# Viscous change of the magnetic structure of spin glass under the influence of a magnetic field

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An even "hysteresis" effect in the field dependence and a field-induced maximum of the temperature dependence of small-angle neutron scattering were observed in the spin glass $Fe_{65}Ni_{25}Cr_{10}$. These effects are due to slow relaxation of the spatial magnetic structure.

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Measurements of small-angle magnetic scattering of neutrons in the spin glass $Fe_{65}Ni_{25}Cr_{10}$ have shown[1] that when a magnetic field is applied the system goes over into a spatially more homogeneous ordered state followed, when the field is removed, by a very slow ($\tau > 10$ min) return to the initial state. We present here the field and temperature dependences of these effects, demonstrating thereby the extraordinary changes produced in the spatial magnetic structure by the magnetic viscosity of the spin glass. A detailed formulation of the problem, the experimental procedure, and a bibliography are given in Ref. 1.

The measured field dependence of small-angle neutron scattering is shown in Fig. 1. It can be seen (Fig. 1a) that with increasing field (curves 1, 4–6) the integrated scattering intensity decreases, i.e., the degree of magnetic inhomogeneity of the system decreases. The field dependence of the sizes of the magnetic inhomogeneities, calculated in the Guinier approximation from the angular dependences (Fig. 1a) is given in Fig. 1b. A joint analysis of the field dependences of the integrated scattering intensity and of the cube of the size of the inhomogeneities leads to the conclusion that the decrease of the degree of magnetic inhomogeneity is due at $H < 0.5$ kOe mainly to the decreased sizes, and at $H > 0.7$ kOe to smaller number of magnetic inhomogeneities. Consequently, the kink of the plot of the field dependence of the scattering (the middle curve of Fig. 1c) is due to substantial change of the mechanism through which the system responds to the action of the magnetic field. It can be assumed, in particular, that the change in the magnetic structure in weak fields is due to a transition to a more uniform ferromagnetically ordered state (F) of the spin glass (SG), resulting from the F → SG transition as the temperature is varied, while in strong field it is due to the decrease of the magnetic inhomogeneity of the cluster-glass subsystem.

The system relaxes, after the field is turned off, in two stages: at the first instant the system goes over almost immediately into a state with a degree of inhomogeneity smaller than the initial state (curves 2 and 3 of Fig. 1a), and only then does it acquire viscosity. Accordingly, the field dependence of the scattering (Fig. 1c) exhibits "hysteresis," and it can be seen that irreversibility is more pronounced in weaker fields. It can thus be stated that the physical cause of the hysteresis

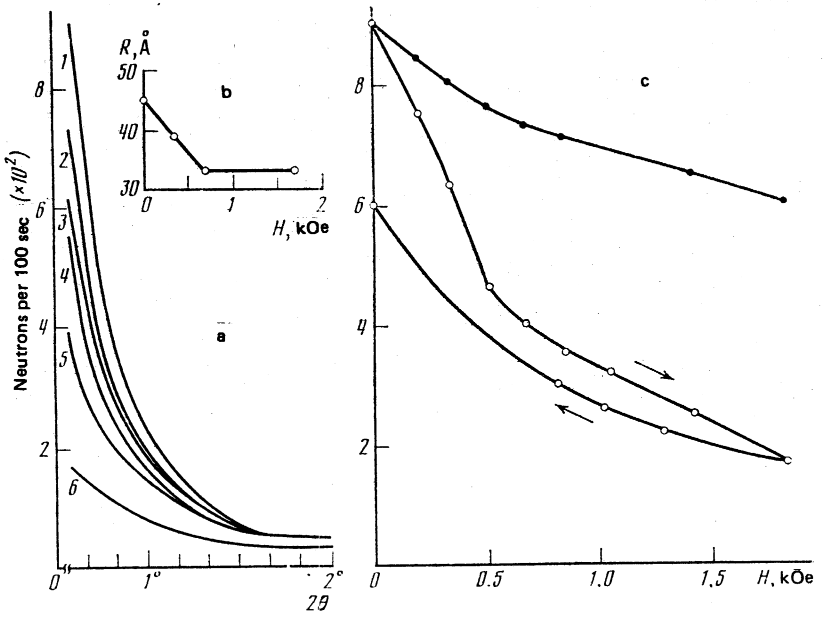

FIG. 1. Influence of magnetic field on the small-angle neutron scattering at 4.2 K: a—angular dependences of the scattering in a field $H = 0$ (1), 340 Oe (4), 680 Oe (5) and 1710 Oe (6), as well as after turning off the 640 Oe (2) and 1710 Oe (3) fields; b—field dependences of the sizes of the magnetic inhomogeneities; c—field dependence of the intensity of scattering through a fixed angle $2\theta = 0°35'$ in the presence of (○) and after turning off (●) the corresponding field. The arrows indicate the direction of the field variation.

