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INFLUENCE OF MAGNETIC FIELDS ON THE CRYSTAL STRUCTURE OF DYSPROSIUM. II

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The effect of magnetic fields of strength up to 16 kOe on the crystal structure of polycrystalline dysprosium is studied at temperatures between 77 and 300°K. Special attention is paid to investigation of the anisotropic effects due to different orientations of the crystallites (and domains) in the polycrystalline aggregate with respect to the magnetic field vector. It is shown that a magnetoheterogeneous state, i.e., coexistence of ferromagnetic and antiferromagnetic phases, occurs in a certain range of temperatures and magnetic field strengths. Reorganization of the crystal lattice of dysprosium in the magnetic field is responsible for the giant magnetostriction effect in the magnetically-ordered state. It is found that the discontinuities of the crystal lattice parameters in the antiferromagnetism-ferromagnetism first-order transitions increase with decreasing temperature. The true magnetostriction of dysprosium is characterized by strong anisotropy.

DYSPROSIUM is one of the most thoroughly investigated rare-earth magnetics. It is known that it can be in the ferromagnetic state (below $T_C = 85°K$), in the antiferromagnetic state (85–178°K), and in the paramagnetic state (above $T_N = 178°K$).[2] In the antiferromagnetic state, the magnetic moments in dysprosium are arranged helicoidally, in accordance with the simple spiral (SS) type. The ferromagnetic structure is collinear, with all the magnetic moments directed along ⟨210⟩ of the hexagonal close-packed (HCP) lattice. The helicoidal antiferromagnetism of dysprosium is destroyed in moderately strong magnetic fields ($H_{cr}^{max} = 11$ kOe, when the field is applied along the easy-magnetization axis[3]). On the basis of the results of magnetic measurements[4] and experiments on depolarization of neutrons[5] carried out on polycrystalline samples, it was suggested that there exists a magnetoheterogeneous state of dysprosium at intermediate temperatures and fields.

The transition from the antiferromagnetic to the ferromagnetic state, both with respect to the temperature[6] and with respect to the field[1] is accompanied by a lowering of the symmetry of the crystal lattice from HCP to rhombic and by a jump of the atomic volume, i.e., it is a first-order phase transition. In the paramagnetic and ferromagnetic states, the symmetry of the crystal lattices (HCP and rhombic, respectively) does not change in fields of intensity up to 16 kOe. In a number of papers[7–9] there are indications of the existence of the effect of giant magnetostriction in dysprosium ($\lambda = \Delta l/l \sim 10^{-3}$, where l is the length) in the ferromagnetic and antiferromagnetic states. To find the correlation between the giant magnetostriction changes of the dimensions of the sample and the structure effects in external magnetic fields it is necessary to make a quantitative study of the influence of the magnetic field on the crystal structure of dysprosium in the magnetically-ordered state. The purpose of the present study was the investigation of the structure changes in dysprosium in wide temperature and magnetic field strength intervals.

RESULTS OF INVESTIGATION

The object of the investigation in the present paper was polycrystalline dysprosium of 99.2% purity. The use of polycrystalline metal naturally hinders both the performance of diffraction experiments in magnetic fields and the interpretation of the results. However, the presence in the polycrystalline aggregate of crystallites with various orientations of the crystallographic axis and of the magnetic moments relative to the magnetic field intensity **H** broadens the possibility of obtaining information on the behavior of dysprosium in a magnetic field.[2)]

The procedure of low-temperature x-ray investigations in magnetic fields did not differ noticeably from that described earlier.[1] X-ray diffraction patterns of the investigated samples were obtained at temperatures 77–300°K in fields of intensity up to 16 kOe. The photographs were made in chromium and iron radiations. Reflections from a number of planes of the hexagonal lattice were registered at room temperature, and when the dysprosium went over into the ferromagnetic state these reflections were "split" into rhombic reflections in accordance with the following scheme.[3)]

The interplanar distances were measured with accuracy not worse than $\pm 1 \times 10^{-4}$ Å. The temperature was stabilized within ±2°K, and the magnetic field intensity within the limits ±0.1 kOe.

