Frequency dependence of the "freezing" point of the spin glass $Fe_{45}Ni_{35}Mn_{20}$

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(Submitted 19 December 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **39**, No. 3, 129–131 (10 February 1984)

The reversible susceptibility of the spin glass $Fe_{45}Ni_{35}Mn_{20}$ is investigated. It is found that the "freezing" point T_f is displaced due to a change in frequency by an amount exceeding the displacement of "frustrated" spin glasses by one to two orders of magnitude.

The question as to whether the formation of a spin glass is a true phase transition continues to attract a great deal of attention. To solve this problem, investigations of the dependence of the "freezing" point of the spin glass T_f on the characteristic measurement time τ are of great value. Such investigations have been performed primarily for RKKY spin glasses.[1] At the same time, a system with sign-alternating direct-exchange interaction is examined in most modern models of a spin glass.[2,3] In studying such "frustrated" systems (for example, the dielectric compounds $Eu_xSr_{1-x}S$[4]), some displacement of T_f was observed with a change in τ. However, this effect is small (less than 0.1 K), which makes it difficult to interpret the experiment.

We investigated a different type of "frustrated" system: the alloy $Fe_{45}Ni_{35}Mn_{20}$, whose composition is close to the critical concentration for the ferromagnetism—antiferromagnetism transition ($x_c \approx 43$) in the system $Fe_xNi_{1-x}Mn_{20}$.[5,6] In the alloys Fe-Ni-Mn, the direct-exchange interaction between the atoms and the nearest neighbors is sign-alternating,[7] which leads to the formation of the spin glass state with $x \sim x_c$ with very high values of T_f (up to 110 K[6]).

We studied the remanent magnetization M_r and differential reversible susceptibility χ of the alloy $Fe_{45}Ni_{35}Mn_{20}$ in the temperature range 60–120 K (0.7–1.3 T_f). The residual magnetization was measured by the Weiss-Forrer method (with the temperatures measured to within ≈ 0.05 K) as a function of time. The reversible susceptibility was studied on a low-frequency magnetometer in the frequency range 17–1020 Hz (the amplitude of the magnetization-reversal field did not exceed 0.04 Oe). The temperature was measured with a platinum resistance thermometer to within ≈ 0.02 K.

A sharp peak is observed at $T_f \approx 90$ K in the temperature dependence of the reversible susceptibility of the alloy $Fe_{45}Ni_{35}Mn_{20}$. As the frequency of magnetization reversal was varied from 17 to 1020 Hz, the displacement of the peak in $\chi(\Delta T_f)$ was found to be 2.2 K (Fig. 1). This value is approximately 20 times greater than that for the alloys $Eu_xSr_{1-x}S$ with $x \sim x_c$ (Ref. 4) and exceeds by a factor of two the maximum value of ΔT_f observed previously in RKKY spin glasses.[1] Figure 1 shows the values of the reversible susceptibility, measured in the absence of a constant magnetizing magnetic field H. For $H \neq 0$, the displacment of T_f becomes even larger, but the

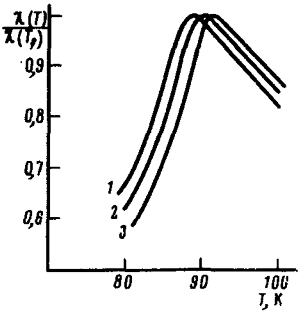

FIG. 1. Temperature dependence of the relative magnitude of the reversible differential susceptibility $\chi(T)/\chi(T_f)$ at the following magnitization-reversal frequencies: 1) 32 Hz, 2) 317 Hz, and 3) 1020 Hz.

accuracy with which ΔT_f is determined in this case is less due to the "smearing" of the peak in χ.

