Observation of two length scales of magnetic correlations in the Invar $Fe_{75}Ni_{25}$ alloy above T_C by means of small-angle neutron scattering and neutron depolarization

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The magnetic phase transition in the iron-nickel fcc alloy $Fe_{75}Ni_{25}$ doped by carbon is investigated. Combining neutron depolarization and small-angle neutron scattering analysis, we demonstrate the coexistence of two length scales of magnetic correlations above T_C in this intrinsically disordered system. A smaller scale length is attributed to the critical fluctuations. The shape of these fluctuations is well described by the Ornstein-Zernike expression. According to the strong depolarization above T_C the larger-scale correlations with characteristic length R_d cannot be described by the Ornstein-Zernike expression and its shape could be roughly modeled by the ''squared Ornstein-Zernike'' formula: $\langle M(r)M(0)\rangle \sim \exp(-r/R_d)$. [S0163-1829(98)03425-0]

The small-angle neutron scattering (SANS) experiments proved to be a powerful method for investigation of ferromagnetic phase transitions. The SANS technique allows one to measure a Fourier image of spin-spin correlation function, in particular, its shape and its length, although the typical resolution of SANS is limited by the range 10–1000 Å. On the other hand, the neutron depolarization (ND) is mostly contributed by the large magnetic inhomogeneities which cannot be resolved in conventional SANS experiments. For this reason, the SANS and ND experimental techniques could be viewed as complementary ones, capable to provide important information about the investigated disordered systems. Apart from the size of the magnetic inhomogeneity, ND provides indirect evidence about its shape. It is shown in Refs. 1–3, that in the case of critical fluctuations ND is rather small and magnetic correlations with a shape similar to critical fluctuations lead to very small depolarization. As a result the observed depolarization can be ascribed to the magnetic clusters with relatively homogeneous distribution of the induction inside them and with very large spatial dimension.

This paper is devoted to the investigation of a disordered magnetic system undergoing the ferromagnetic phase transition. In the experiment described below we observe a strong growth of the neutron depolarization in the sample of Invar FeNi alloys in the paramagnetic temperature range, while approaching from above T_C. The enhancement of the neutron depolarization is attributed to the appearance of the large magnetic clusters (10^4-10^5 Å) in the system. Along with this finding the usual critical correlations (with radius R_c about 100 Å) are observed at the same temperatures by small-angle neutron scattering. As a result we demonstrate the coexistence of two length scales in Invar FeNi alloy above T_C.

The similar situation with the coexistence of two inhomogeneity scales arises apparently in the SANS and neutron depolarization experiments in reentrant spin glasses.[4,5] The analysis of this problem is, however, not completed. Here we wish also to mention the paper by Wong *et al.*,[6] where the coexistence of the short-range spin-glass behavior and antiferromagnetic long-range ordering well below Néel temperature was demonstrated in the $(Fe_{0.55}Mg_{0.45})Cl_2$ compound. Apparently two length scales could manifest themselves in this system also. Regretfully, the corresponding results have not been reported yet.

The situation with two length scales above T_C was also discussed for nominally pure materials.[7–16] Actually, the results reported therein were stimulating issues for our study of the disordered ferromagnet compounds above T_C. The discussion of the two-scale problem was initiated by Andrews' report[7] on the two-component line shape observed in the critical x-ray scattering associated with structural phase transition in $SrTiO_3$. At the temperature just above T_C a very narrow peak appeared which was superimposed on the already present broad peak of the usual critical scattering. This fact implied the existence of a second, and larger, length scale simultaneously with the usual correlation length of the critical fluctuations just above T_C. Up to now the two-component line shape has been observed by both x-ray and neutron-scattering measurements in the following substances: $SrTiO_3$,[7,8] Ho,[9] $RbCaF_3$,[10] $KMnF_3$,[11] UPd_2Al_3,[12] and Tb.[13] In the last paper it was demonstrated that the intensity of the narrow component was enhanced near the edge of the crystal which showed that its origin was mainly located within the near-surface volume with a thickness of about 0.2 mm. At the same time the broad component has been observed over the whole crystal volume. As a result it was suggested that the long-range correlations (the narrow component) above the transition appeared due to the influence of defects and surface strains on the ordering parameter. Preliminary theoretical interpretations of these experiments were proposed recently in Refs. 14,15. It was assumed that the second length scale could stem from quenched long-range disorder. It was argued in Ref. 14 that this length scale could be attributed to new critical behavior in the near-surface region, while the bulk displayed the critical behavior of the pure system. It should be contrasted though to the recent paper,[12] where it was shown that the second length scale was apparently inherent for UPd_2Al_3. We note that up to now two length scales were observed in the nominally pure materials. However appearance of the second length is attributed to some kind of disorder in the systems undergoing a first-order transition related to the coupling of the strain and order parameter.[16]

It is well known that alloys of Fe with Ni in the Invar concentration range are strongly disordered systems.[17] The question arises whether an appearance of the large-scale inhomogeneities at $T>T_C$ is connected with a disorder of magnetic subsystem in Invar FeNi or it has another origin. We cannot now resolve this problem which needs further investigation. We believe however that the intrinsic disorder plays the crucial role in the appearance of the second length scale.

