Anomalous behavior of the effective field at Fe^{57} nuclei in an elastically-stressed Invar alloy

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A reversible change of the hyperfine structure of the Mössbauer spectrum of the Invar alloy Fe_3Pt under the influence of uniaxial elastic tension stresses has been observed.

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Invar alloys have various anomalous properties, including a noticeable influence of the elastic stresses on the magnetization. It has been suggested that the elastic stresses, owing to the strong change in the exchange interaction, exert an additional correlating action on the spins within the regions of spontaneous magnetization, thus changing the total magnetization. Evidence of large "slope" of the resultant exchange integral is taken to be the anomalous dependence of the Curie temperature T_C of Invars on external elastic stresses. The cause of this strong dependence, however, is still not clear enough.[1] The Invar properties manifest themselves particularly strongly in the alloy close to Fe_3Pt in composition. This alloy was therefore used to investigate the influence of uniaxial elastic tension stresses σ on the effective fields, the values of which are directly connected with the magnetization.

We investigated first alloys quenched from different temperatures, for the purpose of determining the influence of the degree of long-range order S on the Mössbauer spectra. It turned out that the Mössbauer change shape in succession from a single line (quenching from 1000 °C) to a sum of a singlet and a spectrum with hyperfine structure hfs (quenching from lower temperatures T_{qu}). The Mössbauer spectrum of a sample with $S = 0.9$ (650 °C) is a sextet with a line-intensity ratio close to that typical of ferromagnetic foils. According to[2], the alloy Fe_3Pt has an order of the same type as Cu_3Au with ferromagnetic orientation of the atomic spins in both the ordered and disordered states.

Figures 1 and 2 show the Mössbauer spectra of the sample (720 and 755 °C) to which the largest stresses σ_{max} were applied in our measurements, but not exceeding the elastic limit. In the spectrum of the (720 °C) sample, besides a change in the ratio of the hfs line intensities due to the partial reorientation of the regions of the spontaneous magnetization along the direction of the action of σ (the magnetostriction of the Fe_3Pt alloy is positive[1]), we observed an increase of the average field $\langle H_p \rangle$ at the Fe^{57} nuclei, $\langle \Delta H_p \rangle / \langle H_p \rangle = (8.5 \pm 1.0) \times 10^{-2}$ (Fig. 1b), this being larger by almost three orders of magnitude than for pure iron.[3] For the other sample (755 °C) (Fig. 2b), the fraction of the ferromagnetic "phase" increased substantially at σ_{max}, the resolution of the spectrum improved, and at the same time, the fraction of the paramagnetic "phase" decreased, i.e., the area of the hfs spectrum has been decreased as a result of the decrease in the area of the singlet. Just as for the first sample, $\langle H_p \rangle$ in-

