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SHIFT OF THE FERROMAGNETISM-ANTIFERROMAGNETISM TRANSITION POINT IN DYSPROSIUM UNDER HYDROSTATIC PRESSURE

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A hydrostatic pressure of 1800 atm shifts the ferromagnetism-antiferromagnetism point in dysprosium towards the lower temperatures by approximately 7°. The shift is ascribed to the influence of the change in the interatomic distances on the exchange interaction between the atoms lying in the basal planes of the hexagonal lattice of dysprosium; as a result, the temperature interval in which a "helicoidal" arrangement of the magnetic moment exists in the basal planes, expands towards the lower temperatures.

1. In an earlier article[1] we pointed out that dysprosium displays, in addition to the magnetostriction due to the magnetic anisotropy forces in the basal plane, also magnetostriction corresponding to the change in energy of the exchange interaction between the layers when the helicoidal magnetic structure is destroyed by the magnetic field. There should exist a "thermodynamically bound" effect—the influence of pressure on the exchange energy between the indicated layers. This in turn should lead to a change in the helicoidal magnetic structure and to a shift in the point Θ_1 of the transition from ferromagnetism to "helicoidal" antiferromagnetism under the influence of the pressure. The present investigation was an attempt to observe the shift of the point Θ_1 under the influence of hydrostatic pressure.

2. Figure 1 shows the temperature dependence of the magnetization, measured in a magnetic field H = 3100 Oe, and of the coercive force of a polycrystalline specimen of dysprosium at a pressure of 1800 atm and without the pressure. The hydrostatic pressure was produced by freezing water[2] in a small beryllium-bronze bomb containing the investigated specimen in the form of a rod. The magnetization and the coercive force were determined ballistically by measuring the inductive kick produced when the bomb with the specimen was drawn out of a measuring coil wound on the Dewar. The magnetization and the coercive force were measured after the specimen was demagnetized by heating above the Curie point (Θ_2 = 177°K).

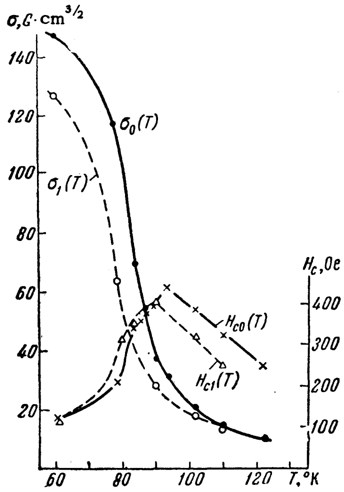

FIG. 1. Effect of hydrostatic pressure on the magnetization σ and on the coercive force H_c of dysprosium in the ferromagnetism-antiferromagnetism transition region. $\sigma_0(T)$, $\sigma_1(T)$ – magnetization at p = 1 atm and p = 1800 atm (H = 3100 Oe); $H_{c0}(T)$, $H_{c1}(T)$ – coercive force at p = 1 atm and p = 1800 atm (H_{max} = 3250 Oe).

It is seen from Fig. 1 that a hydrostatic pressure of 1800 atm causes the steep part of the $\sigma(T)$ curve to shift parallel to itself toward the lower temperatures by approximately 7°. This means that the point Θ_1 has shifted toward the lower temperatures by the same number of degrees. An equal shift toward the low temperature side occurs also in the maximum of the $H_c(T)$ curve, situated near Θ_1.

3. The helicoidal magnetic structure of dysprosium can be destroyed by a magnetic field that exceeds a certain critical field value H_{cr}. At temperatures considerably above Θ_1, the value of the critical field is determined essentially by the exchange in direction between the layers, which tends to turn the magnetic moments of the layers through

a certain angle relative to each other. This leads to the formation of the helicoidal structure.

It follows from a thermodynamic analysis[3] that the magnetic-anisotropy energy and the magneto-elastic energy in the basal plane, which increase with decreasing temperature and with approach to the point Θ_1, decrease the value of the critical field H_{cr}, which in this case is equal to

$$H_{cr} = H_{cr0} - K/M_s - \lambda^2 E/M_s. \qquad (1)$$

Here H_{cr0} is the critical field in the case when there is no anisotropy energy and no magnetoelastic energy in the basal plane, K is the anisotropy constant in the basal plane, M_s is the saturation magnetization, and λ and E are the magnetostriction and Young's modulus in the basal plane.