I. THEORETICAL BACKGROUND

We demonstrate below how the complementary analysis of the small-angle neutron scattering (SANS) and neutron depolarization (ND) data allows one to establish the coexistence of two magnetic correlation lengths in disordered ferromagnets just above T_C.

It is known that the usual resolution of SANS ranges about 10–1000 Å, while the method of ND provides information on a larger scale. It is very instructive to adopt the unified, quantum-mechanical point of view on the neutron scattering and depolarization. We sketch below some basic notions. If a neutron interacts with inhomogeneity of size R, its momentum acquires uncertainty of order of $\hbar/R$. This interaction gives rise to a small-angle scattering with $\vec{q} \sim \hbar/R$ perpendicular to $\vec{k}$. The depolarization of neutrons transmitted through the sample is a result of unresolved small-angle magnetic scattering within angular width of the beam (Maleyev and Ruban[1–3]). In this case depolarization is determined by the integral cross section of scattering normalized per one magnetic atom σ_Ψ, within the acceptance angle of the central detector Ψ. It has been shown that the magnitude of the neutron depolarization depends on the relative orientation of the initial polarization $\vec{P}_0$ and neutron wave vector $\vec{k}$ as well as on the magnetic anisotropy of the sample.[1–3] For a magnetically isotropic sample and if $\vec{P}_0 \perp \vec{k}$ we have for the polarization of transmitted beam

$$P = P_0 \exp((-3/2)\cdot \sigma_\Psi N_0 L), \tag{1}$$

where N_0 is the density of magnetic atoms and L is the thickness.

We see that the neutron depolarization allows one to determine the total scattering cross section σ_Ψ for $q \leqslant k\Psi = q_{\min}$, i.e., it contains the integral information about the inhomogeneities with large size, $R \geqslant 1/q_{\min}$. On the other hand, for SANS the momentum transfer lies in the range $q \geqslant k\Psi$ which corresponds to inhomogeneities with a size $R \leqslant 1/q_{\min}$.

It is well known from neutron scattering that one can obtain the spin-correlation length of critical fluctuations and its temperature dependence.[18,19] This spin-correlation length is the single important length scale which exists in the critical region above T_C. As the Curie point is approached, the size of the critical correlation R_c increases unlimitedly as $R_c = a\tau^{-\nu}$, where a is of order of the interatomic distance, $\tau = (T - T_C)/T_C$ is the reduced temperature, and ν is the critical exponent of correlation length; in ferromagnetic materials we have $\nu \approx 2/3$. The diffuse cross section of SANS above T_C is given by the Ornstein-Zernike formula and increases as temperature approaches T_C:[18–20]

$$\frac{d\sigma}{d\Omega} = \frac{2}{3} r_0^2 \gamma^2 S(S+1) \frac{1}{r_1^2} \frac{1}{R_c^{-2} + q^2}, \tag{2}$$

where $q \approx k \cdot \theta$ is momentum transfer, $(\gamma_0 r_0)^2 = 0.292$ b, S is an atomic spin, and r_1 is of order of interatomic distance.

For the cross section σ_Ψ we have near T_C

$$\sigma_\Psi = \frac{2}{3} \pi r_0^2 \gamma^2 S(S+1) \frac{1}{(kr_1)^2} \ln[1 + (ka\Psi\tau^{-\nu})^2]. \tag{3}$$

In real experiments the temperature stabilization and temperature gradient within the sample restrict the value of τ by the condition $|\tau| \geqslant \tau_{\min}$, where usually $\tau_{\min} \sim 10^{-4}$. Substituting this minimum value $\tau_{\min}$ into Eq. (3) for $\lambda \sim 10$ Å one obtains $\sigma_\Psi \leqslant 0.5$ b. If L is of order of a few millimeters and $N_0 \approx 10^{23}$, the depolarization reaches a value of the order of a few percent only. The small value of the critical ND has been confirmed experimentally:[21] the value of $\Delta P/P_0 \approx 1\%$ has been found for Ni monocrystal with $L = 0.5$ cm and $\lambda = 3$ Å at $\tau = 10^{-4}$.