[1)] The first part is [1].

[2)] In comparison with diffraction experiments on single crystals. In all other cases the use of single crystals is naturally preferable.

[3)] The index h pertains to the HCP lattice, and the index r to the rhombic lattice.

The parameters of the field dependence of the interplanar distances $d_{(203)_h}$, $d_{(043)_r}$, and $d_{(223)_r}$ are shown in Fig. 1. The $d_{hkl}(H)$ plots for other crystallographic planes are similar in form.

After a certain critical value of the magnetic field intensity H_{cr} is reached, there appear on the x-ray patterns, besides the reflections from the HCP (antiferromagnetic) phase, also lines of the rhombic (ferromagnetic) phase. With further increase of H, the lines of the antiferromagnetic phase vanish from the x-ray patterns. This means that the transformation from the antiferromagnetic into the ferromagnetic state in polycrystalline dysprosium is stretched out over a certain interval of values of the magnetic field intensity, in which a magnetoheterogeneous state exists, namely a mixture of the antiferromagnetic (HCP) and ferromagnetic (rhombic) crystallite.[4)]

Two circumstances are striking on the isotherms $d_{hkl}(H)$: first, depending on the indices of the reflecting planes hkl, the jumps on the $d_{hkl}(H)$ curves occur at different values of H_{cr} ($H_{cr}^{105} < H_{cr}^{210} < H_{cr}^{203}$); second, not all the rhombic components of the hexagonal lines are present at $H > H_{cr}$. Since these effects can be connected with different orientations of the grains in the polycrystalline sample relative to the magnetic field intensity vector **H**, experiments were performed in which the angle ρ (see the scheme in Fig. 2) between the projections of the vector **H** and the projections of the normal to the reflecting plane $\mathbf{N}_{hkl}$ on the plane perpendicular to the incident beam of the x-rays $\mathbf{S}_0$ ranged from 0 to 2π. To this end it was sufficient to register on the x-ray patterns the complete Debye rings from the crystallographic planes (hkl).

Figure 3 shows plots of the angular distribution of the the values of the interplanar distances $d_{(210)_h}(\rho)$ and $d_{(310)_r}(\rho)$ for the range $0 \le \rho \le \pi/2$,[5)] obtained at T = 140°K and H = 12 kOe. This choice of x-raying conditions corresponds to the magnetoheterogeneous state,[6)] i.e., to the coexistence of the antiferromagnetic and ferromagnetic dysprosium. In the entire range of variation of the angle ρ, no qualitative changes were observed on the x-ray patterns, but with increasing angle ρ (i.e., on going over from the so-called longitudinal to transverse photography), the HCP and rhombic phase lines behave differently, namely, $d_{(210)_h}$ decreases and $d_{(310)_r}$ increases.

Besides the measurements of $d_{hkl}(H)$ and $d_{hkl}(\rho)$, we also plotted the temperature dependences of the interplanar distances (at 77–300°K) in the absence of a magnetic field (H = 0) and at the maximum magnetic field intensity (H = 16 kOe) (Fig. 4). Just as in our earlier investigation,[1] no noticeable difference between the $d_{hkl}(T)$ curves was observed at H = 0 and at H = 16 kOe. In the antiferromagnetic region, the interplanar distances $d_{(105)_h}$ increased somewhat, while $d_{(210)_h}$ decreased upon application of the magnetic field,

$(203)_h \rightarrow (043)_r + (223)_r$,

$(210)_h \rightarrow (150)_r + (240)_r + (310)_r$,

$(105)_h \rightarrow (025)_r + (115)_r$,

$(211)_h \rightarrow (151)_r + (241)_r + (311)_r$,

$(213)_h \rightarrow (153)_r + (243)_r + (313)_r$.

