# Detection of a magnetic viscosity in a spin glass through small-angle neutron scattering in a magnetic field

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A slow relaxation of spatial magnetic inhomogeneities, which gives the system a magnetic viscosity, has been observed for the first time in a spin glass. The experimental method was to study the time dependence of the small-angle magnetic scattering of neutrons in the spin glass $Fe_{65}Ni_{25}Cr_{10}$ during the application and removal of a magnetic field. A possible mechanism for the magnetic viscosity is discussed with reference to a possible double transition paramagnet → ferromagnet → spin glass.

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A spin-glass state occurs in 3*d* alloys near a concentration ferromagnetic–antiferromagnetic transition.[1] The magnetic phase diagrams of such systems[2,3] are like those of classical spin glasses[4] in that the magnetic state has a twofold nature at concentrations just beyond the ferromagnetic threshold: As the temperature is lowered, there is initially a transition from a paramagnetic state to a ferromagnetic state ($F$), and then a spin glass (SG) appears. It has not yet been resolved, however, whether the spin glass forms as a result of the $F \rightarrow$ SG transition as the temperature is changed[5,6] or whether it forms along with the ferromagnetic state.[7,8] We have carried out experiments to determine whether the use of small-angle neutron scattering in a magnetic field to study a characteristic property of a spin glass–its magnetic viscosity–would yield direct evidence on the dynamics of the spatial magnetic structure and thus on the mechanism for the formation of the spin glass.

We studied the $\gamma$-phase alloy 65 at.% Fe, 25 at.% Ni, 10 at.% Cr from a quasibinary cut of $Fe_{65}$ $(Ni_{1-x}Cr_x)_{35}$ (Refs. 3 and 9). The diffraction patterns were recorded on a neutron diffractometer with a wavelength of 1.59 Å in a helium cryostat. A superconducting solenoid could produce a magnetic field in the direction perpendicular to the scattering vector.

This particular composition was chosen because it allows the $F \rightarrow$ SG transition as the temperature is changed (Fig. 1a), while it also maximizes the small-angle neutron scattering[3] and the magnetic viscosity.[10] It is important to note that this composition is similar to that of an alloy in which the low-temperature magnetization anomaly which reflects the $F_{65}Ni_{25}Cr_{10}$ transition is suppressed by a magnetic field of about 2 kOe (Refs. 11 and 12).

Figure 1b shows the results of the measurements, which were carried out in the following order: 1–The sample was cooled to 4.2 K in the absence of an external

  

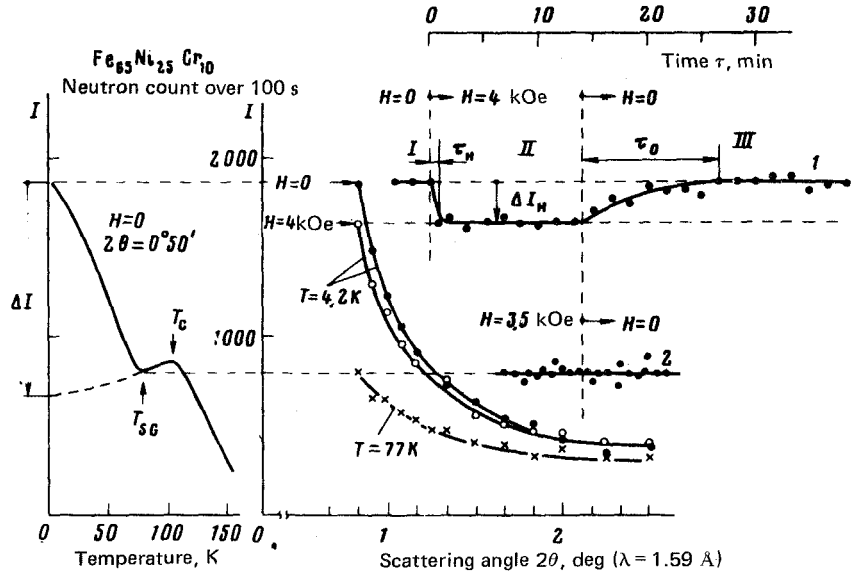


FIG. 1. Small-angle neutron scattering in the spin glass $Fe_{65}Ni_{25}Cr_{10}$. a–Temperature dependence of the intensity with $H=0$ and $2\theta=0°50'$ (Ref. 3); b–angular dependence at 4.2 K. •) $H=0$; ○) $H=4$ kOe; ×) 77 K. Curves 1 and 2 were recorded at $2\theta=0°50'$ during the imposition and removal of the magnetic field at 4.2 and 77 K, respectively.

magnetic field. 2–The angular dependence of the neutron scattering was measured at 4.2 K and $H=0$. 3–The neutron counter was placed at the angle $2\theta=0°50'$; after several control points were measured at $H=0$ (see part I of curve 1 in Fig. 1b), a magnetic field of 4 kOe was applied, and the time dependence of the intensity was measured (region II). 4–The angular dependence of the neutron scattering was measured at 4.2 K and $H=4$ kOe. 5–The counter was returned to its original position, $2\theta=0°50'$; after the field was removed, the time dependence of the intensity was measured with $H=0$ (region III).

The entire measurement cycle was carried out three times to eliminate systematic errors.

If the basic state of this alloy were a spin glass formed in an $F\rightarrow$SG transition, we would expect the intensity of the small-angle scattering at 4.2 K to be reduced by a factor of 2-2.5 ($\Delta I$ in Fig. 1a) by a magnetic field of 4 kOe (this is twice the field which suppresses the $F\rightarrow$SG transition[11,12]). We see from Fig. 1b, however, that the actual intensity decrease $\Delta I_H$ is only about 10%. It follows that the magnetic field, which was found to suppress the $F\rightarrow$SG transition, causes only very slight change in the degree of magnetic inhomogeneity and the spatial structure of the spin glass. We interpret these results as evidence against a double $F\rightarrow$SG transition.

Curve 1 in Fig. 1b shows the relaxation to the equilibrium spatial structure at 4.2 K. The viscous change in the magnetic structure, as in the magnetization,[10] is not seen in strong magnetic fields. The relaxation time after the field is turned on is $\tau_H<40$ s, while that after the field is turned off is $\tau_0\sim 10$ min. We might note that

in measurements[10] of the magnetic viscosity of samples of similar composition the magnetization continued to vary for 30 min or more.

After the sample was heated in a zero field to 77 K, corresponding measurements were carried out in a field of 3.5 kOe. In this case, however (curve 2 in Fig. 1b), the magnetic field does not affect the small-angle scattering. This result is in agreement with the data of Ref. 10, where measurements at 77 K also failed to reveal a magnetic viscosity. These facts can be explained on the basis of a solidification temperature $T_{SG} = 75$ K for this spin glass (Fig. 1a).

Analysis of all of these results suggests that the magnetic field causes only a partial transition in this system, to a spatially more homogeneous ferromagnetically ordered state.

The magnetic viscosity detected in these neutron-diffraction measurements after the removal of the magnetic field was caused by a slow, reversible $F \rightarrow SG$ transition. The small values of $\Delta I_H$ and $\tau_0$, however, show that the primary mechanism for the viscosity observed in the magnetization measurements of Ref. 10 was a slow relaxation of the magnetization of a subsystem of a cluster spin glass proper.

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