This small depolarization is a result of weakness of the magnetic correlations inside the range R_c. Indeed in real space the Ornstein-Zernike correlation function is proportional to $(1/r)\cdot \exp(-r/R_c)$, i.e., for $r < R_c$ it decreases as $1/r$. At the same time in the case of the finite-size inhomogeneities with range R_d the corresponding correlation function is essentially independent of r for $r < R_d$. In this case if $[\Psi \gg (kR_d)^{-1}]$ all scattered neutrons enter the central detector and the neutron depolarization may be considered classically. As a result one may rewrite Eq. (1) in the Halpern-Holstein form and for $\vec{P}_0 \perp \vec{k}$ we have[1]

$$P = P_0 \exp\left(-\frac{1}{2}\left(\frac{\gamma B(T)}{v}\right)^2 R_d L\right), \tag{4}$$

where B is the magnetic induction inside the inhomogeneity, v is the neutron velocity, and the factor (1/2) appears instead of (1/3) due to above-mentioned dependence of the depolarization on the relative orientation of $\vec{P}_0$ and $\vec{k}$. In this classical limit we have $\sigma_\Psi \sim R_d$, while for the Ornstein-Zernike correlations $\sigma_\Psi \sim a \ln(kR_c\Psi) \ll R_c$. It is the reason why the Ornstein-Zernike fluctuations give rise to much weaker depolarization than the finite-size inhomogeneities. The main consequence of the above consideration is the statement that the Ornstein-Zernike correlations cannot produce strong ND and it does not depend on their range R_c.

The studies of traditional ferromagnets, e.g., Ni powder[21] and Fe polycrystal[22] undergoing a magnetic phase transition, confirm this description of the neutron depolarization. Contrary to these previous experiments, in the study reported here, the depolarization above T_C is revealed to be much larger than the one calculated with the use of SANS data and Eqs. (1) and (3). We attribute the enhancement of the neutron depolarization to the appearance of large-scale magnetic inhomogeneities along with the usual critical fluctuations at $T > T_C$.

II. EXPERIMENTAL DETAILS

We chose for the present study the $Fe_{75}Ni_{25}$ alloy with fcc structure doped by carbon 0.7 at. %. The addition of carbon helps one to get a wholly austenite sample at room temperature with Curie temperature T_C higher than martensite transition temperature T_m. In our sample we have $T_m = 150$ K and according to magnetic susceptibility $T_C = 190$ K.[23] We will demonstrate below that the Curie point determined this way coincides with the temperature of magnetic transition obtained from SANS data. Additionally, the identification of austenitic fcc structure above T_m and martensitic bcc structure below T_m was carried out by means of neutron diffraction on the Mini SFINKS high-resolution Fourier time-of-flight powder diffractometer.[24] These measurements confirmed that the sample had fcc structure in the initial state without admixture of any other phase and acquires the bcc structure after cooling below T_m.

The sample had the form of a plate with dimensions $45 \times 10 \times 1.3$ mm^3. It was mounted in the refrigerator RNK10-300. The temperature stability was about 0.1 K. The temperature was lowered from 270 to 120 K in steps of 1 K. The temperature dependences of SANS and both depolarization and intensity of the transmitted beam were measured simultaneously. The magnetic contribution was separated using the scattering intensity at temperature 270 K as a nonmagnetic one, where ND completely disappears. The polarization of the transmitted beam is determined in the usual way. The neutrons were polarized perpendicularly to their initial momentum $\vec{P}_0 \perp \vec{k}$ and parallel to the measured momentum transfer $\vec{P}_0 \| \vec{q}$. This experimental geometry allowed us to estimate the inelastic contribution to the magnetic scattering (see below). A guide field of 0.5 Oe was applied to the sample.

In this experiment the SANS facility ''Vector'' installed at the reactor WWR-M (Gatchina) has been employed.[25] It contains 20 ^{3}He detectors supplied with the polarization analysis for each scattering channel. The initial polarization was better than 94%; intensity at the sample amounted to $I_0 = 7 \times 10^3$ n/(s cm^2), the incident wavelength was set to $\lambda = 10$ Å with $\delta\lambda/\lambda \approx 30\%$. The setup vector covers the range of the momentum transfer $3 \times 10^{-3} \leqslant q \leqslant 3 \times 10^{-2}$ Å^{-1} in a horizontal direction with a step equaling 3×10^{-3} Å^{-1}.

III. RESULTS AND DATA ANALYSIS

A. Constant-q temperature scan

The temperature dependence of the scattering intensity $I(T)$ at various momentum transfers is shown in Fig. 1. Two principal features are mentioned. First, a broad maximum centered near $T_C = 190$ K occurs which is associated with the critical neutron scattering. As momentum transfer q diminishes, this maximum shifts to lower temperatures. Since the position of the maximum changes with q the critical temperature cannot be unambiguously defined this way. However, the critical temperature determined below by the scaling analysis coincides with T_C obtained by susceptibility measurements.