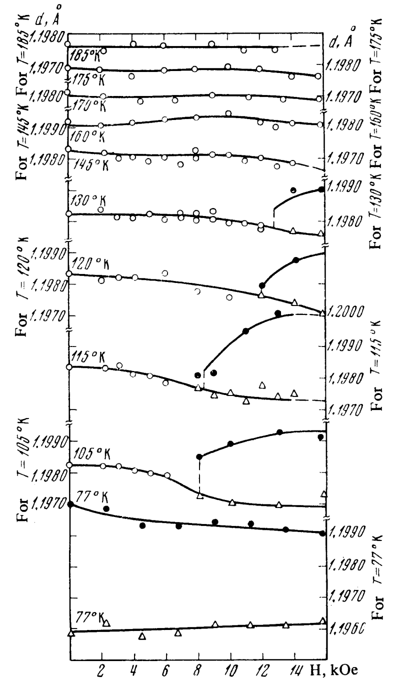

FIG. 1. Interplanar distances of dysprosium vs. magnetic field intensity: ○–$(203)_h$, ●–$(043)_r$, Δ–$(223)_r$.

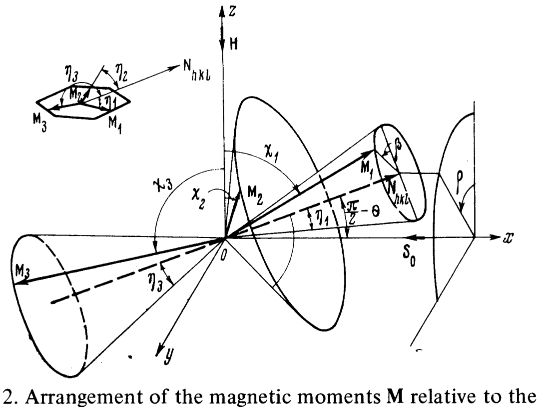

FIG. 2. Arrangement of the magnetic moments **M** relative to the magnetic field intensity vector **H** and the incident beam of x-rays $\mathbf{S}_0$. Here $\mathbf{N}_{hkl}$ is the normal to the reflecting plane (hkl), η_i are the angles between **M** and $\mathbf{N}_{hkl}$, χ_i are the angles between **M** and **H**, ϑ is the diffraction angle, ρ is the angle between the projections of $\mathbf{N}_{hkl}$ and **H** on the yOz plane, and β is the angle between the projection of **M** and an arbitrary direction in the (hkl) plane.

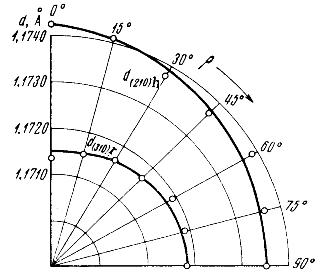

FIG. 3. Angular dependence of $d_{(210)_h}$ and $d_{(310)_r}$ at 140°K and 12 kOe.

[4)] The stresses on the boundary of the antiferromagnetic and ferromagnetic phases [4] do not lead, however, to a strong smearing of the diffraction lines, since the sample surface whose x-ray pictures are being taken is in fact in a free state.

[5)] The d(ρ) curves are symmetrical with respect to the axes z and y (see Fig. 2).

[6)] In any case at ρ = 0.

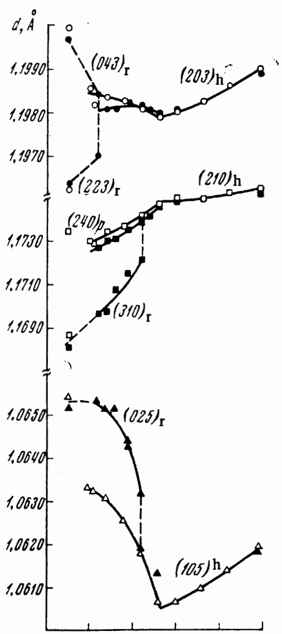

FIG. 4. Temperature dependence of interplanar distances (transverse photography, $\rho = \pi/2$): ○, ●–(203)h, (043)r, (223)r, □, ■–(210)h, (240)r, (310)r, △, ▲–(105)h, (0.25)r. Open points–H = 0, dark–H = 16 kOe.

and at H = 16 kOe the $d_{(203)_h}(T)$ curve behaved in a complicated manner. At certain temperatures, depending on the indices of the reflecting planes hk*l*, the $d_{hkl}(T)$ curves plotted in a magnetic field showed jumps connected with the transition of the dysprosium from the antiferromagnetic state to the ferromagnetic one. In the ferromagnetic region (77°K), the values of d_{hkl} at H = 16 kOe differed somewhat from d_{hkl} at H = 0.