Hydrostatic compression causes a shift in the point Θ_1 of the transition from ferromagnetism to helicoidal antiferromagnetism. This shift can be connected with the change in H_{cr} with pressure, on the basis of the thermodynamic relation

$$\partial\Theta_1/\partial p = -h^{-1}\partial H_{cr}/\partial p, \qquad h = \partial H_{cr0}/\partial T. \qquad (2)$$

Since the change of H_{cr} with pressure can be found by differentiating (1), we can write (2) in the form

$$\frac{\partial\Theta_1}{\partial p} = -\frac{1}{h}\frac{\partial H_{cr}}{\partial p} + \frac{1}{h}\frac{\partial}{\partial p}\left(\frac{K}{M_s} + \frac{\lambda^2 E}{M_s}\right). \qquad (3)$$

It is seen from (3) that the shift of Θ_1 due to the pressure can result, generally speaking, either from a change in the exchange interaction between the layers [first term in (3)] or as a result of a change in the energy of the magnetic anisotropy and the magnetoelastic energy in the basal plane [last term in (3)].

It follows from our experiments that in the ferromagnetic region at 60°K, the hydrostatic pressure decreases the magnetization, whereas the coercive force is not noticeably changed (see Figs. 1 and 2). It follows therefore that we can expect only an increase in the effective field of the anisotropy energy and of the magnetoelastic energy under the influence of the pressure. This increase, according to (3), should cause a shift in Θ_1 toward higher temperatures, since the increased effective field of the anisotropy and magnetoelastic energies prevails over the effective field of exchange interaction at higher temperatures. In fact, the shift of Θ_1 is toward lower temperatures, which can be attributed to the strong pressure-induced increase of the effective field of exchange interaction between the layers, owing to the sharp dependence of this field on the distance between the layers.

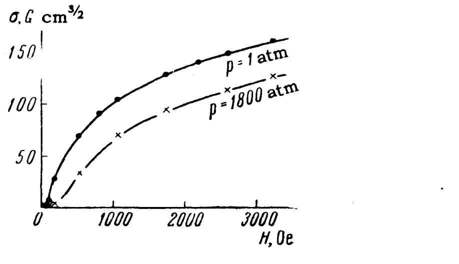

FIG. 2. Effect of hydrostatic pressure on the magnetization curve $\sigma(H)$ of dysprosium in the ferromagnetic region ($T < \Theta_1$) in fields that are smaller than the saturation field (T = 60°K).

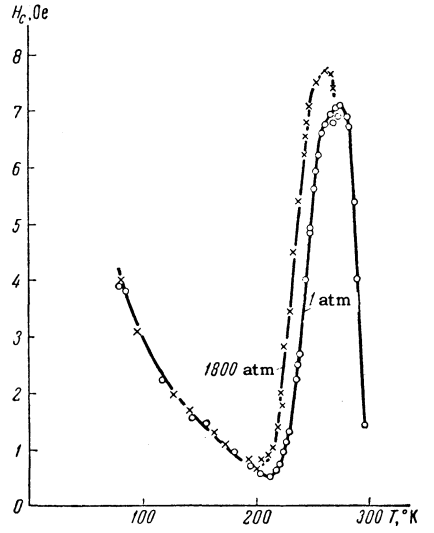

FIG. 3. Effect of hydrostatic pressure on the temperature variation of the coercive force of gadolinium (the coercive force H_c was measured at the maximum magnetizing field H_{max} = 2000 Oe).

4. As was already reported by us earlier[4], polycrystalline gadolinium exhibits at 210°K a decrease in magnetization in very weak magnetic fields and a minimum of the coercive force. The question of the existence of a ferromagnetism-antiferromagnetism transition at the point Θ_1 = 210°K is at present debatable and calls for further research.

The method described above was used for experiments on the influence of the hydrostatic pressure on the $H_c(T)$ curve of polycrystalline gadolinium. Figure 3 shows the curves of the temperature dependence of H_c without pressure and at 1800 atm. It is seen that the minimum of H_c shifts toward lower temperatures by approximately 10°. We assume that this shift is also due to a change in the exchange interaction between the basal planes of the hexagonal lattice of gadolinium under the influence of the hydrostatic pressure. A more detailed interpretation of the results of these experiments will be possible after data are obtained on the character of the magnetic structure in this metal.

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