Anomaly of subcritical neutron scattering and effect of ferromagnetic-matrix depolarization in an antiferro-ferromagnetic transition

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Measurements of critical small-angle scattering of neutrons in the $Fe_{65}(Ni_{1-x}Mn_x)_{35}$ system have revealed for the first time an anomalous increase of the scattering cross sections in the subcritical temperature region $4.2 \leq T \leq T_0 < T_c$. The hypothesis is advanced that the depolarization effect that leads to subcritical scattering is of antiferromagnetic origin.

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The antiferromagnetic—ferromagnetic concentration transition in the disordered system $Fe_{65}(Ni_{1-x}Mn_x)_{35}$ takes place via production, in the antiferromagnetic matrix ($x > 0.3$), of individual regions of ferromagnetic polarization, the overlap of which at $x < 0.3$ leads to a vanishing of the long-range antiferromagnetic order and to establishment of long-range ferromagnetic order with spatially inhomogeneous magnetization.[1] The latter is due to the existence of clusters with increased content of Fe and Mn, which leads to formation of regions with decreased moment and even to antiparallel orientation of the individual atomic and magnetic moments relative to the direction of the spontaneous magnetization (local antiferromagnetism). So far, however, no direct data have been obtained on the interaction of the observed elements of the magnetic structure. To this end, we have investigated in the present study the temperature dependence of magnetic small-angle scattering (SAS) of neutrons in alloys with $x = 0.07$, 0.14, 0.20, and 0.28.

The measurements were made with a neutron diffractometer with wavelength $\lambda = 1.59$ Å in the temperature interval 4.2—700 K. The scattering cross sections $d\sigma/d\Omega$ were determined from the SAS intensities with the aid of a vanadium standard.[2] The observed SAS are of strictly magnetic origin, as is confirmed by measurement at temperatures up to 700 K, at which the values of $d\sigma/d\Omega$ for different combinations tend to a common insignificant value of nuclear scattering.

The temperature dependences of $d\sigma/d\Omega$ at certain values of the scattering angle 2θ are shown in Fig. 1. The curves for alloys 2 and 3 show maxima of the critical SAS, and their positions determine the Curie temperatures T_C, namely 160 ± 5 K and 265 ± 10 K, respectively, in agreement with the values of T_C obtained from magnetic measurements.[3] Alloy 4 has $T_c = 410$ K, so that Fig. 1 shows only the increase of $d\sigma/d\Omega$ as T_C is approached. Since a long-range antiferromagnetic order with a Neel temperature $T_N = 11$ K is observed in sample 1, and the ferromagnetic regions do not overlap,[1] it is assumed that the temperature dependence shown in Fig. 1 is evidence of the existence in the alloy of local values $T_C \approx 70$ K.

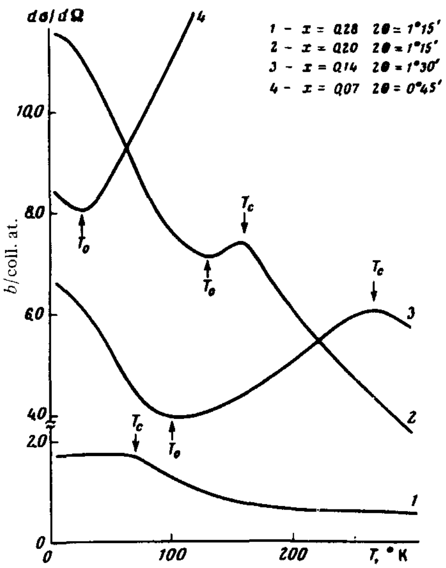

FIG. 1. Temperature dependences of the cross sections for magnetic small-angle scattering of neutrons: 1—$x=0.28$; 2—$x=0.20$; 3—$x=0.14$; 4—$x=0.07$.