Secondly, at temperatures below $T_m = 150$ K a growth of the SANS intensity is observed. The analysis of both q dependence of SANS intensity and diffraction measurements at temperature $T < T_m$ allows one to identify this phenomenon with the appearance and growth of bcc structure in the sample. The difference between T_C and T_m amounts to 40 K, and therefore one can neglect a direct influence of the structure phase transition upon the magnetic one.

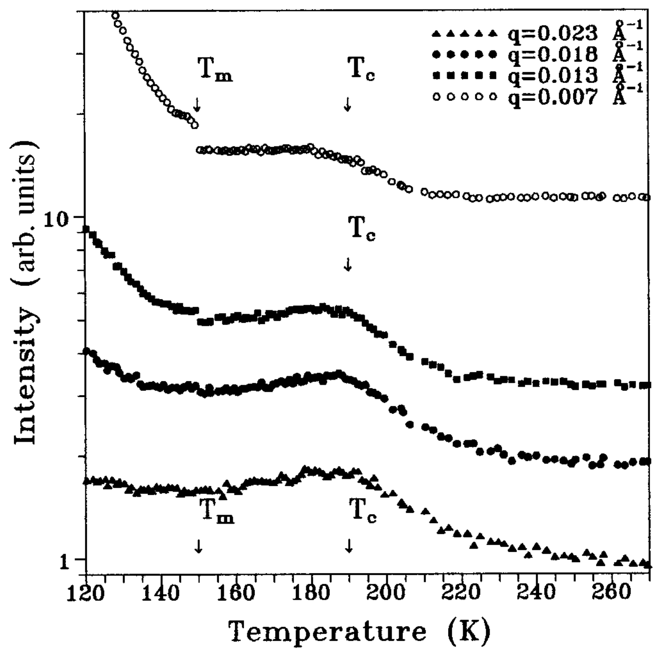

FIG. 1. The temperature dependence of SANS intensity at various momentum transfers q (0.007, 0.013, 0.018, 0.023 Å^{-1}). No background corrections have been made.

The temperature dependence of the polarization $P(T)$ and the intensity of the neutron scattering at $q = 0.013$ Å^{-1} is given in Fig. 2. The similar data for pure Fe shows that the beginning of depolarization coincides with the small-angle scattering maximum (see, for example, Fig. 3 in Ref. 21). This result is in agreement with the above-mentioned theoretical predictions for depolarization by critical

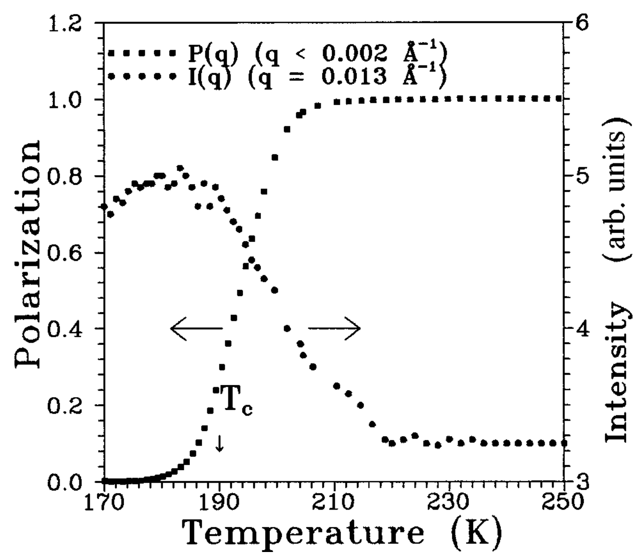

FIG. 2. The temperature dependence of the transmitted beam polarization and scattering intensity at momentum transfer $q = 0.013$ Å^{-1} for Invar FeNi alloy.

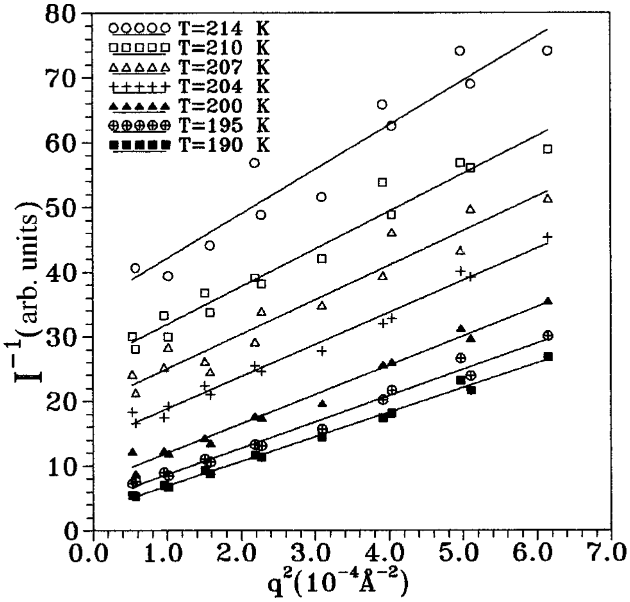

FIG. 3. The inverse intensity $I^{-1}(q)$ as a function of q^2 for $q < 0.03$ Å^{-1} at various temperatures $T > T_C$.