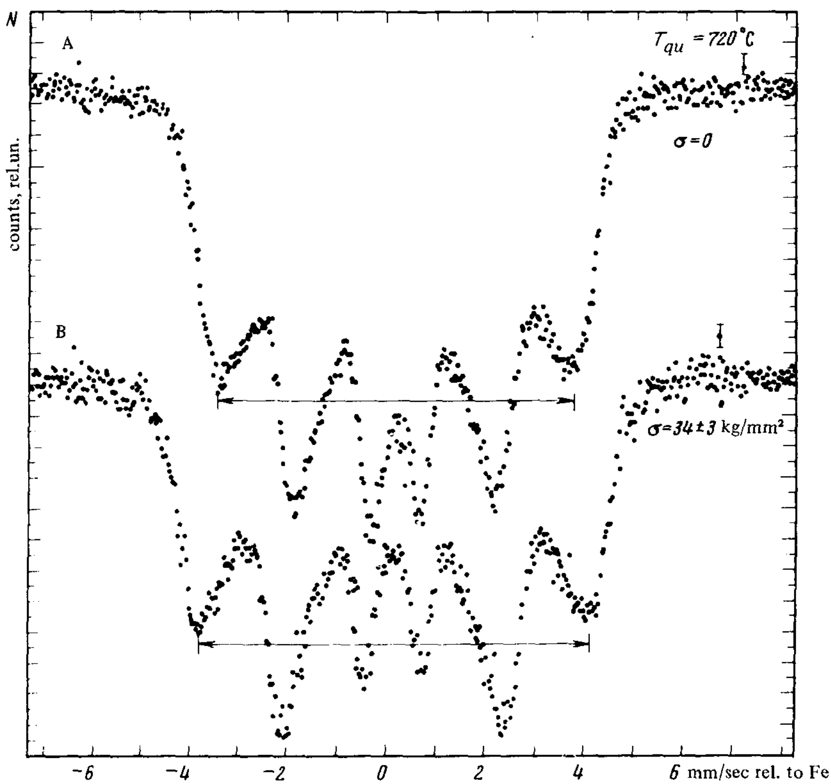

FIG. 1. Change in the effective field $\langle H_p \rangle$ at the Fe^{57} nuclei in an Fe_3Pt sample (quenched from 720 °C) with $S = 0.6 \pm 0.1$ under the influence of uniaxial tension: A – $\sigma = 0$; $\langle H_p \rangle = 227 \pm 1$ kOe; B—$\sigma = 34 \pm 3$ kg/mm²; $\langle H_p \rangle = 250 \pm 1$ kOe.

creased, as can be seen from a comparison of Figs. 2(c) and 2(d). These effects decreased regularly for $\sigma_i < \sigma_{max}$ and when the stresses were removed ($\sigma = 0$) the initial Mössbauer spectra were fully restored (Figs. 1a and 2a). For identical σ, the increase of $\langle H_p \rangle$ is much smaller for the most ordered sample used in our measurements (650 °C). The parameters of the Mössbauer spectra (the value of $\langle H_p \rangle$, the fraction of the ferromagnetic "phase") at σ_{max} correspond to those of the Mössbauer spectra of the most ordered samples with $\sigma = 0$.

The observed influence of σ on the change of the form of the Mössbauer spectrum can be explained from the point of view of superparamagnetism, the existence of which is verified in our case by the complete agreement (at $\sigma = 0$) between the spectra of samples having different quenching temperatures, on the one hand, and the Mössbauer spectra of superparamagnetic single-domain particles.[4,5]

The superparamagnetic behavior is determined by the relaxation time τ, for which, without allowance for the weak interaction between the regions, we can write