DISCUSSION OF RESULTS

In the study of the influence of the magnetic field on the crystal structure of dysprosium, as seen from the foregoing, two groups of effects are observed: first, effects connected with the influence of the orientation of the crystals relative to the magnetic field intensity vector (the anisotropy of the critical fields[7]) and temperatures, the presence of the magnetoheterogeneous state, etc.), and second, effects connected with the change of the dimensions of the crystal lattice (jumps in the values of the interplanar distances during the phase transition in a magnetic field, magnetic deformation of the crystal lattice, etc.). These two groups of phenomena can be considered separately.

A. Orientation Factor

An examination of the role of the orientation factor is best carried out for the ferromagnetic state, i.e., for the magnetic structure in which the directions of the magnetic moment coincide with the crystallographic axes $\langle 210\rangle_h$ (Fig. 2). In this case the magnetic moments **M** form a cone relative to the vector of the normal to the reflecting plane $\mathbf{N}_{hkl}$; the aperture angle of the cone 2η is determined from the well-known crystallographic relation for a hexagonal lattice[8] [10]

$$\cos\sphericalangle(\mathbf{MN}_{hkl}) = \cos\eta$$
$$= \frac{uh+vk+wl}{[{}^4/_3(h^2+hk+k^2)+(a/c)^2l^2]^{1/2}[3(u^2+uv+v^2)+(c/a)^2w^2]^{1/2}} \quad (1)$$

where u, v, and w are the crystallographic indices of the easy magnetization axis ($\langle 210\rangle_h$ or $\langle 010\rangle_r$).

On the other hand, the angle χ of the magnetic moments **M** with the magnetic-field intensity vector **H** depends on the orientation of the vector normal to the reflecting plane $\mathbf{N}_{hkl}$ relative to the vector **H**. It can readily be shown that in the general case

$$\cos\sphericalangle(\mathbf{MH}) = \cos\chi = \cos\eta\cos\vartheta\cos\rho$$
$$+ \sin\eta\sin\vartheta\cos\beta(1-\cos^2\vartheta\cos^2\rho)^{1/2}, \quad (2)$$

where ϑ is the diffraction angle and β is the azimuthal angle reckoned in a plane perpendicular to N_{hkl}, i.e., in the reflecting plane hk*l*. It is necessary further to average $\cos\chi$ over all the positions of the crystallites taking part in the production of the diffraction pattern, i.e., over the angle β. Since the considered effects of the interaction of the magnetic moments with the field do not depend on the "sign" of the direction of the vector **H**, the averaging should be carried out over even powers of $\cos\chi$ (in first approximation—over $\cos^2\chi$). For the particular cases of longitudinal ($\rho = 0$) and transverse ($\rho = \pi/2$) photography, the effective cosines are equal to

$$(\overline{\cos^2\chi})^{1/2}_{\rho=0} = (\overline{\cos^2\chi})^{1/2}_{\parallel} = (\cos^2\eta\cos^2\vartheta + {}^1/_2\sin^2\eta\sin^2\vartheta)^{1/2}, \quad (3)$$

$$\overline{(\cos^2\chi)}^{1/2}_{\rho=\pi/2} = \overline{(\cos^2\chi)}^{1/2}_{\perp} = \frac{1}{\sqrt{2}}\sin\eta. \quad (4)$$

The results of the calculation of the effective cosines for different crystallographic plates are listed in the table.