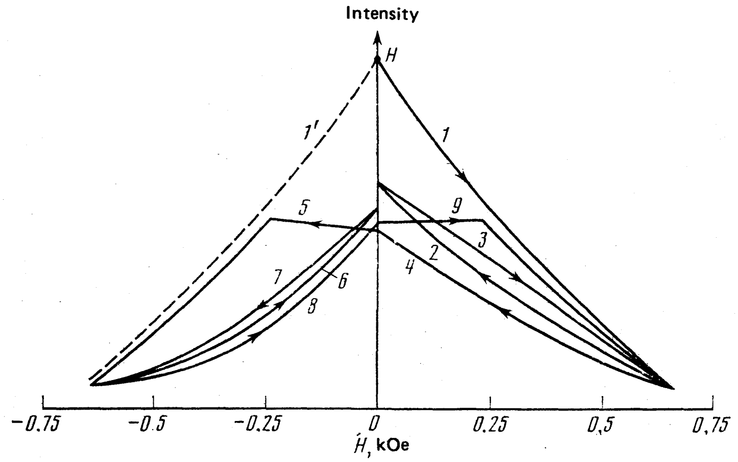

FIG. 2. Field dependence of the intensity at the angle $2\theta = 0°35'$ at 4.2 K in the course of the complete magnetization reversal, in the sequence 1–9 from the initial point.

in the change of the magnetic structure of the investigated spin glass is the slow relaxation of the system after turning off the magnetic field in the course of the inverse $F \rightarrow SG$ transition as the time is varied.

The relaxation character of the hysteresis of the magnetic structure manifests itself strongly in the singularities of the magnetization reversal, which are observed in Fig. 2. On the one hand, the magnetic structure depends on the prior history if the magnetic field is varied at a fixed polarity (curves 1–4 at $H > 0$ or 1 and 6–8 at $H < 0$). On the other hand, when the polarity is changed (curve 9 or 5)) the magnetic structure "does not remember" its prior history, and its change corresponds to motion along the initial curve 1 (or 1'). It is important also to note that if an intermediate field value $H \approx 0.1$ kOe is maintained in the course of obtaining curve 9 (or 5), the scattering intensity will increase with time and tend to its limiting value corresponding to the given field on the initial curve 1 (or 1'). It is thus obvious that the "hysteresis" of the field dependence of the spin-glass structure has a unique even character and is due entirely to the slow-relaxation processes.

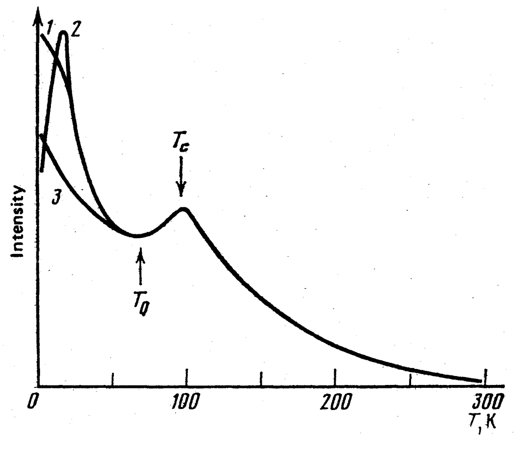

FIG. 3. Temperature dependences of the neutron scattering by an angle $2\theta = 0°35'$: 1—with the sample cooled from 300 to 4.2 K in a zero field; 2 (or 3)—when heated from 4.2 to 300 K in a zero field (or in a 240 Oe field) after turning on and off a magnetic field of 1710 Oe at 4.2 K.

Figure 3 shows the effect of temperature on the change of a magnetic structure produced at 4.2 K under the influence of a magnetic field. The appearance of a nonequilibrium maximum on curve 2, plotted with continuous heating at a rate $\approx 1$ deg/min, is due to superposition of two processes. On the one hand, the temperature rise increases the relaxation rate of the ferromagnetically ordered state induced by the field to the initial spin-glass state, i.e., the $F \rightarrow SG$ transition with changing time is accelerated and leads to an increase of the scattering. On the other hand, with rising temperature a natural $SG \rightarrow F$ transition with changing temperature is produced and leads to a decrease of the scattering in accord with curve 1 of Fig. 3. The absence of a maximum on curve 3 can therefore be naturally attributed to the restraining action of the magnetic field on the first of these factors. It is important to note that the difference in the temperature dependences of curves 1–3, i.e., the slow-relaxation effects inherent in spin glass, are substantial up to the temperature $T_0$ of the start of subcritical scattering. This is a weighty argument in favor of identifying $T_0$ with the temperaure at which the spin glass begins to freeze.

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[1] B. N. Mokhov, Pis'ma Zh. Eksp. Teor. Fiz. **35**, 216 (1982) JETP Lett. **35**, 270 (1982).

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