acta phys. slov. 31. (1981), No. 2—3

THERMODYNAMIC PROPERTIES OF THE AMORPHOUS HEISENBERG FERROMAGNET[1]

A. BOBÁK*, Košice

In the presented paper an exactly solvable Heisenberg model for an amorphous ferromagnet is proposed. It is shown that random fluctuations of the exchange integral around its crystalline mean value cause an increase of the Curie temperature. In addition, the influence of fluctuations of the exchange integrals on the properties of an amorphous ferromagnet in the critical region is studied.

ТЕРМОДИНАМИЧЕСКИЕ СВОЙСТВА АМОРФНЫХ ГЕЙЗЕНБЕРГОВСКИХ ФЕРРОМАГНЕТИКОВ

В работе приводится точно решаемая модель Гейзенберга для аморфного ферромагнетика. Показано, что температура Кюри в результате случайных флуктуаций обменного интеграла вокруг своего среднего кристаллического значения повышается. Кроме того, изучено влияние флуктуаций обменных интегралов на свойства аморфного ферромагнетика в критической области.

I. INTRODUCTION

It is well known that the mean field theory for a crystalline ferromagnet becomes exact in the thermodynamic limit for a constant infinite-range exchange interaction, provided that the interaction is appropriately scaled with the number of spins in the system [1]. In this paper we define and exactly solve the analogous infinite-range problem for an amorphous system.

We begin with the Heisenberg model

$$\mathcal{H} = -\frac{1}{2}\sum_{i \neq j} \mathcal{J}_{ij}\, \hat{\boldsymbol{S}}_i \hat{\boldsymbol{S}}_j - g\mu_B \boldsymbol{H} \sum_i \hat{\boldsymbol{S}}_i , \qquad (1)$$

[1] Contribution presented at the 6th Conference on Magnetism in Košice, September 2—5, 1980.

* Katedra teoretickej fyziky a geofyziky, PF UPJŠ, Komenského 14, CS-041 54 KOŠICE.

where $\boldsymbol{S}_i$ is the spin operator of the i-th atom, μ_B is the Bohr magneton, g is the Landé factor and $\boldsymbol{H}$ is the external magnetic field. The amorphous nature of the material is accounted for by considering the exchange integral between spins at the places i and j, $\mathcal{J}_{ij}$, as having random variations from a mean value.

We shall now assume that the random varibles $\mathcal{J}_{ij}$ may be expressed in the following "separable" form:

$$\mathcal{J}_{ij} = \frac{\mathcal{J}_i \mathcal{J}_j}{\langle \mathcal{J} \rangle N}, \tag{2}$$

where N is the number of spins; $\mathcal{J}_i$ are short-range correlated random variables, which fluctuate randomly about the crystalline mean value $\langle \mathcal{J} \rangle$: $\mathcal{J}_i = \langle \mathcal{J} \rangle + \Delta\mathcal{J}_i$. The factor $1/N$ insures the mean field behaviour (if $\Delta\mathcal{J}_i = 0$, this gives the usual mean field type theory of a crystalline ferromagnet [1]).

II. EVALUATION OF THERMODYNAMIC QUANTITIES

The free energy per spin $F_N = -(\beta N)^{-1} \ln Z_N$ in the thermodynamic limit $(N \to \infty)$ for the model described above is the non-random value F [2]:

$$F = \min_t \left\{ \frac{\langle \mathcal{J} \rangle t^2}{2} - \beta^{-1} \left\langle \ln \frac{\operatorname{sh}\left[\beta\left(S+\frac{1}{2}\right)(\mathcal{J}t + g\mu_B H)\right]}{\operatorname{sh}\left[\beta\left(\frac{\mathcal{J}t + g\mu_B H}{2}\right)\right]} \right\rangle \right\}, \tag{3}$$

where $\beta = 1/k_B T$ and $\langle \ldots \rangle$ denotes the configuration averaging.

The necessary condition for the minimum in (3) is given by

$$t = \frac{\langle S\mathcal{J}B_S[\beta S(\mathcal{J}t + g\mu_B H)] \rangle}{\langle \mathcal{J} \rangle}, \tag{4}$$

where $B_S(x)$ is the Brillouin function. A nonzero solution (4) clearly requires that

$$T < T_c = \frac{S(S+1)}{3k_B} \frac{\langle \mathcal{J}^2 \rangle}{\langle \mathcal{J} \rangle} = T_c^{(0)}(1 + \Delta^2), \tag{5}$$

where $\Delta^2 = \langle (\Delta\mathcal{J})^2 \rangle / \langle \mathcal{J} \rangle^2$ and $T_c^{(0)}$ is the critical temperature for the corresponding crystal. Therefore we have found that the fluctuations of the exchange integral increase the Curie temperature. This conclusion is in agreement with our result obtained for the Ising model in the Bethe approximation [3] and other earlier works [4—6].

Various thermodynamic properties of the system can now be easily obtained by differentiating the expression (3). For example, the spontaneous magnetization per spin M for $T \sim T_c$ is given by

$$M = g\mu_B S \left[\frac{10}{3} \frac{(S+1)^2}{(S+1)^2 + S^2}(1 - 5\Delta^2)\right]^{1/2} \left(1 - \frac{T}{T_c}\right)^{1/2}; \quad \Delta^2 \ll 1,$$

the zero-field susceptibility per spin χ by

$$\chi = \frac{C}{(1+\Delta^2)|T - T_c| A_\pm}; \quad T \to T_c \pm 0, \quad A_+ = A_-/2 = 1,$$

where $C = (g\mu_B)^2 S(S+1)/3k_B$ is the Curie constant. Thus the fluctuations in the exchange integral have no effect on the critical coefficients for M and χ. However, the presence of fluctuations decreases the value pre-factor for M.

The specific heat per spin C_V for $T \sim T_c$ and $\Delta^2 \ll 1$ is given by

$$C_V(T_c - 0) = 5k_B \frac{S(S+1)}{(S+1)^2 + S^2}(1 - 4\Delta^2), \quad C_V(T_c + 0) = 0.$$

The fluctuations Δ lead therefore to the decrease of a jump discontinuity of the specific heat at the transition point.

REFERENCES

[1] Stanley, H. E.: *Phase transitions and critical phenomena*. Oxford Univ. Press, New York 1971.
[2] Pastur, L. A., Figotin, A. L.: Teor. i mat. fiz. *35* (1978), 193.
[3] Bobák, A.: Phys. Stat. Sol. *(b) 97* (1980), K 101.
[4] Kobe, S., Handrich, K.: Fiz. tverd. tela *13* (1971), 887.
[5] Šlechta, J.: Phys. Stat. Sol. *b (67* (1975), 595.
[6] Brown, H. A.: Phys. Stat. Sol. *(b) 90* (1978), K 165.

Received November 4th, 1980