Since there are three physically equivalent directions of the type $\langle 210\rangle_h$ in the HCP lattice, Fig. 2 shows three cones of the magnetic moments relative to the normal vector N_{hkl}. By virtue of the symmetry of the hexagonal lattices, consideration of the angles between N_{hkl} and the three easy axes $\langle 210\rangle_h$ is equivalent to consideration of the angles between one easy direction and the normals to three planes $\{hkl\}_h$. In the case of the transition of an HCP lattice into a rhombic (ferromagnetic) one, such an analysis becomes the only one possible, since in the collinear ferromagnetic structure of dysprosium there is only one direction of easy magnetization; the table gives values of $\overline{\cos^2\chi})^{1/2}$ for three planes of the rhombic lattice.

It is obvious that the energywise most favored orientation of the magnetic moments **M** relative to the vector **H** is the one in which the angle between them is minimal. By virtue of this, a magnetic texture is produced,[1] i.e., a rearrangement of the crystal lattice of the ferromagnetic dysprosium in such a way that all the magnetic moments are at minimal possible angles to the

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[7] We have in mind not the true anisotropy of H_{cr} due to the presence of a strictly fixed position of the magnetic moment in a single-domain single crystal, but the macroscopic effect, which is connected with the different orientations of the grains of the polycrystalline aggregate relative to the magnetic field **H** and is (see below) a consequence of the presence of the effect of true anisotropy of H_{cr}.

[8] We neglect for the time being the small difference between the HCP and rhombic lattices.

Effective cosines, critical fields, and critical temperatures for different crystallographic planes of dysprosium

$(hkl)_h$	$(hkl)_r$	ϑ, deg	η, deg	$(\overline{\cos^2\chi})^{1/2}_{\|}$	$(\overline{\cos^2\chi})^{1/2}_{\perp}$	H_{cr}, kOe; T = 130° K	T_{cr}, °K H = 16 kOe	$(hkl)_r$ H = 16 kOe, T = 130°K
			K_β-radiation of Cr					
105	115	79.0	80.2	0.684	0.696	7	160	115
	025		70.1	0.656	0.665	>7	<160	
			K_α-radiation of Cr					
210	310	77.5	79.1	0.679	0.694	10	145	310
	240		40.9	0.480	0.463	>10	<145	
	150		19.1	0.305	0.230	>10	<145	
203	223	73.0	67.4	0.634	0.653	13	130	223
	043		39.5	0.486	0.450	13	130	043
211	311	85.0	79.3	0.692	0.695	—	—	311
	241		42.3	0.477	0.475	—	—	
	151		22.3	0.277	0.268	—	—	
			K_α-radiation of Fe					
213	313	76.5	80.8	0.678	0.698	—	—	313
	243		50.1	0.548	0.547	—	—	243
	153		36.8	0.452	0.423	—	—	153

Note. A dash denotes absence of data.

field. Consequently the x-ray pattern shows only one line in place of two or three diffraction lines (see the table), namely, the reflection from the plane for which $(\overline{\cos^2\chi})^{1/2}$ is maximal.

It must be stipulated immediately that considerations connected with different effective cosines should be considered as purely qualitative: it is quite unclear just which differences in $(\overline{\cos^2\chi})^{1/2}$ lead to a rearrangement of the crystal lattice. Thus, as can be seen from the table, the line $(213)_h$ at 105°K and H = 16 kOe is split into three components, whereas the line $(210)_h$ has only one rhombic component under the same conditions. Yet the differences in the values of $(\overline{\cos^2\chi})^{1/2}$ of these lines are approximately of the same order.

Inasmuch as in ferromagnetic (rhombic) dysprosium the ratio of the axes b/a differs from $\sqrt{3}$, the rearrangement of the lattice in the magnetic field should lead to noticeable macroscopic changes of the dimensions. Thus, giant magnetostriction in the ferromagnetic state[7-9] can be entirely due to processes of this type. An elementary geometrical calculation gives for the magnetostriction of the single crystals in the case when the field is applied along the axes a and b ($\lambda_{\|a}$ and $\lambda_{\|b}$):

$$\lambda_{\|a} = 0, \quad \lambda_{\|b} = {}^1/_3(2 - \sqrt{9(a/b)^2 + 1}). \tag{5}$$

For b/a = 1.74[6] the magnetostriction along the b axis amounts to ~3 $\times 10^{-3}$, in good agreement with the experimental data.[7]

