A study of the critical factorization of ternary dynamical spin correlations by the scattering of polarized neutrons in Fe above T_c

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It is shown experimentally that in the critical region $qR_c > 1$ the temperature dependence of the ternary dynamical spin correlator agrees with the predictions of the Polyakov-Kadanoff operator algebra generalized to dynamical correlations.

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The higher correlators of the order parameter play an extremely important role in the physics of critical phenomena. In particular, they govern the interaction processes between critical fluctuations, various types of nonlinear effects, etc. In the theory of static scaling,[1] for example, Polyakov[2] has formulated a correlation-coalescence rule, which determines the asymptotic properties of the coupling amplitude for critical fluctuations having highly different momenta. Analogous results were obtained by Kadanoff[3] in the language of the algebra of the fluctuating quantities. According to those authors,[2,3] a critical factorization of the momentum dependence of the many-particle correlators occurs in this case. For example, if one of the momenta q appearing in the correlator is large in comparison with the rest, then the dependence on this momentum can be factored out at q^t in the region $q \gg \kappa = R_c^{-1}$, where $R_c \sim \tau^{\nu}$ is the correlation length, $\tau = (T - T_c)/T_c$, $\nu \simeq 2/3$, $t = 1/\nu - 1 - \eta \simeq 1/2$, and η is the parameter introduced by Fisher. In spite of the fundamental nature of this result, it has never, as far as we know, been verified experimentally, for lack of suitable experiments.

The special role of the higher spin correlators, both even and odd, in the critical dynamics of ferromagnets was pointed out in Ref. 4. In that paper it was hypothesized that the same factorization applies to ternary dynamical vertices that holds in the static case. A way of studying the ternary correlations experimentally in zero magnetic field **H** was also proposed in Ref. 4; the corresponding experiment was reported in Ref. 5. Finally, it was shown in Refs. 6 and 7 that it is more promising to study the ternary correlations using the right-left asymmetry of the scattering of polarized neutrons in ferromagnets above T_c in a weak magnetic field. This effect was discovered in Ref. 7 in the scattering of neutrons in iron. A way of checking the critical factorization was also proposed in Ref. 6.

The statistical accuracy achieved in Ref. 7 and the interval over which the parameters q and τ were varied turned out to be insufficient for reliable verification of the critical factorization hypothesis. We therefore undertook further studies at large $q(k\theta = 0.1\ \text{Å}^{-1})$ and over a wide range of τ on the D-7 apparatus of the high-current

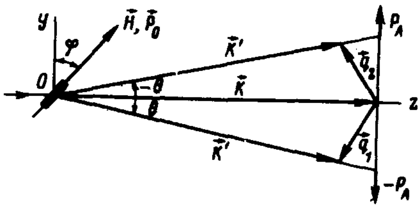

FIG. 1. Kinematic diagram of the experiment.

reactor at the Laue-Langevin Institute.Here we report the results of these studies. The method we used is essentially as follows. The magnetic scattering intensity of polarized neutrons at angle θ in a ferromagnet above T_c in a weak magnetic field **H** is, up to a factor,[6]

$$I(\theta, \mathbf{H}) \sim \int \frac{d\omega}{\omega} \frac{k'}{k} \left\{ \operatorname{Im} G^{(1)}(q, \omega) + g\mu(\mathbf{He})(\mathbf{eP}_0) \operatorname{Im} G^{(3)}(q, \omega) \right\}, \tag{1}$$

where $\omega = E' - E$ is the energy transfer in the scattering, $\mathbf{q} = \mathbf{k}' - \mathbf{k}$ is the momentum transfer, **k**, **k**′, **E**, and **E**′ are the momentum and energy of the neutrons before and after the scattering, $\mathbf{P}_0$ is the initial polarization of the neutrons, $\mathbf{e} = \mathbf{q}q^{-1}$, and $G^{(1)}$ and $G^{(3)}$ are the two- and three-spin Green's functions. If the vector **H** lies in the scattering plane (see Fig. 1) and the angle between **H** and the perpendicular to the direction of **k** is given by φ, then for $\theta \ll 1$, $\omega \ll E$ these formulas imply that

$$\Delta I_\theta = I(\theta, H) - I(-\theta, H) \sim P_0 H \sin 2\varphi \int d\omega \frac{2E\theta}{\omega^2 + (2E\theta)^2} \operatorname{Im} G^{(3)}(q, \omega). \tag{2}$$

Thus, if critical factorization holds for $G^{(3)}$, then for the entire critical region $k\theta \gg \kappa$ the temperature dependence of $\Delta I_\theta(\tau)$ should be governed by the temperature dependence of $G^{(3)}(\tau)$, i.e., ΔI_θ should be proportional to τ^{-x}, where $x \simeq 2/3$ (see Ref. 6).