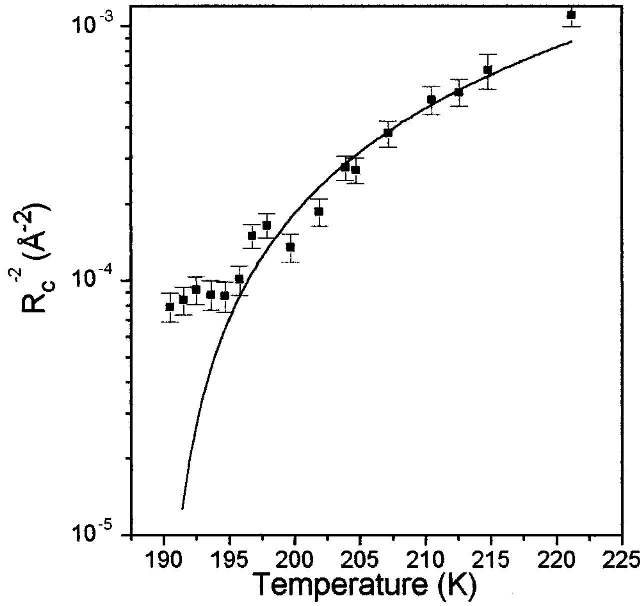

FIG. 4. The temperature dependence of square of inverse correlation length $\kappa^2 = R_c^{-2}(T)$.

fluctuations.[1–3] Namely, the depolarization by the critical fluctuations cannot exceed a few percent within the whole paramagnetic range ($T > T_C$).

The strong discrepancy between the results of experiments with pure Fe and with Invar FeNi alloy becomes now obvious. For FeNi alloy as well as for pure Fe the polarization of a transmitted beam pertains to its value at $T \gg T_C$ and is equal to the polarization of an incident beam P_0. As the temperature of the sample approaches the transition temperature, depolarization appears. However, in contrast with the iron sample, the polarization begins to diminish for the investigated FeNi alloy at temperature $T_0 \approx T_C + 25$ K and continues to fall within the range 215–180 K. At the Curie temperature ($T_C = 190$ K) polarization is equal to 25% of the incident one. According to the analysis given in Sec. I it corresponds to the appearance of the magnetic finite-size inhomogeneities in the temperature range $T_C \leqslant T \leqslant T_0$.

B. *q* dependence of the scattered intensity

In the data presented in Fig. 1 the nonmagnetic background has not been subtracted. Following the standard procedure we determine the q dependence of pure magnetic scattering, adopting as a background the spectra at the highest temperature $T = 270$ K.

The resulting inverse intensity $I^{-1}(q)$ is plotted in Fig. 3 as a function of q^2 at various temperatures so as to verify a validity for the Ornstein-Zernike expression:

$$I(q) = \frac{A}{q^2 + \kappa^2}, \tag{5}$$

where A and κ are the scattering amplitude and the inverse correlation length, respectively. We see that all data sets show the linear dependence of $I^{-1}(q)$ on q^2. More precise results are further obtained by fitting the experimental points with the function $I(q,\kappa)$ convoluted with the resolution function. The temperature dependence of parameters A and κ^2 is obtained from least-squares fits of Eq. (5) in the momentum transfer range $q \in (0.01-0.025)$ Å^{-1}.

The value of A increases monotonically with lowering of the temperature and has a weak maximum near T_C. The square of inverse correlation length $\kappa^2(T) = R_c^{-2}$ first decreases with lowering temperature at $T > 195$ [corresponding to parameter $\tau = (T - T_C)/T_C$ in the range (0.02–0.2)] and then becomes essentially constant (Fig. 4). The temperature dependence of κ^2 in this range obeys the power law $\kappa^2(\tau) = \kappa_0^2 \cdot \tau^{2\nu}$ with $\nu = 0.68 \pm 0.04$, $\kappa_0^2 = 0.014 \pm 0.002$ Å^{-2}. The calculated dependence $R_c^{-2}(T)$ with the parameters obtained from the fits is plotted in Fig. 4 by the full line.