The orientation factor is quite important for the explanation of the anisotropy of the critical fields and temperatures on going from the antiferromagnetic to the ferromagnetic state. The scheme of Fig. 2, strictly speaking, is not applicable to the case of the antiferromagnetic helicoidal state. It should be assumed that the minimum values of the critical field should be observed when **H**||**M**, and the transformation from the antiferromagnetic state to the ferromagnetic one begins in just such crystallites. Subsequently the magnetic moments, bypassing the stage of random distribution, become oriented relative to the magnetic-field intensity vector at a minimal angle. Naturally, the first to go over into the ferromagnetic state are the crystallites for which the values of $(\overline{\cos^2\chi})^{1/2}$ are maximal. The values of the critical fields themselves are determined by the values of the effective cosines.

Apparently, the "critical-field anisotropy" should not depend on the temperature (i.e., the inequality $H_{cr}^{105} < H_{cr}^{210} < H_{cr}^{203}$ should hold at all temperatures). This is indeed observed in the experiments (Fig. 5), although at high temperatures ($T \rightarrow T_N$) there is a tendency for H_{cr}^{203} to decrease. A discussion of this effect is beyond the scope of the present paper; we note only that the presence of a maximum of H_{cr} at ~160°K was noted in the literature a number of times.[2, 11]

The anisotropy of the critical temperature (see the table) is in essence a consequence of the anisotropy of the critical field, and requires no special discussion.

B. Change of Dimensions of Crystal Lattice

The strongest effect connected with the deformation of the crystal lattice of dysprosium in a magnetic field is the jumplike change of the shape and dimensions of the unit cell on going from the antiferromagnetic state into the ferromagnetic one.[1] The presence of jumps of the lattice parameters is evidenced by the jumplike change of the interplanar distances in H_{cr} (Fig. 1). Unfortunately, the method of x-ray structure analysis of polycrystals in a magnetic field does not yield sufficiently correct information on the change of the lattice parameters. This is due to the different orientations of the different crystallographic planes (more accurately, of the crystallites, for which the given planes are in a reflecting position) relative to the magnetic field intensity vector, i.e., to the anisotropy of the critical field, etc. (see above); therefore the values of the crystal-lattice parameters calculated from the corresponding $d_{hkl}(H)$ curves cannot in principle be connected with the concrete orientations of the axes of the lattice relative to the vector **H**.

By way of an example, Fig. 6 shows the field dependences of the parameters of the HCP (antiferromagnetic) and rhombic (ferromagnetic) lattices at T = 105°K. The constants of the HCP lattice (a_h and c_h) were calculated from the lines $(203)_h$ and $(210)_h$, and those of the rhombic lattice (a_r, b_r, and c_r) from the lines $(223)_r$, $(043)_r$, and $(310)_r$. Owing to the anisotropy of the critical field (H_{cr}^{210} = 4 kOe, H_{cr}^{203} = 8 kOe), calculations of a_r, b_r, and c_r is possible only at H ≥ 8 kOe. We see that at H = kOe there are observed positive jumps of the parameters b and c and a negative jump of the parameter a.

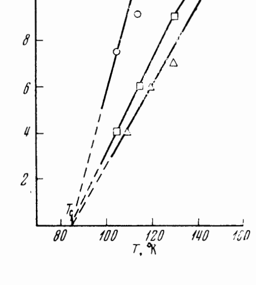

FIG. 5. Temperature dependence of H_{cr}^{hkl}.

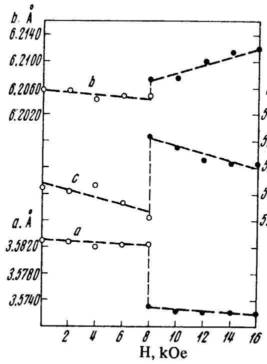

FIG. 6. Field dependence of the crystal-lattice parameters at 105°K: ○—HCP lattice, ●—rhombic lattice.

