Investigation of metamagnetic transition in $FeCl_2$ with polarized neutrons in a wide temperature range

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It was observed in[1] that a metamagnetic transition causes depolarization of polarized neutrons passing through single-crystal $FeCl_2$. In the present study we use this phenomenon to investigate the transition in a wide temperature interval $1.3 \leqslant T \leqslant 90$ °K and in a wide range of magnetic fields $1 \leqslant H \leqslant 60$ kOe.

The results of experiments with magnetization along the [0001] axis are shown in Fig. 1. The experimental setup and the sample dimensions are indicated in the figure. The sample was an assembly of three single-crystal plates each 0.5 mm thick. We used such plates because their quality, from the point of view of perfection of the crystal structure, was better than that of thick samples. We see that the function $R = f(H)$ has a minimum corresponding to the maximum depolarization, and that the magnitude of the minimum and its position in the magnetic field depend on the temperature. The field at which the depolarization begins does not depend on the temperature. Taking into account the connection between the depolarization and the magnetic susceptibility,[2] we can set the position of the depolarization maxima in correspondence with the susceptibility maxima. It appears therefore that it is more correct to determine the critical field of the metamagnetic transition in accord with the minimum of R. The function $H_c(T)/H_c(4.2) = f(T) \approx M(T)/M(4.2)$ is plotted in Fig. 2. Our experimental points lie somewhat lower than the theoretical plot of $M(T)/M(4.2)$.[3] This difference can be attributed to the inaccurate determination of $H_c(T)$, owing to the large widths of the minima. This method of determining the critical field H_0 differs from the method of[4].

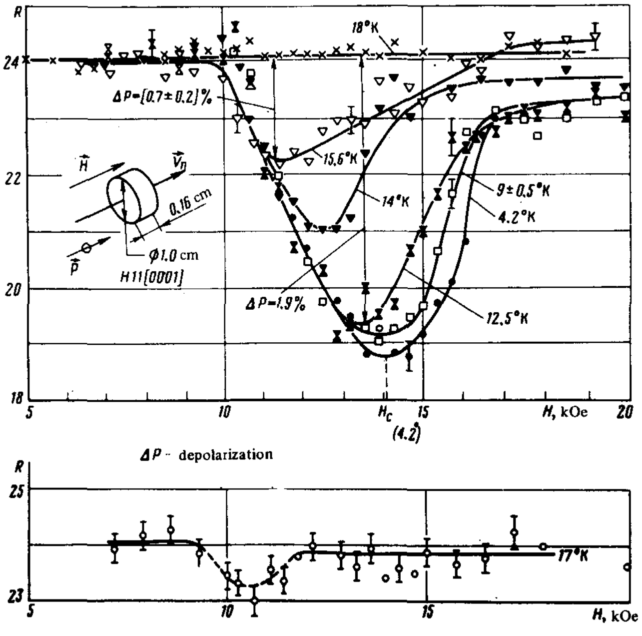

FIG. 1. Dependence of the polarization ratio R of a neutron beam on the value of the magnetic field H ($H \parallel [0001]$) at various temperatures. A decrease of R corresponds to a decrease of the polarization P. $R(4.2°) = f(H) = R(1.3°)$.

It is seen from Fig. 1 that at $T > 17°$ the depolarization of the neutrons vanishes and it can be assumed that this corresponds to T^* of[4]. The large shift in the direction of lower temperatures in comparison with T_N can be attributed to the influence of the magnetoelastic coupling. Favoring this explanation are the results of[5], where an anomaly of the thermal-conductivity coefficient was observed at 17 °K.

The results of an investigation with magnetization in the perpendicular direction are shown in Fig. 3. A characteristic feature of $R = f(H)$ is the small depolarization at $H < 10$ kOe, pointing to the presence of a magnetic moment with components perpendicular to the magnetic field, and of a unique domain structure with magnetization parallel and antiparallel to [0001]. The nonmonotonic variation of $R(H)$ near the rapid decrease can be attributed here to spatial spin resonance[6] on the domain structure, transverse to the field, of the entire sample or of part of the sample. From the relation $\pi v/\delta = \gamma_H H_p$, where δ is the dimension of the domain and γ_H is the gyromagnetic ratio of the neutron, we get the estimate $\delta \sim 0.01$ cm.

