Ferromagnetic regions of polarization in an antiferromagnetic matrix in the system Fe$_{65}$(Ni$_{1-x}$Mn$_x$)$_{35}$

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Neutron diffraction by an antiferromagnetic matrix and by ferromagnetic regions was investigated at 4.2°K. The formation of ferromagnetic-polarization regions in an antiferromagnetic matrix is demonstrated for the first time and the parameters of the magnetic structure on going to the ferromagnetic state are determined.

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The antiferromagnetic structure of a matrix and the onset of magnetic inhomogeneities near the critical composition are investigated by methods of thermal-neutron diffraction at 4.2 °K. Diffraction and small-angle magnetic scattering of neutrons by quenched polycrystals were investigated with neutron diffractometers at wavelengths $\lambda = 1.07$ Å and $\lambda = 1.59$ Å, respectively. The sample compositions are listed in the table.

Sample No.	Ni, at.%	x	T_N, K	μ_a, μ_B	$\bar{\mu}$, μ_B	C, %	$M(0)$, μ_B
1	0	1	450	1.85	–	–	–
2	23.6	0.37	100	0.65	0.01	0.004	241
3	25.2	0.28	11	0.50	0.13	0.2	63
4	30.7	0.14	–	–	0.83	2.2	37

The neutron-diffraction patterns of samples 1—3 (Fig. 1) show, besides the nuclear reflections (220), also superstructure magnetic reflections (110) that demonstrate the existence of a long-range antiferromagnetic order. No antiferromagnetic reflections were observed on the neutron-diffraction pattern of sample 4. The sizes of the antiferromagnetic coherent scattering regions, estimated from the half-widths of the reflection (110), amount to > 350 Å and 100 Å for alloys 2 and 3, respectively. The Néel temperatures T_N determined from the temperature dependence of the peak intensity of (100) are given in the table and agree well with results of magnetic measurements.[1] The average sublattice magnetic moment μ_a was calculated using the magnetic structure factor,[2] assuming a spin structure of the γ-FeMn type, from the ratio of the integrated intensities of the reflections (110) and (220).

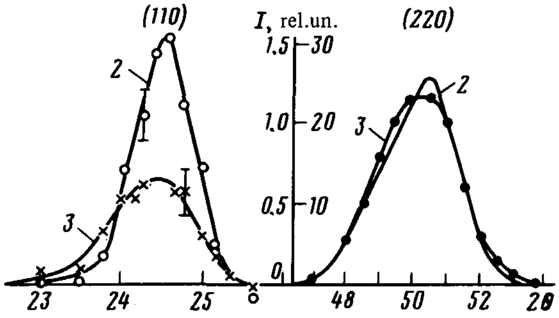

FIG. 1. Parts of neutron diffraction patterns of samples 2 and 3.

Thus, a well-developed long-range antiferromagnetic order exists in the alloys 1—3. The values of μ_a in the table, together with the data of[3], yield for μ_a a concentration dependence that can be extrapolated into the region of ferromagnetic compositions with $x < 0.3$. The deviation from zero of the extrapolated values of μ_a for alloys 4, and up to the binary composition $Fe_{65}Ni_{35}$ ($x = 0$), suggests that local antiferromagnetism exists in ferromagnetic alloys in this range of compositions.

Small-angle magnetic scattering (Fig. 2) is observed for samples 2 and 3 below T_N and is maximal in ferromagnetic sample 4, where short-range antiferromagnetic order is assumed. If the small-angle scattering is ascribed to magnetic inhomogeneities of the matrix, which are produced by the ferromagnetic regions, then the cross section can be expressed, according to[4], in the form

$$d\sigma/d\Omega = 0.0486\, C(1 - C)[M(S)]^2 , \tag{1}$$

where C is the concentration of the ferromagnetic regions, $S = 4\pi \sin\theta/\lambda$, $M(S)$ is the Fourier transform of the magnetic-moment density $\rho(\mathbf{r})$ in the region. The linear dependence of $(d\sigma/d\Omega)^{-1/2}$ on S^2 makes it possible to describe $M(S)$ by a Lorentzian[5]: $M(S) = M(0)/(1 + \kappa^{-2}S^2)$, where $1/\kappa$ is a parameter of the size of the inhomogeneity and $m(0)$ is the average total magnetic moment in the region. The function $\rho(\mathbf{r})$, where $\mathbf{r}$ is the distance from the center of the region, is of the Yukawa type,[4] indicating that the matrix is polarized around the ferromagnetic centers. The solid lines of Fig. 2a show the calculated plots of $d\sigma/d\Omega$ against S, which agree satisfactorily with the experimental points. The concentration dependence of κ is shown in Fig. 2b.

To estimate C and $M(0)$, the results were reduced by the method of[5], assuming no overlap of the ferromagnetic regions. The values of the average magnetic moment $\bar{\mu}$, obtained by interpolating the data of[6], together with the values of C and $M(0)$, are listed in the table.

It follows from the table that the ferromagnetic regions exist near the critical composition $T_C = 0$,[1] and that their concentration increases with the Ni content. The values of C for alloys 2 and 3 are close to the concentrations of the clusters

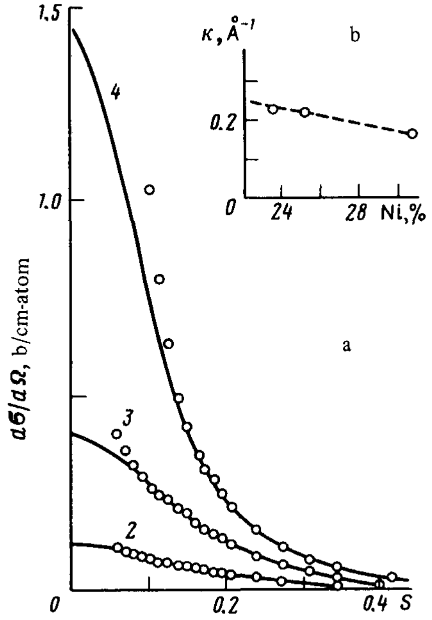

FIG. 2. a) Angular dependences of the cross sections of small-angle neutron scattering by alloys 2, 3, and 4; b) concentration dependence of κ.

produced as a result of fluctuation of the composition, and contain from 10 to 12 and from 8 to 12 nickel atoms, respectively, in the first coordination sphere of the iron or manganese atoms. It appears that these clusters are indeed the nuclei of the ferromagnetism in the antiferromagnetic matrix and produce regions of ferromagnetic polarization with the parameters represented in Fig. 2 and in the table.

Estimates of the volume fraction of the ferromagnetic-polarization regions, based on κ and C, for the alloy 4 indicate a partial overlap of the ferromagnetic regions, so that the analysis by the method of[5] is approximate. Since sample 4 is ferromagnetic with $T_C = 285\,°\mathrm{K}$, Eq. (1) describes in this case scattering by inhomogeneities resulting from the presence of weakly magnetic regions, and C denotes their concentration. The smallest value $C = 1.2\%$ is the concentration of clusters consisting of iron and manganese atoms in the first coordination sphere around the iron or manganese. Apparently it is in these clusters that the local antiferromagnetic order assumed above is produced.

The investigated transition from the antiferromagnetic state to the ferromagnetic one with increasing nickel concentration holds equally well for the magnetic structure of iron-nickel invars, where no long-range antiferromagnetic order is observed because of the martensitic transformation at low nickel contents.

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