Magnetic hysteresis of the hyperfine field at impurity tin in metallic holmium

P. V. Bogdanov, S. K. Godovikov, M. G. Kozin, and V. S. Shpinel'

Nuclear Physics Institute of the Moscow State University
(Submitted July 13, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **26**, No. 4, 327–330 (20 August 1977)

Cancellation of the internal and hyperfine fields at the Sn^{119} nuclei in Ho has been observed following application of an external magnetic field, and hysteresis of the hyperfine interaction was observed after the field was removed. A connection is established between these phenomena and the realignment and "freezing" of the magnetic structure.

PACS numbers: 75.60.Ej, 76.60.−k

We report here an investigation, by the nuclear gamma resonance (NGR) method, of residual phenomena in hyperfine interactions produced at Sn^{119} nuclei in the region of the helicoidal magnetic structure when the external magnetic field is decreased to zero.

The experiment was carried out on polycrystalline Ho powder with 0.5 at.% Sn^{119} added. The sample in the form of a disk of 30 mm diameter was placed in a cryostat with a superconducting solenoid that produced a longitudinal 40-kOe magnetic field. The temperature at the sample was 25 K. The NGR spectra obtained prior to application of the external field (1), in the field (2), and after turning the field off (3) are shown in Fig. 1. The computer reduction of the spectra was based on the model of two sextets of Lorentz lines. The parameters were the fields H_1 and H_2 at the nuclei, the isomeric shifts δ_1 and δ_2, the sextet intensities A_1 and A_2, and the line width Γ. The intensities of the components in the sextet were taken in the form 3 : 2 : 1 for the spectra 1 and 3, and 3 : X : 1 for the spectrum 2. The results of reduction of the principal parameters are listed in Table I.

When an external field H_0 is applied, an external field $H_{int} = H_0 + H_{Lor} + H_{demag}$ is produced in the sample. Using the magnetization curve of polycrystalline holmium[1] and knowing the demagnetizing factor $N = 1$ of the sample, we can estimate the demagnetizing field $H_{demag} \approx 29$ kOe and the Lorentz field $H_{Lor} \approx 9$ kOe. When allowance is made for the noncollinearity of the magnetization

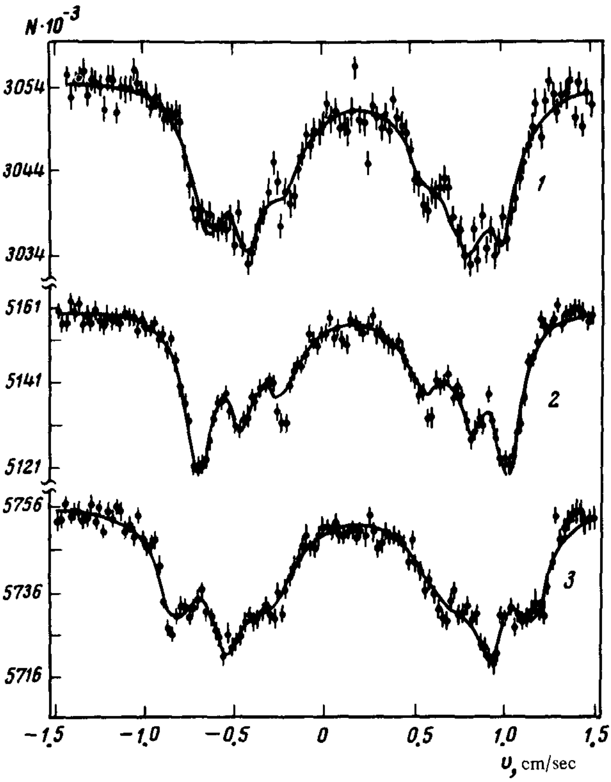

FIG. 1. NGR spectra of Ho+0.5 at.% Sn^{119}; solid line—result of computer reduction.

vectors of the domains, the changes of the parameters H_1 and H_2 in experiment 2 should be 17 kOe on the average. It is seen from Fig. 1 and from Table I, however, that the maximum splitting of the spectrum and the parameters H_1 and H_2 have changed little, whereas the general shape of the spectrum (2) has become strongly deformed. On the contrary spectra 1 and 3, which correspond to a zero field H_0, have greatly differing splittings and parameters H_1 and H_2, thus pointing to appreciable residual magnetic phenomena.