The critical exponent of correlation length ν coincides within the error bars with the value found for the Heisenberg ferromagnets.[4,5] Extrapolating the above τ dependence of κ^2 on the temperatures below 195 K we get $\kappa^2 = 0$ at $T_C = 190$ K which coincides with the Curie temperature determined by the susceptibility measurements.[23] The fact that R_c^{-1} does not apparently vanish at T_C may be attributed to a distribution of T_C's in the sample. Meanwhile it could be an intrinsic feature of systems with a competition of the exchange interactions.[26]

In the previous analysis we assumed that the inelasticity of the scattering could be neglected. However we use the neutrons with a large wavelength $\lambda \approx 10$ Å and this assumption should be verified. Performing the analysis of the polarization of the scattered neutrons one can estimate the contributions of elastic and inelastic scattering to $I(q)$.[7] It is known[27,28] that in the case of small-angle quasielastic scattering on magnetic fluctuations, the polarization of the scattered neutrons P changes its sign without any depolarization if the initial polarization $\vec{P}_0$ is along the scattering vector $\vec{q}$. It is a consequence of the expression

$$\vec{P} = -\vec{e} \cdot (\vec{e} \cdot \vec{P}_0), \quad \vec{e} = \vec{q}/q, \tag{6}$$

where $\vec{q}$ is the vector of the momentum transferred. We have measured the final polarization in the geometry when

$\vec{P}_0 \| \vec{q} \perp \vec{k}$, and have found that $P = -\vec{P}_0 \cdot (1 \pm 0.05)$ for all temperatures above T_C. It means that the inelastic contribution does not exceed 5% of the total magnetic scattering and lies in the error limits. As a result we conclude that the quasistatic approximation is valid in our case.

The theoretical estimate confirms the experimental results. Indeed, the characteristic energy of the critical fluctuations in ferromagnets for $q > \kappa$ is given by Refs. 29,30: $\Omega(q) = T_C (q \cdot a)^{5/2}$, where a is of the order of the interatomic distance. For $T_C \approx 200$ K ≈ 20 meV and intermediate values of q $(q \cdot a)^{5/2} \approx 10^{-3}$, we have then $\Omega(q) \approx 2 \times 10^{-2}$ meV $\ll E_n \approx 1$ meV. As a result, we see that inelasticity of the critical scattering is small as compared with the elastic contribution, in spite of the rather small neutron energy.

C. The mean free path of the neutrons

The simplest analysis of the obtained data can be carried out using the concept of the mean free path of the neutrons scattered in the ranges $q \geq k\Psi = q_{\min}$ and $q \leq k\Psi$ that correspond to inhomogeneities of a size $R \leq 1/q_{\min}$ and $R \geq 1/q_{\min}$, respectively.

We saw above that in the case $\vec{P} \perp \vec{k}$ the cross section σ_Ψ for the magnetic scattering in the range $q \leq k\Psi$ may be determined by Eq. (1). This equation defines also the mean free path of neutrons in magnetic media for the scattering on large-scale inhomogeneities $(R \geq 1/q_{\min})$ as $l_\Psi = (3/2 \cdot \sigma_\Psi N_0)^{-1}$.

At the same time the transmission coefficient $I(T)/I_0$ can be considered to be a result of absorption and small-angle scattering off the angular width of the transmitted beam, where $I(T)$ and I_0 are the intensity of neutrons passed through the sample and intensity of the incident beam. We can attribute the whole temperature dependence of the transmission coefficient $t(T) = I(T)/I(270\ \text{K})$ to the critical magnetic scattering off the central detector (here $T = 270$ K is the highest paramagnetic temperature of the measurements, where the magnetic scattering disappears). A corresponding cross section is denoted as $\sigma_{(1-\Psi)}$. As a result we have

$$t(T) = I(T)/I(T_p) = \exp(-\sigma_{(1-\Psi)} \cdot N_0 L), \tag{7}$$

and we can determine $\sigma_{(1-\Psi)}$ and the corresponding mean free path $l_{1-\Psi} = (\sigma_{(1-\Psi)} N_0)^{-1}$ of neutrons in magnetic media for small-scale correlations $R \leq 1/q_{\min}$.

The values L/l_Ψ, $L/l_{1-\Psi}$ are numbers of scattering events $N_1(R > 1/q_{\min})$ and $N_2(R < 1/q_{\min})$ in the sample of the thickness L, respectively. The temperature dependence of both values is shown in Fig. 5. From this figure it is seen that the values N_1 and N_2 have different temperature dependences. As temperature decreases, N_2 increases weakly, while the temperature evolution of N_1 is similar to that of N_2 at the temperature $T \gg T_C$ and has strong growth at temperature $T \leq T_0 \approx 215$ K. The dramatic growth of N_1 is observed as temperature diminishes from T_0 to T_C and the strong scattering on the large-scale inhomogeneities becomes evident.