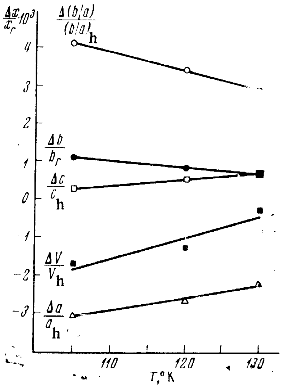

FIG. 7. Jumps of structural characteristics in the antiferromagnetic-ferromagnetic transition in a magnetic field.

Greatest interest attaches to a study of the temperature dependence of the jumps of the parameters in H_{cr}. For reasons indicated above, it becomes necessary to take into consideration only finite differences of the values of the structure characteristics (a, b, c, V, b/a) in the antiferromagnetic (at H = 0) and ferromagnetic (H = 16 kOe) regions (Fig. 7). Although the jumps of the parameters could be determined only at three temperature points,[9] namely 105, 120, and 130°K, we see that the jumps of the parameters a and b increase with decreasing temperature, although they have different signs ($\Delta a = a_r - a_h < 0$, $\Delta b > 0$), the jump of c depends little on the temperature. A consequence of the different directions of the jumps of a and b is a strong increase in the quantity

$$\frac{\Delta(b/a)}{(b/a)_h} = \frac{(b/a)_p - \sqrt{3}}{\sqrt{3}}$$

and a decrease of the ratio $\Delta V/V_h$ with decreasing temperature.

The volume effect in H_{cr} is directly connected with the change of other thermodynamic quantities. If we use the Clausius–Clapeyron equation for the thermal effect q in first-order phase transitions

$$q = T_c \Delta V \left(\frac{dT_c}{dp}\right)^{-1}, \quad q = T_c \Delta\sigma \frac{dH_{cr}}{dT}, \tag{6}$$

where $\Delta\sigma$ is the jump of the magnetization, then the jump of the volume amounts to

$$\Delta V = \Delta\sigma \frac{dT_c}{dp} \frac{dH_{cr}}{dT}. \tag{7}$$

The jump of the magnetization is positive on going from the antiferromagnetic to the ferromagnetic state, $dH_{cr}/dT > 0$ (see Fig. 5); the Curie temperature of dysprosium drops with increasing pressure (D_{T_C}/dp) = (1.27 ± 0.02) deg/kbar[12]). It follows therefore that the jump of the volume should be negative, and this agrees with the results given in Fig. 7. In addition, the growth of $\Delta\sigma$ with decreasing temperature[2] should be accompanied by an increase in the absolute value of ΔV, which also agrees with the results of the present investigation.

The jump of the lattice parameters in the antiferromagnetism–ferromagnetism phase transition in a magnetic field is responsible to a considerable degree for the giant magnetostriction of dysprosium in the antiferromagnetic state.[7] The jumps of the lattice parameters $\Delta x/x$ (Fig. 7) observed in the present study are close in order of magnitude to the macroscopically measured values of the magnetostriction ($\lambda = \Delta l/l$). Like the jumps of the parameters, the magnetostriction increases with decreasing temperature. Thus, there is a fundamental difference between the giant magnetostriction in the ferro- and antiferromagnetic states: in the former case the effect takes place as a result of reorientation of the domains, and in the latter as a result of phase transition (unlike in magnetostriction, the parameter c also changes when $T < T_C$ [7]).

As to the true magnetic deformation of the crystal lattice, judging from the results of the present study, it is relatively small even in the magnetically-ordered state. Although, as already mentioned, it is difficult to make any quantitative estimates of the changes of the lengths of the crystallographic axes, even on the basis of a consideration of the field dependence ($d_{hkl}(H)$, Fig. 1) and the angular dependence ($d_{hkl}(\rho)$, Fig. 3) of the interplanar distances, it can be concluded that the true magnetostriction has noticeable anisotropy. In the paramagnetic state, the magnetostriction is negligible.

