THEORY OF ANTIFERROMAGNETIC SPIN GLASSES AND STRONGLY DISORDERED ANTIFERROMAGNETS

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One of the most interesting results of the infinite-ranged model of disordered frustrated magnets is the prediction of the so-called «reentrant» transition from the ergodic state with long-ranged magnetic order (ferro- or antiferromagnetic) into a nonergodic one. Such transitions is a commonly observed phenomenon in a variety of materials /1/. In this paper we present the results of meanfield (MF) theory of frustrated antiferromagnets (AF). The theory predicts many striking features of such AF in an external magnetic field and reproduces qualitatively the main experimental results.

Let us consider a two-sublattice AF with frustrated inter- and intrasublattice exchange interactions. The Hamiltonian of the model is:

$$\mathcal{H}=\sum_{ij} J_{ij}S_{1i}S_{2j}-\sum_{ij,p} V_{ij}S_{pi}S_{pj}-H\sum_{i,p} S_{pi}\,, \tag{1}$$

where the subscript p=1,2 numerates spin subsystems, H is the external magnetic fields. Let us discuss Ising case $S_{pi}=\pm 1$ in detail, although Heisenberg model can be investigated in a similar way. The inter- and intrasublattice exchange interactions J_{ij} and V_{ij} do not depend on the distance between spins in the spirit of Sherrington-Kirkpatrick model and are distributed randomly according to the Gaussian distribution with mean values J_0/N and V_0/N and variances J^2/N and V^2/N respectively, N being the number of spins in a sublattice.

Using the replica trick, a free energy and equations of state can be derived. The sublattice magnetization $m_{1,2}$ and Parisi functions $q_{1,2}(x)$ can be obtained by solving a complicated system of integro-differential equations. In the ergodic state the Parisi parameters $q_{1,2}(x)$ do not depend on x. Then the system simplifies significantly and transformes into algebraic one.

$$\begin{gathered} m_p=<tanhE_p>\,,\quad q_p=<tanh^2E_p>\,,\quad p=1,2\,. \\ E_{1,2}=1/T(H+V_0m_{1,2}-J_0m_{2,1}+z(V^2q_{1,2}+J^2q_{2,1})^{1/2})\,, \end{gathered} \tag{2}$$

where

$$<\Psi>=\int e^{-z^2/2}\,\Psi(z)\,dz/\sqrt{2\pi}\,;$$

The transition from the ergodic state to the nonergodic one (this state will be called antiferromagnetic spin glass (AFSG) takes place at the line Tg(H) (de Almeida-Thoulsess) (AT) line) which in our case is determined by the equation

$$(Tg^2-V^2<cosh^{-4}E_1>)(Tg^2-V^2<cosh^{-4}E_2>)-J^4<cosh^{-4}E_1><cosh^{-4}E_2>=0\,. \tag{3}$$

Suppose at first that the intrasublattice exchange is much smaller than the intersublattice one: $(V_0,V)<<(J_0J)$. In this case the long-range magnetic order disappears in a magnetic field via the second-order phase transition. The main features of the phase diagram are as follows.

i) There is a field interval, where the temperature Tg(H) increases with H up to the field H_0, where antiferromagnetism is destroyed. The Tg(H) line has a cusp when crosses Neel line $T_N(H)$ at H_0. At

$H>H_0$ Tg(H) decreases monotonously. The increasing of transition temperature Tg(H) with the application of an external field is one of the most striking phenomena qualitatively discriminating between frustrated AF and previously studied frustrated ferromagnets. The physical origin of such an increasing is that applied field suppresses both antiferromagnetism and nonergodicity, causing a competition between AF and AFSG states.

ii) Solving the equations of state in the nonergodic phase close to the AT line, we predicted that a phase transition (on the magnetic field or the temperature) from the AFSG into a nonergodic state without antiferromagnetic order is possible. Recently, such a transition was observed experimentally /2/.

iii) If we take into account a mean value of intrasublattice, it is the first order phase transition line which crosses the AT line, Tg having a jump to a higher value at the crossing point. An interesting conclusion can be drown from that result: the discontinuous transition into the nonergodic state.

If $J<<V$ the field dependence of T_g has a sharp maximum (cusp) into AF part of phase diagram, the maximum of Tg(H) being very close to the Neel line. Similar T_g vs.H behaviour was observed recently at experiment /3/. The structure of materials under investigation was in correspondence with the assumption $J<<V$.

In conclusion it should be stressed that it would be too optimistic to believe that the MF theory can reproduce in detail all experimental results, but our investigation shows that it satisfactorily describes main features of real disordered AF /2—4/ and can be used to predict some new phenomena.

REFERENCES

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