Asperomagnetism in FeNiCr alloys

G. A. Takzeĭ and A. M. Kostyshin
A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR

(Submitted 28 August 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **40**, No. 7, 308–310 (10 October 1984)

Anomalies in the imaginary part of the dynamic magnetic susceptibility, associated with the asperomagnetic state, have been observed below the Curie temperature of disordered FeNiCr alloys with alternating exchange.

The phase diagram of a system of Ising spins was first constructed by Sherrington and Kirkpatrick[1] in the approximation of the molecular field with an infinite interaction range. In particular, they predicted a "ferromagnet–spin-glass" (FM–SG) transition. In experiments, however, we deal most often with Heisenberg rather than Ising systems. For this reason, it is important to clarify how the form of the phase diagram changes in the Heisenberg case. An examination of this problem[2–4] led to the prediction of a new, asperomagnetic (ASM) state, which is a result of the evolution of a disordered collinear FM as it cools. This state is characterized by the presence of spontaneous magnetization (FM ordering) in some direction and spin-glass ordering of the transverse spin components.[5]

As the temperature is further decreased, the system transforms from the asperomagnetic phase into a new mixed phase that is characterized by strong degeneracy.[3,4] This state, which has been observed in many experiments[6] and which is often identified with the SG state, displays macroscopically irreversible phenomena such as magnetic viscosity and thermomagnetic history. We shall not, however, study this state in detail, since it has already been discussed.[7]

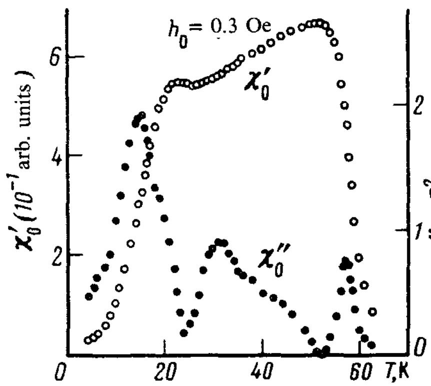
By measuring the dynamic magnetic susceptibility in disordered fcc alloys $Fe_{82-X}Ni_XCr_{18}$($X \geqslant 26$ wt.%), we have attempted to observe experimentally the ASM state in the FM–SG transition.

If a magnet is placed in an alternating magnetic field, $h = h_0 \cos \omega t$, its dynamic magnetic susceptibility $\chi_0(\omega)$ can, in general, be written in the form

$$\chi_0(\omega) = \chi'_0(\omega) - i\chi''_0(\omega),$$

where the imaginary part χ_0'' of the susceptibility, which is the Fourier transform of a correlation function, describes the dynamics of the magnetic system.[8]

Figure 1 shows the temperature dependences of the real and imaginary components of the susceptibility of the alloy $Fe_{56}Ni_{26}Cr_{18}$ for two values of the exciting alternating 36-Hz magnetic field. The susceptibility χ_0' has two anomalies, which are characteristic of systems that undergo an FM–SG transition. The high-temperature anomaly is associated with the appearance of spontaneous magnetization in the alloy, while the sharp temperature drop is associated with the transition to the SG state.[7,9] The behavior of χ_0'' is more complicated (Fig. 1, $h_0 = 0.3$ Oe). Near the Curie temperature $T_c = 57$ K, there is a peak that reflects the appearance of long-range ferromagne-



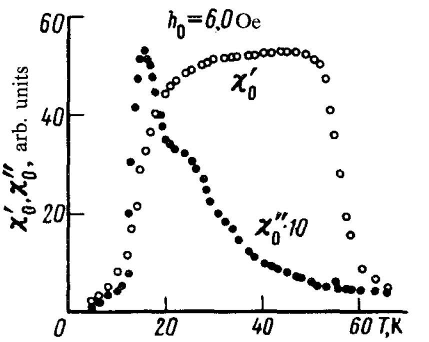


FIG. 1. Temperature dependence of the real χ_0' and imaginary χ_0'' parts of the dynamic magnetic susceptibility of the alloy $Fe_{56}Ni_{26}Cr_{18}$. A 36-Hz magnetic-field frequency was used for the measurements; h_0 is the amplitude of the measuring field.

tic order in the alloy. At low temperatures ($T_f = 15$ K), the peak in χ_0'', which is associated with the transition of the sample to the SG stage, agrees with the data on nonlinear magnetic susceptibility.[7] There is yet another anomaly in χ_0'' in the intermediate temperature range ($T_{asm} = 31$ K). We shall consider the reasons for the appearance of this anomaly.