It is obvious that the x-ray diffraction method of measuring the magnetostriction, in spite of its low accuracy, is more objective than the macroscopic methods. The latter give in the general case a sum of three effects: the reorientation of the domains in the ferromagnetic state, the jump of the crystal lattice parameters in the antiferromagnetism–ferromagnetism phase transition (with respect to the field), and the magnetostriction proper. To separate these effects, it is necessary to carry out parallel magnetostriction and x-ray diffraction measurements at fixed positions of the crystallographic and magnetic axes of the crystal relative to the magnetic-field intensity vector.

CONCLUSION

We have continued the study of the influence of magnetic fields on the crystal structure of dysprosium in the ferro-, antiferro-, and paramagnetic states. We have established that in the antiferromagnetism–ferromagnetism phase transition "with respect to the field" an important role is played by anisotropic effects connected with the different orientations of the crystallites (more accurately, of the magnetic domains) relative to the magnetic-field vector, resulting in a smearing of

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[9] Only at these temperatures are the lines $(223)_r$, $(043)_r$, and $(310)_r$ simultaneously present on the x-ray patterns.

the phase transition with respect to the field and with respect to the temperature. The oriented growth of the domains of the ferromagnetic phase in the magnetic field is responsible for the giant magnetostriction of dysprosium below T_C, whereas the giant magnetostriction at $T_C < T < T_N$ is connected with the presence of jumps of the crystal-lattice parameters when the HCP lattice becomes transformed into a rhombic one (antiferromagnetism–ferromagnetism transformation). To explain the giant magnetostriction of rare-earth metals having noncollinear magnetic structures in the ferromagnetic state (Ho, Er) it is apparently necessary to use other mechanisms or to review the existing notions concerning the character of the magnetic structures of these metals.
of the magnetic structures of these metals.

In the present paper we did not consider the question of hysteresis effects in dysprosium in magnetic fields, although a difference does exist between the values of the critical fields for increasing and decreasing magnetic fields. An examination of effects of this type will be the subject of our next communication. In addition, we propose to continue the study of the changes in the dimensions of the crystal lattice of dysprosium in a magnetic field, i.e., of the true magnetostriction.

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[1] V. A. Finkel' and V. S. Belovol, Zh. Eksp. Teor. Fiz. **57**, 774 (1965) [Sov. Phys.-JETP **30**, 424 (1970)].

[2] K. P. Belov, M. A. Belyanchikova, R. Z. Levitin, and S. A. Nikitin, Redkozemel'nye ferro- i antiferromagnetiki (Rare-earth Ferro- and Antiferromagnetics), Nauka, 1965.

[3] D. Behrendt, S. Legvold, and F. Spedding, Phys. Rev. **109**, 1544 (1958).

[4] S. A. Nikitin, FMM **15**, 187 (1963)

[5] E. Löffler and H. Rauch, J. Phys. Chem. Sol. **30**, 2175 (1969); Zs. Phys. **210**, 265 (1968).

[6] V. A. Finkel' and V. V. Vorob'ev, Zh. Eksp. Teor. Fiz. **51**, 786 (1966) [Sov. Phys.-JETP **24**, 524 (1967)].

[7] K. P. Belov, R. Z. Levitin, S. A. Nikitin, V. I. Sokolov, and B. K. Ponomarev, Vestnik MGU No. 6, 108 (1966); K. P. Belov, R. Z. Levitin, and B. K. Ponomarev, Zh. Eksp. Teor. Fiz. **49**, 1733 (1965) [Sov. Phys.-JETP **22**, 1185 (1966)].

[8] S. Legvold, J. Alstad, and J. Rhyne, Phys. Rev. Lett. **10**, 509 (1963).

[9] E. W. Lee, Proc. Phys. Soc. **84**, 693 (1964).

[10] H. M. Otte and A. G. Crocker, Phys. Stat. Sol. **9**, 441 (1965).

[11] R. B. Flippen, J. Appl. Phys. **35**, 1047 (1964); A. C. Hudgins and A. S. Pavlovic, J. Appl. Phys. **36**, 3628 (1965); P. H. Bly, W. D. Corner, and K. N. R. Taylor, J. Appl. Phys. **40**, 4787 (1969).

[12] H. Bartholin and D. Bloch, J. Phys. Chem. Sol. **29**, 1063 (1968).

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