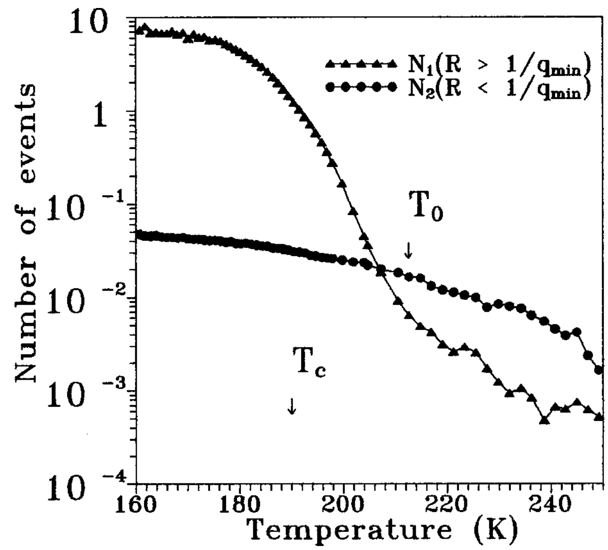

FIG. 5. The temperature dependence of the numbers of scattering events $N_1(R \geq 1/q_{\min})$ and $N_2(R \leq 1/q_{\min})$ along the sample length L. T_0 is temperature where the depolarization appears.

IV. DISCUSSION: TWO LENGTH SCALES

In this section we will demonstrate the coexistence of two length scales for magnetic fluctuations above T_C. In Fig. 6 we present the temperature dependence of the correlation length R_c extracted from scattering data. It is seen that correlation length R_c increases smoothly as T decreases in value from about 30 ± 10 Å at $T = 220$ K up to 120 ± 10 Å at $T = T_C$.

Simultaneously from the neutron depolarization data we establish the size of magnetic clusters. Using Eq. (4) one can determine the product $\langle B^2 \rangle R_d$ only. Therefore we should make some rather arbitrary assumption about the value $\langle B^2 \rangle$ to roughly estimate R_d. This approach is justified since our task is to demonstrate that $R_d \geq R_c$. According to Ref. 17 the magnetic moment per atom in the alloy $Fe_{75}Ni_{25}$ is equal to $0.4\mu_\beta$ at $T = 0$, and taking into account $N_0 \approx 10^{23}$ we obtain

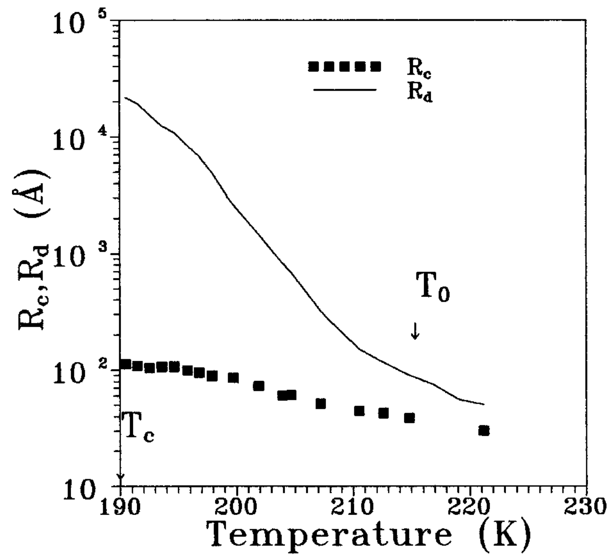

FIG. 6. The temperature dependence of correlation radius R_c and roughly estimated size of inhomogeneities R_d.

$B(0)=4\pi M(0)\approx 4$ kG. Substituting $L=0.13$ cm and $B=B(0)/2$ into Eq. (4), the temperature dependence of R_d is calculated and is shown as a full line on Fig. 6.

It is clear that R_d obtained in this way may be considered only as a lower boundary and no possibility exists to obtain the real temperature dependence of magnetic inhomogeneity size. Nevertheless, the obtained size is around 10^3-10^5 Å, that is by two orders of magnitude larger than critical correlation length over all the temperature range $T\geqslant T_C$. Therefore the polarization data have been interpreted as a result of the appearance of a second, larger scale of inhomogeneity $R_d(T)$ as compared to the critical correlation length $R_c(T)$. At the same time, as we mentioned above, the structures of inhomogeneities appropriate for both scales strongly differ from each other. The low-scale correlations are described by the Ornstein-Zernike expression: $(1/r)\cdot\exp(-r/R_c)$. At the same time, as it is shown in Sec. I the observed depolarization may be explained if the large-scale correlations have a finite-size shape presumably the Ornstein-Zernike squared, which in real space is given by $\exp(-r/R_c)$. As a consequence of that we believe that the mechanism of the appearance of both types of inhomogeneities is different. In summary, we demonstrate the coexistence of two length scales of magnetic correlations above T_C in the intrinsically disordered system using neutron depolarization and small-angle neutron scattering measurements.