According to the theory of critical scattering,[4] when the temperature is lowered in the subcritical region $0 \leq T < T_C$ one expects a continuous decrease of the values of $d\sigma/d\Omega$, which reflect an increase of the spontaneous magnetization of the ferromagnetic matrix. In Fig. 1, however, the values of $d\sigma/d\Omega$ of alloys 2—4 begin to increase anomalously below certain temperatures $T_0 < T_C$. The observed increase of the critical scattering at $T < T_0$ can be called *subcritical* scattering. According to[4], $d\sigma/d\Omega$ is proportional to the fluctuation of the square of the magnetization at the given temperature, i.e., to the difference of the densities of the magnetic moments in the regions with decreased moment and of the ferromagnetic matrix. Therefore the growth of $d\sigma/d\Omega$ at $T < T_0$ reflects a deviation of the density of the moment of the region from the average moment of the matrix.

From the angular dependences of $d\sigma/d\Omega$ at 4.2, 77, and 295 K we have determined, in analogy with[2], the size parameters $1/\kappa$ of the regions with the decreased value of the moment. Thus, in alloy No. 3 we have $1/\kappa = 4.8$ and 6.1 Å at temperatures 77 and 4.2 K, respectively. An analogous increase in the values of $1/\kappa$ with decreasing temperature in the region of the subcritical scattering is observed also in the alloy 2. Consequently, subcritical scattering is accompanied by an increase of the dimensions of the region on account of the matrix, which undergoes partial ferromagnetic ordering in the interval $T_0 < T < T_C$.

Thus, the establishment of the long-range ferromagnetic ordering with decreasing temperature $T < T_0$ in alloys 2—4 is hindered by magnetic *depolarization* of the matrix, a process characterized by a deviation of the density of the moment and by an increase of the dimensions of the regions with decreased moments.

As seen from Fig. 1, when x increase $(T_C - T_0)/T_C$ decreases. The growth of the relative values of the subcritical scattering reflects in this case the in-

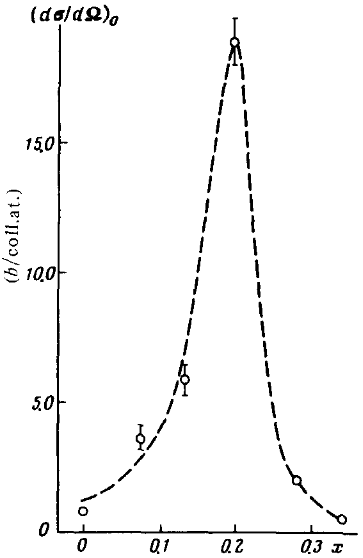

FIG. 2. Concentration dependence of the cross sections of magnetic small-angle scattering of neutrons.

crease of the matrix depolarization, which leads to an increase of the magnetic inhomogeneity of the alloys. Indeed, the concentration dependence of the quantity $(d\sigma/d\Omega)_0$ in Fig. 2, defined as the cross section at $2\theta = 0°$ according to[2], predicts an increased inhomogeneity of the alloys with increasing x in the interval $0 \leq x \leq 0.20$, where $T_0 < T_C$. It is obvious that at $T_0 \approx T_C$ the alloy will have the maximum magnetic inhomogeneity, the critical and subcritical scatterings in it are indistinguishable, and the long range ferromagnetic order cannot be observed. Using the concentration dependence of the values of $(T_C - T_0)/T_C$, we obtain at $T_0 = T_C$ the critical value $x_0 = 0.23$, which is close to the position of the maximum on Fig. 2.

It follows from Fig. 2 that the formation of long-range antiferromagnetic order at $x > 0.23$ is accompanied by a sharp decrease of the inhomogeneity of the alloy. Then the different character of the temperature dependence of the alloy 1 in Fig. 1, which is in the form of a "step," is apparently connected with the condition $T_0 > T_C$.

Recognizing that long-range antiferromagnetic order is formed in alloy 1, the growth of the values of T_0 with increasing x suggests that the depolarization centers are regions with local antiferromagnetism.

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