate the specific heat C(t) at H = 0 , the spontaneous polarization (or order parameter) n(t) , below the critical point , the generalized suceptibility , x(t), above it and the field dependent polarization $m_c(h)$, at $T = T_c$, by the following equations :

$$C(T) = \frac{-T}{T_c^2} \frac{\partial^2 F(o,t)}{\partial t^2} \simeq -T_c^{-1} \frac{\partial^2 F}{\partial t^2}(o,t) \qquad (A.3)$$

$$n(t) = \lim_{h \to 0} - \frac{\partial F}{\partial h}(o,t) \text{ , for } t < 0 \text{ ,} \qquad (A.3)$$

$$x(t) = -\left(\frac{\partial^2 F}{\partial h^2}(h,t) \right)_{h = 0} \text{ , for } t > 0 \text{ ,} \qquad (A.5)$$

and

$$n_c(h) = - \frac{\partial F}{\partial h}(h,0) \qquad (A.6)$$

The theoretical and experimental investigations on the behaviour of these functions near the critical point reveal that they are all governed by simple power laws , possibly complicated by logarithms , i.e.

$$C(t) \sim |t|^{-\alpha} \quad (\text{or } |t|^{-\alpha} \ln|t|) \text{ , with } \alpha \geqslant 0 \qquad (A.7)$$

$$X(t) \sim |t|^{-\gamma} \ (\text{or} \ |t|^{-\gamma} \ln|t|) \text{ , with } \gamma > 0 \text{ , } (t > 0) \qquad (A.8)$$

$$n_c(t) \sim |t|^{\beta} \text{, with } \beta > 0 \ (t < 0) \text{ ,} \qquad (A.9)$$

and $$n_c(t) \sim |h|^{\delta} \text{ with } \delta > 0. \qquad (A.10)$$

The constants α , β , γ and δ appearing in thes formulae are termed critical indices.

According to a wealth of theoretical and experimental evidence , the thermodynamics of the critical region follows simple scaling laws. These may be summarized by the statement that value of the free energy F(h,t) is invariant under transformations $h \rightarrow \lambda^{s} h$, $t \rightarrow \lambda^{r} t$ and $F \rightarrow \lambda^{-1} F$ for certain indices s and r and arbitrary positive λ , i.e.

$$F(\lambda^{s} h, \lambda^{r} t) = \lambda F(h,t) \text{ for positive } \lambda$$

or $$F(h,t) = \lambda^{-1} F(\lambda^{s} h, \lambda^{r} t) \quad . \qquad (A.11)$$

From Eqs. (A.3 - A.5) , we obtain

$$C(h,t) = \lambda^{2r-1} C(\lambda^{s} h , \lambda^{r} t) \qquad (A.12)$$

$$X(h,t) = \lambda^{2s-1} X(\lambda^{s} h , \lambda^{r} t) \qquad (A.13)$$

$$n(h,t) = \lambda^{s-1} n(\lambda^{s} h , \lambda^{r} t) \qquad (A.14)$$

We now consider the special cases $h = 0$, $\lambda = |t|^{-1/r}$, and $t = 0$, $\lambda = |h|^{-1/s}$ to obtian

$$C(0,t) = |t|^{-(2r-1)/r}\, C\,(0,-1) \qquad (A.15)$$

$$X(0,t) = |t|^{-(2s-1)/r}\, \chi\,(0,1) \qquad (A.16)$$

$$n(0,t) = |t|^{-(s-1)/r}\, n\,(0,-1) \qquad (A.17)$$

$$n(h,0) = |h|^{-(s-1)/s}\, n\,(\pm 1\,,\,0) \qquad (A.18)$$

From Eq. (A.15 - A.18) , by comparing with Eq. (A.7 - A.10) , respectively , we find

$$\alpha = \frac{2r - 1}{r}$$

$$\beta = -\frac{s - 1}{r}$$

$$\gamma = \frac{2s - 1}{r}$$

$$\delta = -\frac{S - 1}{s}$$

We see that there are only two independent critcal exponents and that the scaling relations

$$\alpha + 2\beta + \gamma = 2 \qquad (A.19a)$$

$$\delta^{-1} = 1 + \gamma / \beta \qquad (A.19b)$$

A.3 Evaluation of Critical Indices of the Coefficicients Temperature Dependent

According to Eq. (4.6) ,

$$F - F_{no} = - \frac{A^2}{2B} \qquad (A.6)$$

The specific heat , C , should have a weak power - law divergence at T_c , in contrast to the discontinuity of the Ginzburg - Landau theory. This divergence can be writhen as

$$C \sim |T - T_c|^{-\alpha} \quad \text{with} \quad \alpha \approx 0. \qquad (A.20)$$

Since ,

$$C = - T \frac{\partial^2 F}{\partial T^2} = - T_c^{-1} \frac{\partial^2 F}{\partial t^2} (0,t)$$

where $t = \frac{T - T_c}{T_c}$, Thus

$$F_s - F_{ns} \sim | T_c - T |^{2-\alpha} \qquad (A.21)$$

and Eq. (4.) , the order parameter

$$|\Psi|^2 = - \frac{A}{B} \qquad (4.5)$$

$$|\Psi| = \left(\frac{|A|}{B} \right)^{1/2} \sim | T_c - T |^{\beta} \qquad (A.22)$$

we assume that

$$A = -A_o\left(\frac{T_c - T}{T_c}\right)^{\theta_1} \qquad (A.23a)$$

$$B = B_o\left(\frac{T_c - T}{T_c}\right)^{\theta_2} \qquad (A.23b)$$

Substituting Eq. (A.23) into Eqs. (4.6) and (4.5) , we obtian

$$F_s - F_{no} \sim |T_c - T|^{2\theta_1 - \theta_2} \qquad (A.24)$$

$$\Psi \sim |T_c - T|^{(\theta_1 - \theta_2)/2} \qquad (A.25)$$

By comparing terms Eqs. (A.24 – A.25) with Eqs (A.21-A.22), we find

$$2\theta_1 - \theta_2 = 2 - \alpha \qquad (A.26a)$$

$$\theta_1 - \theta_2 = 2\beta \qquad (A.26b)$$

Experimentally found that (83) , $\alpha \simeq 0$ and $\beta \approx 1/3$, and substituting in Eq. (A.26) , we obtian

$$\theta_1 = 4/3$$

$$\theta_2 = 2/3 .$$

VITA

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