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[1] S. V. Maleyev and V. A. Ruban, Zh. Eksp. Teor. Fiz. **62**, 416 (1972) [Sov. Phys. JETP **35**, 222 (1972)].
[2] S. V. Maleyev, J. Phys. C **7**, 23 (1982).
[3] S. V. Maleyev and V. A. Ruban, Fiz. Tverd. Tela (Leningrad) **62**, 416 (1976).
[4] V. V. Runov, S. L. Ginzburg, B. P. Toperverg, A. I. Okorokov, A. D. Tret'yakov, and E. I. Mal'stev, Zh. Eksp. Teor. Fiz. **67**, 181 (1988).
[5] T. Sato, T. Ando, T. Watanabe, S. Itoh, Y. Endoh, and M. Furusaka, Phys. Rev. B **48**, 6074 (1993).
[6] Po-zen Wong, S. von Molnar, T. T. Palstra, J. A. Mydosh, H. Yoshizawa, S. M. Shapiro, and A. Ito, Phys. Rev. Lett. **55**, 2043 (1985).
[7] S. R. Andrews, J. Phys. C **19**, 3721 (1986).
[8] G. Shirane, R. A. Cowley, M. Matsuda, and S. M. Shapiro, Phys. Rev. B **48**, 15 595 (1993).
[9] T. R. Thurston, G. Helgesen, D. Gibbs, J. P. Hill, B. D. Gaulin, and G. Shirane, Phys. Rev. Lett. **70**, 3151 (1993).
[10] T. W. Ryan, R. J. Nelmes, R. A. Cowley, and A. Gibaud, Phys. Rev. Lett. **56**, 2704 (1986).
[11] U. J. Nicholls and R. A. Cowley, J. Phys. C **20**, 3417 (1987).
[12] K. Hirota, G. Shirane, P. M. Gehring, and C. F. Majkrzak, Phys. Rev. B **49**, 11 967 (1994).
[13] N. Sato, N. Aso, K. Hirota, T. Komatsubara, Y. Endoh, S. M. Shapiro, G. H. Lander, and K. Kakurai, Phys. Rev. B **53**, 14 043 (1996).
[14] M. Altarelli, M. D. Nunez-Regueiro, and M. Papoular, Phys. Rev. Lett. **74**, 3840 (1995).
[15] M. Papoular, M. D. Nunez-Regueiro, and M. Altarelli, Phys. Rev. B **56**, 166 (1997).
[16] R. A. Cowley, Phys. Scr. **T66**, 24 (1996).
[17] M. Matsui and S. Chikazumi, J. Phys. Soc. Jpn. **45**, 485 (1978).
[18] M. F. Collins, V. J. Minkievicz, R. R. Nathans, L. Passal, and G. Shirane, Phys. Rev. **179**, 417 (1969).
[19] V. J. Minkievicz, M. F. Collins, R. Nathans, and G. Shirane, Phys. Rev. **182**, 624 (1969).
[20] A. Z. Patashinskii and V. L. Pokrovskii, *Fluctuation Theory of Phase Transition* (Pergamon, Oxford, 1979).
[21] A. I. Okorokov, V. V. Runov, and A. G. Gukasov, Nucl. Instrum. Methods **157**, 487 (1978).
[22] A. I. Okorokov, V. V. Runov, A. G. Gukasov, and G. M. Drabkin, Izv. Acad. Nauk SSSR, Ser. Fiz. **42**, 1770 (1978).
[23] K. Ullakko (private communication).
[24] O. K. Antson, A. P. Bulkin, P. E. Hiismaki, T. K. Korotkova, V. A. Kudryashev, H. S. Kukkonen, V. G. Muratov, H. O. Poyry, A. F. Shchebetov, A. T. Tiitta, V. A. Trunov, and V. A. Ul'yanov, Physica B **156&157**, 567 (1989).
[25] S. V. Grigoriev, V. V. Runov, A. I. Okorokov, A. D. Tret'yakov, O. A. Gubin, and G. P. Kopitsa (unpublished).
[26] G. Aeppli, S. M. Shapiro, R. J. Birgeneau, and H. S. Chen, Phys. Rev. B **28**, 5160 (1983).
[27] O. Halpern and M. Johnson, Phys. Rev. **55**, 898 (1939).
[28] S. V. Maleyev, V. V. Runov, A. I. Okorokov, and A. G. Gukasov, J. Phys. (Paris), Colloq. **43**, 83 (1982).
[29] P. C. Honenberg and B. I. Halperin, Rev. Mod. Phys. **49**, 435 (1977).
[30] S. V. Maleyev, in *Physics Reviews*, edited by I. M. Khalatnikov (Harwood Academic, Chur, 1987), Vol. 8, p. 323.