MAGNETIZATION AND MAGNETIC PART OF SPECIFIC HEAT OF A CLUSTER SYSTEM[1])

P. NOZAR[2]), V. SECHOVSKÝ[2]), Prague

In the contribution the formulae of temperature and field dependences of magnetization and the magnetic part of specific heat for the system of magnetic clusters with vanishing intercluster interaction are derived.

НАМАГНИЧЕННОСТЬ И МАГНИТНАЯ ЧАСТЬ УДЕЛЬНОЙ ТЕПЛОЕМКОСТИ КЛАСТЕРНЫХ СИСТЕМ

В работе выведены формулы для зависимости от температуры и поля намагниченности и магнитной части удельной теплоемкости для системы магнитных кластеров с исчезающе мелым взаимодействием между кластерами.

I. INTRODUCTION

We report our calculation of the magnetic properties of a system of magnetic clusters treated as a set of "non-interacting" ferromagnetic particles. The cluster-glass is considered here as a binary solid solution where one component carries a localized magnetic moment. The elementary magnetic moments are distributed into groups (magnetic clusters) comprising (in general) a different number of moments due to the fluctuation of the impurity concentration in the solid solution.

The arrangement of moments into clusters establishes such characteristic properties of the cluster-glass as a finite paramagnetic Curie temperature (without long-range order) and freezing phenomena. The former property is due to the intracluster exchange interaction, the latter is determined by different kinds of magnetic anisotropy [1].

II. MODEL

Let us consider the set of the localized magnetic moments selected into clusters in a non-magnetic matrix. Assume that the magnetic moments interact ferromag-

---

[1]) Contribution presented at the 7th Conference on Magnetism, Košice, June 5—8, 1984.

[2]) Math. Phys. Faculty of the Charles University, Ke Karlovu 5, 120 00 PRAGUE 2, Czechoslovakia.

netically within one cluster while the intercluster interaction is negligible. Our calculations are based on the assumption that the magnetization of the cluster could be described in terms of the molecular field approximation. We consider the molecular field to be constant within one cluster. The moments of each cluster become ordered below the appropriate temperature T_{cn}. The magnetic moment M_n of a cluster with n' elementary moments M_0 is then

$$M_n = nM_0B(h_n) \tag{1}$$

where $M_0 = g\mu_B S$, $h_n = \beta g\mu_B H_0 + (T_{cn}/T)\,(3/S+1)B(h_n)$, g is the Landée factor, μ_B the Bohr magneton, S the spin number, $\beta = (k_B T)^{-1}$, k_B is the Boltzmann constant, T the temperature, T_{cn} the Curie temperature, H_0 the external magnetic field varying with cluster size and $B(h_n)$ is the Brillouin function. For further convenience we define the step function

$$f_{x_0}(x) = \begin{cases} 0 & \text{for } x \geq x_0 \\ 1 & \text{for } x < x_0 \end{cases} \tag{2}$$

and

$$L_1(c) = \sum_{n=1}^{\infty} \langle v_n(c) \rangle \tag{3}$$

a distribution function of clusters. $\langle v_n(c) \rangle$ is an average number of clusters of size n and c is a concentration of magnetic impurity. Then

$$M = \sum_{n=1}^{\infty} (1 - f_{T_{cn}}(T))\, \langle v_n(c) \rangle\, nM_0B(h_n) \tag{4}$$

describes the magnetization of a cluster system at temperatures above $T_{cn,\max}$ ($T_{cn,\max}$ and $T_{cn,\min}$ are maximum and minimum of the set of all T_{cn}, respectively). The moments within one cluster behave as one giant moment below T_{cn}. At these temperatures the influence of cluster anisotropy is switched on. Below the characteristic temperature T_{Fn1} the influence of cluster anisotropy becomes superior and the cluster freezes (i.e. the direction of the cluster moment is aligned to the anisotropy axis). In the temperature range (T_{cn}, T_{Fn1}), however, the cluster system behaves like a superparamagnet. The magnetic moment M'_n of one cluster is given as

$$M'_n = (1 - f_{T_{Fn1}}(T)) f_{T_{cn}}(T) M_n L(x); \quad x = M_n H_0 / k_B T \tag{5}$$

where $L(x)$ is the Langevin function. The distribution of the freezing temperatures T_{Fn1} we define as

$$R(T_{Fn1}) = \sum_{n=n_0}^{\infty} \sum_{\{1\}} \varrho_{n,1}(T_{Fn1}) \tag{6}$$

($\varrho_{n,1}$ is the number of clusters with the same T_{Fn1}). In the temperature range (T_{cn}, T_{Fn1}) the first member of expansion of $L(x)$ in (5) can be considered only and we may write for the whole system

$$M = \frac{H_0}{T} \sum_{n=n_0}^{\infty} \sum_{\{1\}} (1 - f_{T_{Fn1}}(T)) f_{T_{cn}}(T) \varrho_{n,1}(T_{Fn1})\, (nM_0B(h_n))^2 / 3k_B\,. \tag{7}$$

The magnetic contribution of one cluster (considered as a ferromagnetic particle) to specific heat is

$$c_{m,n} = nT_{c,n} \frac{\partial}{\partial T} B^2(h_n) \left(-\frac{1}{2} k_B \frac{3S}{S+1} \right) \tag{8}$$

and for the whole cluster system

$$c_m = \sum_{n=1}^{\infty} \left(-\frac{1}{2} k_B \frac{3S}{S+1} \right) \langle v_n(c) \rangle\, nT_{c,n} \frac{\partial}{\partial T} B^2(h_n)\,. \tag{9}$$

III. CONCLUDING REMARKS

The magnetization M of the cluster system could be expressed as a sum of 4 contribution

$$M = M_1 + M_2 + M_3 + M_4 \tag{10}$$

where

$$M_1 = \frac{H_0}{T} \sum_{n=1}^{n_0 - 1} \langle v_n(c) \rangle\, nM_0^2 / 3k_B \tag{11}$$

realizes from a small percentage of elementary moments which are not ordered at any temperature (for moments of clusters with $n < n_0$ is $T_{cn} = 0$).

$$M_2 = \sum_{n=n_0}^{\infty} \langle v_n(c) \rangle\, nM_0B(h_n)\, (1 - f_{T_{c,n}}(T)) \tag{12}$$

is the contribution of the clustees with $n \geq n_0$ above T_{cn}. This part can be approximated by the Curie-Weiss law in the high temperature limit.

$$M_3 = \frac{H_0}{T} \sum_{n=n_0}^{\infty} \sum_{\{1\}} (1 - f_{F_{n1}}(T)) f_{T_{cn}} \varrho_{n1}(T_{F_{n1}})\, (nM_0B(h_n))^2 / 3k_B \tag{13}$$

is resulting from "giant" moments described formally by the Curie law in the temperature range ($T_{cn,\min}$, $T_{Fn1,\max}$). The part M_4 describes the magnetization of the frozen clusters equal to zero (in first approximation). A more detailed approach to parts M_3 and M_4 is described in [2]. It is remarkable that the temperature dependence of the specific heat exhibits a broad and flat maximum at temperatures $T \gtrsim T_{cn,\,max}$. It is due to hte fact that the contributions of different clusters are realized at different T_{cn}.

REFERENCES

[1] Wohlfarth, E. P.: J. Phys. F, Metal Phys. *10* (1980), L241-6.
[2] Sechovský, V., Nozar, P.: to be published in Acta Phys. Polonica.

Received February 18th, 1985
Revised version received July 9th, 1985