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IMPORTANCE OF MEASURING THE MAGNETIC ANISOTROPY IN THULIUM

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The construction of a microscopic theory of the magnetic anisotropy of magnetic crystals entails considerable difficulties. In rare-earth ferromagnets, however, where the magnetic f-electrons are well described by atomic functions localized at the lattice sites, the problem is greatly facilitated. An important consequence of this localization is the fact that the orbital momenta of the f-electrons remain unquenched and form, together with the spin momenta, total angular momenta $\vec{J}$ in accordance with the Russel-Saunders scheme[1]. The existence of unquenched orbital momenta rigidly coupled with the spin momenta greatly facilitates the analysis of the magnetic anisotropy, for now the angular momentum $\vec{J}$ becomes directly oriented along definite crystallographic axes. In d-magnets, the effect of crystallographic orientation of the spin momenta is attained only in the second approximation in the spin-orbit interaction $\lambda(\vec{L}\vec{S})$, since the first approximation vanishes as a result of the quenching ($L_z = 0$).

Even this qualitative reasoning explains the appreciably larger magnetic anisotropy of rare earths compared with d-magnets. More detailed results can be obtained by analyzing different anisotropic contributions to the energy of the f-electrons in the crystal. It turns out here that for certain main contributions it is possible to obtain the theoretical dependence of the corresponding terms of the Hamiltonian on the number of the element (more accurately, on the quantum numbers S, L, and J of the lowest term of the configuration f^n). By calculating subsequently some macroscopic quantities, we can compare these relations with the experimental data.

We have already presented [1] results on the anisotropy of the paramagnetic susceptibility of rare-earth metals for the anisotropic-exchange mechanism. In the present paper we shall show that it is possible to separate the two main mechanisms (crystal-field and the anisotropic-exchange) of magnetic anisotropy by calculating the magnetic-anisotropy constant K_1.[2]

It is simplest to consider the crystal-field mechanism. The second-order anisotropy energy can be written in the form

$$E_a^{(2)} = 2\alpha_J A_2 J^2 P_2(\cos\theta). \qquad (1)$$

Here A_2 is an energy parameter that determines the splitting in the crystal field, α_J is a certain coefficient tabulated, for example, in [3], and P_2 is a Legendre polynomial.

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[1])Conversely, in magnets of the iron group, the strong crystalline field smears out the atomic levels of the d-electrons into bands, quenching by the same token their orbital momenta.

[2])These results were reported in part at the Tbilisi Conference on Low Temperatures in 1968 [2].

An estimate of the value of A_2 for the case of metal is not a trivial task. Iosida used in a recent review [4] values of A_2 obtained for nonmetallic crystals. In metals, however, a very important role is played in the estimate of A_2 by the screening of the lattice ions by the conduction electrons, as a result of which A_2 can decrease appreciably. Since there is at present no exact procedure for taking screening into account, it is meaningless, in our opinion, to advance any theoretical estimates for A_2. This quantity should be regarded as some constant parameter used in the comparison of the experimental data with the relation obtained from (2) for K_1 as a function of the element number.

A Hamiltonian containing anisotropic-exchange terms was obtained in [1]. Just as in the calculation of the paramagnetic-susceptibility anisotropy, we use a principal anisotropic term in the form

$$E_{exc} = \sum_{12} I(R_{12})(g-1) D_1(R_{12}J_1)(R_{12}J_2), \tag{2}$$

where $I(R_{12})$ is the effective exchange integral between the electrons producing momenta $\vec{J}_1$ and $\vec{J}_2$ and situated at lattice sites spaced a distance R_{12} apart, g is the g-factor, and

$$D_1 = \sqrt{\frac{2J+1}{J(J+1)}} \begin{Bmatrix} L & J & S \\ L & J & S \\ 2 & 1 & 1 \end{Bmatrix}. \tag{3}$$

Calculating K_1 in the standard manner with the aid of (1) and (2), we get at T = 0°K

$$K_1^{cr}(0) = \alpha_J A_2' J(J-1/2), \tag{4}$$

$$K_1^{exc}(0) = (g-1) D_1 I' J^2. \tag{5}$$

There are thus two dependences of the anisotropy constant on the element number: $\alpha_J J(J-1/2)$ for the crystal-field mechanism and $(g-1)D_1J^2$ for the anisotropic-exchange mechanism.

Choosing the constant parameters A_2' and I' such that (4) and (5) coincide with the experimental values of K_1 for Tb, we obtain the following values of K_1 for the entire second half of the series of rare-earth metals at T = 0°K (the experimental data are taken from [5] at 11 and 22°K):

	Tb	Dy	Ho	Er	Tm	
K_1^{cr}	-5.5	-5.05	-1.98	1.97	5.5	10^8 erg/cm^3
K_1^{exc}	-5.5	-4.6	-1.43	1.1	1.85	
K_1^{exp}	-5.5	-5	-	-	-	

As seen from the table, both the crystal-field theory and the anisotropic-exchange theory predict a change of the sign of K_1 on going from Ho to Er, as is apparently observed also in experiment. The maximum difference between the two theories is observed for Tm. An important fact here is that according to

the crystal-field theory the absolute values of K_1 for Tb and Tm are equal[3], whereas according to the anisotropic-exchange theory they differ by a factor of 3.

A similar situation obtains also for the anisotropy of the paramagnetic susceptibility [1],[4] but experimental data on this quantity are again lacking in the case of Tm.

Of course, a noticeable difference in the predicted anisotropy occurs also for Er, but owing to the low accuracy of both the experimental and the theoretical estimates, measurements of the anisotropy in Tm would be of greatest interest at the present time.

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INTERACTION OF HADRONS WITH DEUTERONS AT HIGH ENERGIES, INELASTIC PROCESSES AND DUALITY

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The purpose of the present paper is to trace qualitatively the energy behavior of the screening correction to the total cross section for the interaction between a high-energy hadron (henceforth, a pion) with a deuteron, with allowance for the inelastic processes.

The correction to the impulse approximation for the forward πd-scattering amplitude is given by [1]:

$$\delta F(s) = \frac{1}{m}\int \frac{dq}{(2\pi)^3} A(p_\pi, p_d, q)\rho(q), \tag{1}$$

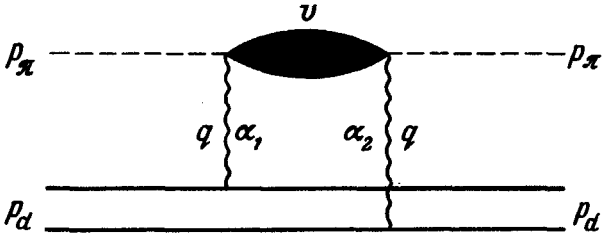

Fig. 1

[3] We emphasize that this equality is exact within the framework of the crystal-field theory.

[4] We note that no term of the type qnD_2 (formula (10) of [1]) arises for conduction electrons within the framework of the isotropic model considered there, by virtue of which the results for $\Delta\theta$ are somewhat altered.