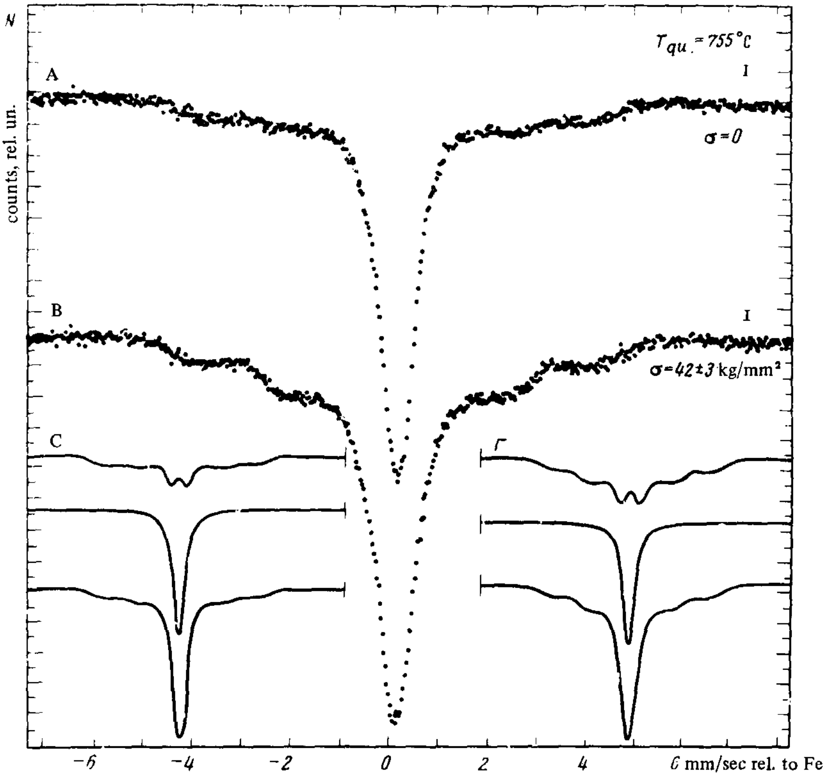

FIG. 2. Change of the Mössbauer spectrum of an Fe_3Pt sample (quenched from 755 °C) with $S=0$ under the influence of uniaxial tension: A—$\sigma=0$; B—$\sigma=42\pm3$ kg/mm^2; C and D show the spectra A and B respectively, resolved (scale 2 : 1) into the "ferromagnetic" component (upper curve) and the "paramagnetic" component (middle curve), the lower curve being their sum. The uniaxial tension changes the ratio of the areas of the "ferromagnetic" and "paramagnetic" components from 0.85 at $\sigma=0$ to 1.45 at $\sigma=42\pm3$ kg/mm^2.

$$\tau = \tau_0 \exp(KV/T), \qquad (1)$$

where τ_0 is the period of the Larmor precession in the effective anisotropy field; K is the maximum density of the effective anisotropy energy; V is the volume of the single-domain region with uniform rotation of the summary magnetic moment; T is the temperature in energy units. Thus, τ determines the dynamic behavior of $\langle H_p \rangle$ at the Fe^{57} nuclei, as is manifest in the shape of the Mössbauer spectra. It follows from (1) that τ depends very strongly on K, V, and T. In our measurements of σ the parameter K ($T=$ const) is changed by an amount equal to the magnetoelastic anisotropy, which is proportional to σ, and this leads to an increase of τ and to the appearance of an anomalous change of the effective field at the Fe^{57} nuclei in the elastically-stressed Invar alloy. It should be noted that σ cannot change the character of the environment of the atoms in the sample, meaning that it cannot influence the concentration inhomogeneities.

Thus, it can be assumed the quenching temperature and the quenching rate of the Invar Fe_3Pt alloy determine the number of disturbances to the regularity of the crystal lattice of the alloy (dislocation loops, vacancies, grain boundaries, pores, etc.), influencing by the same token the dimensions of V and the disperseness of the regions in which the regularity of the lattice is not violated. The lattice defects and various possible nonmagnetic impurities violate the exchange interaction between the regions, in which the magnetic moments of the atoms form a definite structure. At sufficiently high temperatures and quenching rates, the dimensions of the regions can be lower than the critical dimensions $\sim 10^{-6}$ cm which determine the single-domain state, and their superparamagnetic behavior becomes possible. The usually observed change of T_C as a function of the heat treatment is only the consequence of the change of the transition (blocking) temperature T_b from the ferromagnetic state to the superparamagnetic states, and the variations of V and K from (1), including those under the influence of σ, influence T_b and consequently the value of the "effective" T_C. The magnetostriction probably also depends on the relaxation processes, if for no other reason, because at small τ the magnetostriction-deformation wave cannot follow the rotation of the vector of the total magnetization.

[1]K. P. Belov, Uprugie teplovye i élektricheskie yavleniya v ferromagnetikakh (Elastic Thermal and Electric Phenomena in Ferromagnets) Moscow, 2nd ed., 1957.
[2]A. Z. Men'shikov, Yu.A. Dorofeef, V.A. Kazantsev, and S.K. Sidorov, Fiz. Metal. Metalloved. **38**, 505 (1974).
[3]R.C. Mercader and T.E. Granshow, J. Phys. F **5**, 124 (1975).
[4]M. Natta and L. Billard, Solid State Commun. **13**, 47 (1973).
[5]V.A. Makarov, Proc. MKM **3**, 154 (1973).