The measurements were made primarily on an iron sample in a beam of polarized neutrons, in the temperature range $T - T_c = 1$–100 K. As in Ref. 7, the constant-temperature vessel containing the sample was placed in a horizontal **H** field between the poles of an electromagnet, whose axis was directed at an angle φ to the perpendicular to the beam axis in the scattering plane. Measurements were made at angles $\varphi = 35°$ and $\varphi = 22°$. According to (2), the magnitude of the effect increases with increasing field. A linear dependence of $\Delta I_\theta(H)$, however, holds only in the weak-field region: $g\mu H < g\mu H_c \simeq T_c \tau^{5/3}$ (Ref. 6). Here, as in Ref. 7, the value of H_c is given by the intersection of the $\Delta I_\theta(H)$ curves extrapolated from the strong- and weak-field regions, and the working field was chosen to lie in the range $(0.5$–$0.7)H_c$. In the investigated temperature range the working field varied from 14 to 2650 Oe. The result was expressed in the form $\Delta I/H = f(\tau)$, where $\Delta I = \Delta I_\theta(+P_0) - \Delta I_\theta(-P_0)$.

Figure 2 shows this function $f(\tau)$ in a logarithmic scale for two values of the angle φ. It is seen that the power-law behavior $f(\tau) \sim \tau^{-x}$ holds in the region $\tau < 0.014$. An estimate puts the critical region at $\tau < 0.04$, where the value of $k\theta$ used in the experiment is greater than κ. The weak temperature dependence of the scattering cross section in the critical region that one anticipates from the theory is observed for $\tau < 0.025$ (see Fig. 3), from which we conclude that for $\tau \leqslant 0.014$, at which $k\theta/\kappa \geqslant 2$, the

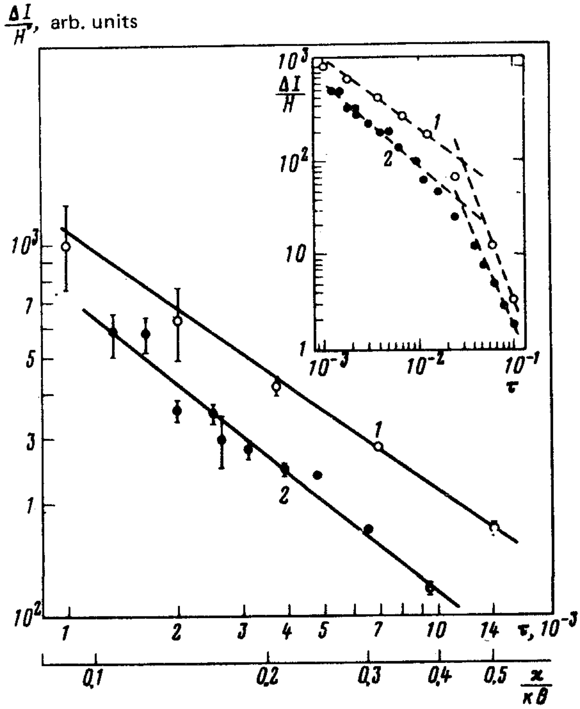

FIG. 2. Temperature dependence of the asymmetry $\Delta I/H$ of the critical scattering of polarized neutrons; $\Delta I = I(\theta,P_0) - I(-\theta,-P_0) + I(-\theta,P_0) - I(\theta,P_0)$.

asymptotic condition $k\theta \gg \kappa$ is sufficiently well satisfied. The temperature dependence of $\Delta I(\tau)/H$ over a wide range of τ is shown in the inset in Fig. 2. The curves demonstrate the transition from the hydrodynamic to the critical regime at $\tau = 0.03$–0.04,

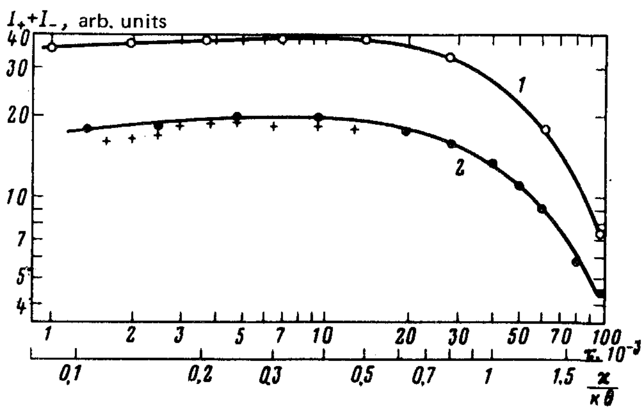

FIG. 3. Temperature dependence of the intensity $I_+ + I_- = I(\theta,P_0) + I(\theta,-P_0)$ of the critical scattering of neutrons for $k\theta = 0.1$ Å^{-1} 1 — $\varphi = 35°$, $H \leqslant (0.5$–$0.7)H_c$; 2 — $\varphi = 22°$, $H \ll H_c$(●), $H \lesssim H_c$(+).

where $k\theta = \kappa$. In the region $\tau < 0.014$ the average value of the exponent x for the two values of φ, obtained by the least-squares method, is $\langle x \rangle = 0.76 \pm 0.05$. If x is determined from the interval $\tau < 0.008$, in which the condition $k\theta \gg \kappa$ is better satisfied, then $\langle x \rangle = 0.67 \pm 0.07$, and for $\tau < 0.006$ one obtains $\langle x \rangle = 0.58 \pm 0.10$. We have thus verified experimentally the hypothesis of critical factorization for ternary dynamical correlations, obtaining a value of the exponent for the temperature dependence of $G^{(3)}(\tau)$ that is close to the theoretical value.

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