We propose the following explanation of the observed facts. According to[2], at low temperatures the regular helicoidal structure in Ho is distorted by the large magnetic anisotropy in the basal plane, as is manifest by the tendency of the magnetic moments to align themselves near the easy magnetization directions B. This can lead to the onset of two magnetically nonequivalent configurations of the local environment of the tin atom: configuration I connected to the main helix with pitch $\alpha = 35°$ at 25 K and with a field H_1, and configuration II connected with distorted helix, with the magnetic moments oriented near the axes B, and with the field H_2. The model assumed in the reduction of the spectra in experiment 1 corresponds to $A_1/A_2 \approx 3$, i.e., the number of configurations I is three times larger. The isomeric shifts of the sextets differ

TABLE I. Parameters of NGR spectra of Ho+0.5 at.% Sn^{119}.

Experiment no.	External field, kOe	H_1, kOe	H_2, kOe
1	0	120 ±0.9	90.6 ±2.7
2	40	124.8 ±0.4	92.9 ±1.0
3	0	143 ±0.7	104.2 ±1.2

here by 0.43 mm/sec, a fact that can be attributed to the different magnetic structures of the local environments. In experiment 2, in the major part of the volume of the sample, the $H_{\rm int}$ component that influences the rotations of the moments in the basal plane exceeds the critical field $H_{\rm cr}$=4 kOe at which the transition from the helicoidal to the fan-shaped structure begins. This increases the combined magnetic moment of the two configurations and lead in turn to an increase of the absolute value of the hyperfine field H_{hf}. However, if H_{hf} is negative, this increase should be offset by $H_{\rm int}$. The absence of a substantial change of the maximum splitting in spectrum 2 indicates that almost complete cancellation takes place. Yet the polarizing action of the longitudinal applied field weakens the average components of the sextets and by the same token deforms the spectrum.

Removal of the external field leads to a strong hysteresis (up to 19%) of the hyperfine fields. The ratio A_1/A_2 becomes equal to 1.5, i.e., the relative number of configurations I is decreased by one-half compared with the initial state, meaning an increase in the distortion of the magnetic structure. The fact that the hysteresis values ΔH_1 and ΔH_2 are close to $H_{\rm int}$ corrected for the polycrystallinity leads to the conclusion that the fan-shaped structure is "frozen" and that the conduction electrons are correspondingly polarized after the removal of the external field. The positive sign of the hysteresis of parameters H_1 and H_2 means that the hyperfine fields at the Sn^{119} nuclei in Ho are negative.

The hysteresis of the hyperfine fields is connected in final analysis with the existence of a potential barrier between two types of magnetic structure; this barrier is caused by the appearance of magnetoelastic terms in the expression for the free energy. According to[3], the corresponding maximal change of the lattice parameter c is given by

$$\Delta c = c_f - c_{\rm af} = 2\frac{\partial a}{\partial c}\frac{M^2}{R},$$

where α is a parameter of the molecular field, M is the magnetization, and R is the rigidity coefficient divided by c^2. Since our data as well as the neutron data[4] indicate that the local magnetization is preserved after the removal of the field, an irreversible change of the lattice parameter should also be observed. This change can be detected in principle by methods of low-temperature x-ray diffraction analysis.

[1]K. P. Belov, O. P. Elyutin, S. A. Nikitin, G. V. Pshechenkova, V. I. Sokolov, and V. P. Taratynov, Fiz. Metal. Metalloved. **30**, 1146 (1970).

[2]Magnetic Properties of Rare Earth Metals, ed. by R. J. Elliott, Plenum Press, New York, London, 1972.

[3]C. Kittel, Phys. Rev. **120**, 335 (1960).

[4]W. C. Koehler, J. W. Cable, H. R. Child, M. K. Wilkinson, and E. O. Wollan, Phys. Rev. **158**, 450 (1967).