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CURIE TEMPERATURE OF AN AMORPHOUS FERROMAGNET IN A CORRELATED EFFECTIVE FIELD THEORY[1])

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A new-type effective field theory with correlations is used to determine the Curie temperature of an amorphous ferromagnet for the Ising model. Due to the structure fluctuations of the exchange integrals a decrease of the Curie temperature is found in comparison with the corresponding crystalline case. The result is compared with other investigations.

ТЕМПЕРАТУРА КЮРИ АМОРФНОГО ФЕРРОМАГНЕТИКА В ТЕОРИИ ЭФФЕКТИВНОГО ПОЛЯ С КОРРЕЛЯЦИЯМИ

Для определения температуры Кюри аморфного ферромагнетика в модели Изинга использован новый тип теории эффективного поля с корреляциями. Вследствие структурных флуктуаций обменных интегралов обнаружено падение температуры Кюри по сравнению с соответстуюшим случаем кристаллического состояния. Проведено сравнение полученных результатов с другими исследованиями.

I. INTRODUCTION

Recently Honmura and Kaneyoshi [1, 2] discussed a new-type effective field method of the Ising model with correlations in a crystalline ferromagnet. The method is realized by introducing a differential operator into an exact spin correlation function and yields results which represent a remarkable improvement on the standard molecular field theory (MFT). In this paper, the method is extended to the case of an amorphous ferromagnet. We use the "lattice model" [3] in which the structural disorder is replaced by the random fluctuations of the exchange integrals around its crystalline mean value. Contrary to the standard MFT we have found that the fluctuations of the exchange integral causes a decrease of the Curie temperature.

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II. THEORY

The Hamiltonian for an amorphous Ising ferromagnet is

$$H=-\frac{1}{2}\sum_{i,j} J_{ij}s_i s_j\,; \quad s_i=\pm 1\,, \tag{1}$$

where J_{ij} is the random exchange integral between spins at the places i and j with $J_{ii}=0$.

According to Callen [4], we can obtain an exact spin correlation function as follows

$$\langle s_i\rangle=\left\langle \tanh\left(\beta\sum_j J_{ij}s_j\right)\right\rangle, \tag{2}$$

with $\beta=1/k_BT$ and $\langle\ldots\rangle$ indicates an ensemble average. Using the differential operator $D=\partial/\partial x$ in relations (2), and neglecting site correlations we obtain

$$\langle s_i\rangle=\prod_j\,[\cosh(DK_{ij})+\langle s_j\rangle\sinh(DK_{ij})]\tanh x|_{x=0}\,, \tag{3}$$

with $K_{ij}=\beta J_{ij}$. For an amorphous system with random exchange integrals, we must perform the configurational average on equation (3). If we restrict ourselves to the z, the nearest neighbours relation (3) reduces to

$$\langle\!\langle s_i\rangle\!\rangle_c=\prod_{j=1}^{z}\,\langle[\cosh(DK_{ij})+\langle s_j\rangle\sinh(DK_{ij})]\rangle_c\tanh x|_{x=0} \tag{4}$$

where $\langle\ldots\rangle_c$ denotes the configurational average. In amorphous ferromagnets, the ensemble-averaged value $\langle s_j\rangle$ should be different at each site, because of the random configuration of the nearest neighbours. However, near the transition temperature, long-range critical fluctuations become dominant. Therefore, near the critical region the homogeneous approximation [3, 5], or $\langle s_j\rangle=\langle\!\langle s_j\rangle\!\rangle_c\equiv m$, might be a better approach, when the spins are strongly correlated and fluctuated collectively. In this approximation, equation (4) becomes, for small exchange fluctuations:

$$m=\left\{[\cosh(DK)+m\sinh(DK)]\left[1+\frac{1}{2}(DK)^2\Delta^2\right]\right\}^z\tanh x|_{x=0}\,. \tag{5}$$

Here $K=\beta J_0$ and $\Delta^2=\langle(\Delta J_{ij})^2\rangle_c/J_0^2$ represents the mean square deviation in the distribution of the random exchange integrals $J_{ij}=J_0+\Delta J_{ij}$, with $J_0\equiv\langle J\rangle_c$.

Near the transition temperature, as the averaged magnitization m is nearly equal to zero, we can linearize equation (5), and then the Curie temperature T_c can be obtained from

$$1=z[\cosh(DK_c)]^{z-1}\sinh(DK_c)\left[1+\frac{z}{2}(DK_c)^2\Delta^2\right]\tanh x|_{x=0} \tag{6}$$

where $K_c=J_0/k_BT_c$. For example, in the case of $z=6$ and $\bar{\bar{Z}}=8$, equation (6) reduces to

$$\frac{T_c-T_c^{(0)}}{T_c^{(0)}}=-A\Delta^2, \tag{7}$$

where $A=0.203$ and 0.144 for $z=6$ and 8, respectively, and $T_c^{(0)}$ is the critical temperature for the corresponding crystal ($\Delta=0$).

Thus the Curie temperature T_c of the amorphous ferromagnet shows indeed a decrease according to the correlated effective field theory, in contrast to the homogeneous MFT which yields no change of T_c (see [6], and references therein). The reason why this method gives a different result from the traditional MFT is due to the fact that it takes exactly into account relations like $s_j^2=1$ and neglects only correlations between different spins (see equation (3)). On the other hand, the MFT neglects all correlations.

Finally, we note that quantitatively similar results for the Curie temperature have been found in [7] by using a δ-function distribution of the exchange integrals.

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