The frequency dependence of T_f of the alloy $Fe_{45}Ni_{35}Mn_{20}$ is described well by the Volger-Fulcher law[1]

$$\tau = \tau_0 \exp \frac{E_a}{k_B(T_f - T_0)}, \tag{1}$$

where E_a is the activation energy, τ_0 and T_0 are characteristic values of the time and temperature, and k_B is the Boltzmann constant.

To determine the time constant τ_0 we used the time dependences of the remanent magnetization of the alloy $Fe_{45}Ni_{35}Mn_{20}$. To analyze them we used the expression

$$M_r(t) = M_r(0)(t/\tau_0)^{-\alpha}, \tag{2}$$

where α is a coefficient proportional to the temperature.[8]

Figure 2 shows the dependence of $\ln M_r$ on $\ln t$, from which the values of the coefficient α and of the sum $\ln M(0) + \alpha \ln \tau_0$ at different temperatures were determined. We have then constructed (assuming that τ_0 is not a function of temperature[8])

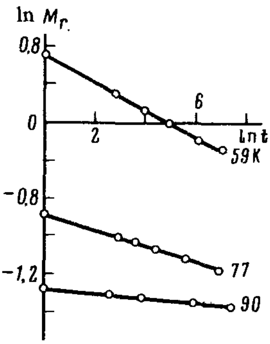

FIG. 2. Time dependences of the residual magnetization M_r in logarithmic coordinates.

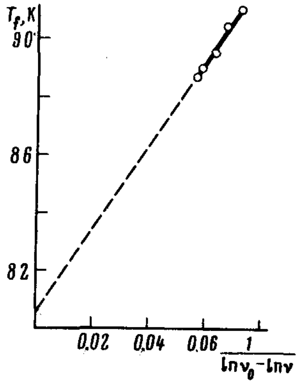

FIG. 3. Dependence of the "freezing" point of the spin glass $Fe_{45}Ni_{35}Mn_{20}$ on the quantity $1/(\ln\nu_0 - \ln\nu)$.

the $\alpha(T)$ dependence of $\ln M(0)$. It turned out to be nearly linear, which permitted calculating the quantity $\tau_0 \approx 10^{-9}$ sec. The value of τ_0 for the alloy $Fe_{45}Ni_{35}Mn_{20}$ turned out to be less than for RKKY spin glasses [sphere $\tau_0 \sim 10^{-10}$–10^{-13} s (Refs. 1 and 9)].

Using the value $\tau_0 = 1/\nu_0$, we have then constructed a graph of $T_f = f(1/(\ln\nu_0 - \ln\nu))$ (Fig. 3) and determined the parameters T_0 and E_a/k_B. It turned out that for the spin glass $Fe_{45}Ni_{35}Mn_{20}$, both the characteristic temperature $T_0 \sim 80$ K and the activation energy $E_a/k_B = 146$ K are anomalously high. For "frustrated" alloys of the type EuSrS and EuGdS, the values of T_0 and E_a do not exceed 20 K, while for RKKY spin glasses we have $T_0 \leqslant 40$ K and $E_a/k_B \leqslant 80$ K.[1,4]

This characteristic of the alloy $Fe_{45}Ni_{35}Mn_{20}$ can be explained within the framework of the "cluster" model of a spin glass.[1,8,10] In this model, the high value of T_0 indicates a stronger intercluster interaction in the alloy $Fe_{45}Ni_{35}Mn_{20}$ than in other spin glasses,[10] and the large value of E_a/k_B indicates that with $x \sim x_c$, clusters in FeNiMn alloys are larger than in alloys of the type AuFe and EuSrS.

According to the results in Ref. 11, it is difficult to explain in terms of the dynamic scaling the displacement of the freezing point of the spin glass $Fe_{45}Ni_{35}Mn_{20}$ by several degrees with a relatively small change in the characteristic measurement time. Therefore, our experimental result can be interpreted as an indication of the absence of a phase transition at the temperature T_f in "frustrated" spin glasses.

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Translated by M. E. Alferieff
Edited by S. J. Amoretty