A possible cause of the appearance of the magnetic moment may be imperfections of the crystal, which produce an anisotropic stress field in the volume of the crystal. These stresses give rise to a magnetic moment analogous to the longitudinal weak ferromagnetic moment. Favoring this analogy are the results of experiments at temperatures above the Néel temperature T_N. It turns out that states with inhomogeneous distribution of the magnetization can arise in a magnetic

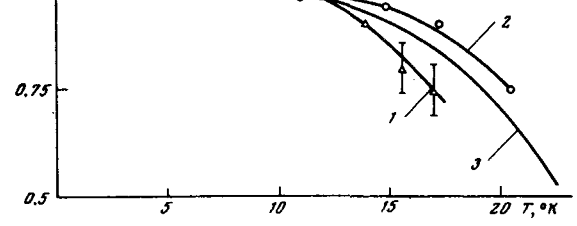

FIG. 2. Temperature dependence of the critical field H_c and of the sublattice magnetization M. $H_c(T)$ and $M(T)$ are normalized to the values at $T = 4.2$°K. Curve 1—present results for $H_c(T)/H_c(4.2)$, 2—results of[4], 3—theoretical plot of $M(T)/M(4.2)$.[3]

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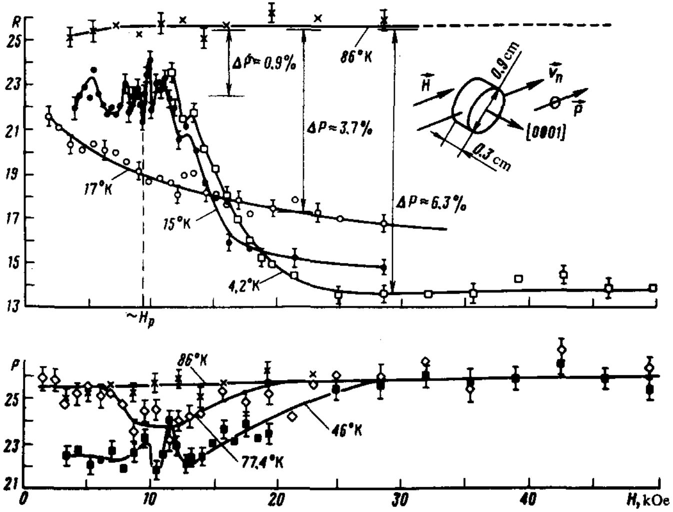

FIG. 3. Dependence of R on the magnetic field $H \perp [0001]$ at various temperatures.

field, and these states cause depolarization of the neutrons up to 80 °K.

Another characteristic feature of the results shown in Fig. 3 is the presence of a sharp decrease of R at $H > 10$ kOe, which takes place only at $T < 17$ °K. The decrease of R at $H > 10$ kOe can be due to disturbance of the stability of the domain structure parallel to [0001], and to a transition to a state with arbitrary orientation of the magnetic moment in the plane perpendicular to H. The latter structure is stable in fields $20 \leqslant H \leqslant 60$ kOe at 4.2 °K. Assuming that at $H > 10$ kOe the domain dimension remains essentially unchanged ($\delta \sim 0.01$ cm), and that the orientation of the magnetic moment changes, we can use the formula[7]

$$P = P_0 e^{-\frac{1}{2}\gamma_n^2} \frac{\langle 4\pi M_\perp \rangle^2}{v^2} \delta d$$

to estimate the magnetic moment $M_\perp$ perpendicular to H.

At $P \sim 1$ and $P_0 \sim 1$ we obtain $\Delta P = P_0 - P \ll 1$.

$$\Delta P \sim \frac{1}{2} \gamma_n^2 \frac{\langle 4\pi M_\perp \rangle^2}{v^2} \delta d \ll 1$$

is the change of the polarization.

Taking $\Delta P = 6.3\%$ from Fig. 3, we obtain $M_\perp \sim 6$ g/cm^3.

The domain structure can provide magnetization-reversal centers in the metamagnetic transition and alter the dynamics of this transition substantially.

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[1] V. A. Trunov, A. Z. Yagud, A. I. Egorov, R. P. Dmitriev, and V. A. Ul'yanov, ZhETF Pis. Red. **14**, 223 (1971) [JETP Lett. **14**, 146 (1971)].
[2] B. P. Toperverg, Fiz. Tverd. Tela **12**, 3028 (1970) [Sov. Phys.-Solid State **12**, 2445 (1971)].
[3] R. Alben, J. Phys. Soc. Japan **26**, 261 (1969).
[4] J. S. Jacabs and P. E. Lawrence, Phys. Rev. **164**, 866 (1967).
[5] G. Laurence and D. Petitgrand, Phys. Rev. **B8**, 2131 (1973).
[6] G. M. Drabkin, V. A. Trunov, and A. F. Shebetov, ZhETF Pis. Red. **10**, 527 (1969) [JETP Lett. **10**, 336 (1969)].
[7] O. Halpern and T. Holstein, Phys. Rev. **59**, 960 (1971).