We assume that the appearance of the intermediate anomaly in χ_0'' is associated with the particular features of the domain structure of the alloy. But this would then inevitably affect the behavior of χ_0'. There is experimental evidence (Fig. 1), however, that χ_0' does not exhibit any appreciable anomalies at the corresponding temperatures. It is therefore unlikely that this anomaly in χ_0'' is associated with spin-flip transitions.

In our view, the only reason for the existence of a peak in χ_0'' below T_c is the appearance of the ASM state in an alloy. This conclusion is indirectly confirmed by data on the effect of an alternating magnetic field on the temperature dependences of χ_0''. According to Ref. 4, weak irreversibilities should indeed appear near T_{ASM} and strong irreversibilities should appear below T_f. On the other hand, χ_0'' is a measure of the magnetic losses in a sample, i.e., its "viscous" behavior. The asperomagnetic anomaly in χ_0'' must therefore be much more sensitive to the action of the magnetic

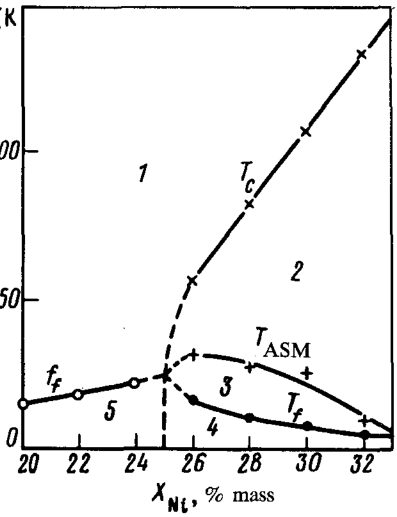


FIG. 2. The magnetic phase diagram of the fcc alloys $Fe_{82-x}Ni_xCr_{18}$. 1) Paramagnetic region; 2) ferromagnetic region; 3) asperomagnetic region; 4 and 5) existence domains of the spin glass. T_c is the Curie temperature, T_{ASM} is the temperature of the asperomagnetic transition, and T_f is the freezing point of the spin glass (T_f for region 5 are taken from Ref. 9).

field than the spin-glass anomaly. Such behavior has in fact been observed. As the amplitude of the exciting magnetic field is increased to 6 Oe, the anomaly in χ_0'' near T_{ASM} disappears almost completely, in contrast to the peak near T_f (Fig. 1). It appears that the ASM phase has not been detected for this reason in the only experiment,[10] in which the χ_0'' was studied in systems in which an FM–SG transition occurs.

In conclusion, we note that an analogous behavior of χ_0'' was observed in other alloys of the system $Fe_{82-x}Ni_xCr_{18}$, making it possible to construct a magnetic phase diagram (Fig. 2). Regions 4 and 5 correspond to the SG state. However, because the first region arises from the asperomagnetic phase (3) and the second one from the paramagnetic phase (1), there is presumably a difference between them. As stated above, this question will not be discussed here. We wish to emphasize, however, that the experimental phase diagram (Fig. 2) is in complete qualitative agreement with the theoretical phase diagram.[3]

Using conventional magnetic methods, we have thus detected for the first time the asperomagnetic state in alloys with competing exchange near the FM–SG transition.

We thank S. L. Ginzburg for valuable suggestions and Yu. P. Grebenyuk for assistance in conducting the experiments.

[1]D. Sherrington and S. Kirkpatrick, Phys. Rev. Lett. **5**, 965 (1975).
[2]M. V. Medvedev and S. M. Goryainova, Phys. Status Solidi B **98**, 143 (1980).
[3]M. Gabay and G. Toulouse, Phys. Rev. Lett. **47**, 201 (1981).
[4]D. M. Cregg, D. Sherrington, and M. Gabay, Phys. Rev. Lett. **49**, 158 (1982).

[5]J. M. D. Coey, J. Appl. Phys. **49**, 1646 (1978).
[6]K. H. Fischer, Phys. Status Solidi B **116**, 357 (1983).
[7]G. A. Takzei, A. M. Kostyshin, and K. V. Chuistov, Pis'ma Zh. Eksp. Teor. Fiz. **39**, 381 (1984) [JETP Lett. **39**, 459 (1984)].
[8]R. Kubo and T. Nagamiya, Solid State Physics, McGraw-Hill, New York, 1969, p. 475.
[9]G. A. Takzeĭ, I. I. Sych, A. Z. Men'shikov, and A. E. Teplykh, Fiz. Met. Metalloved. **52**, 960 (1980); A. Z. Men'shikov, G. A. Takzeĭ, and A. E. Teplykh, Fiz. Met. Metalloved. **54**, 465 (1982).
[10]R. B. Goldfarb, F. R. Fickett, K. V. Rao, and H. S. Chen, J. Appl. Phys. **53**, 7687 (1982).

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