Giant cobalt-induced anisotropic magnetostriction in $GdCo_2$

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(Submitted 20 October 1982)
Pis'ma Zh. Eksp. Teor. Fiz. **36**, No. 10, 367–369 (20 November 1982)

An x-ray diffraction analysis of the crystalline structure of the intermetallic compound $GdCo_2$ was performed in the temperature range 5–500 K and giant anisotropic magnetostriction 1×10^{-3} was observed at a temperature 5.5 K. From a comparison of x-ray diffraction analyses of the compounds $GdAl_2$, $GdNi_2$, and $GdFe_2$, it is concluded that the anisotropic magnetostriction of $GdCo_2$ is due to the cobalt. The longitudinal and transverse magnetostriction of $GdCo_2$ at $T = 4.2$ K in pulsed magnetic fields up to 230 kOe is also investigated and the large magnetostriction of the paraprocess, caused by the band nature of the magnetism of cobalt in the compound $GdCo_2$, is observed.

PACS numbers: 75.80. + q

Intermetallic rare-earth - cobalt compounds $R\,Co_2$ (cubic crystalline structure of a C15 Laves phase type) consist of two magnetic subsystems, one of which is formed by localized moments of the rare earth, while the second, the cobalt subsystem, is usually viewed in terms of a model of the magnetism of collectivized electrons (in compounds with heavy rare earths the magnetic moments of the rare earth and cobalt are antiparallel).[1] Large magnetoelastic effects, both volume and anisotropic, leading to large anomalies in the crystalline structure in the magnetically ordered state, are observed in them. The volume magnetoelastic effects attributable to the cobalt subsystem are ex-

plained within the band model of magnetism, while anisotropic magnetostriction, leading, in particular, to distortion of the cubic crystalline structure in the magnetically ordered state, is due to the rare earth and can be described by a single-ion model of the interaction of an anisotropic cloud of $4f$ electrons with the crystal field of the lattice.[2]

From this point of view, it would be expected that only isotropic magnetostriction would occur in the compound $GdCo_2$, while the anisotropic magnetostriction would be small, since gadolinium is in the s state, its orbital moment is zero, and the spin $4f$ density is spherical.

However, our investigations of the crystal structure of $GdCo_2$ performed using an x-ray diffraction method on polycrystalline specimens in the temperature range 5.5–500 K, showed that this is not the case.

Indeed, below the Curie temperature in $GdCo_2$ ($T_c = 405$ K) large magnetovolume effects are observed. These effects cause the temperature dependence of the unit cell volume to deviate from the normal Debye dependence, characteristic, for example, for the paramagnetic compound YCo_2 (Fig. 1a). The magnitude of the magnetovolume effect attains $\sim 1\times 10^{-2}$ at 0 K, consistent with the data of dilatometric measurements.[3]

However, at low temperatures together with the volume anomaly, there is also a distortion of the cubic crystalline structure of $GdCo_2$. This is evident from Fig. 1b, which shows the (440) x-ray reflection. A single reflection at room temperature, this reflection splits into two reflections at 5.5 K. Analysis shows that the distortion of the crystalline cubic structure of $GdCo_2$ is tetragonal. This type of distortion arises due to the anisotropy of magnetostriction if the directions of easy magnetization are parallel

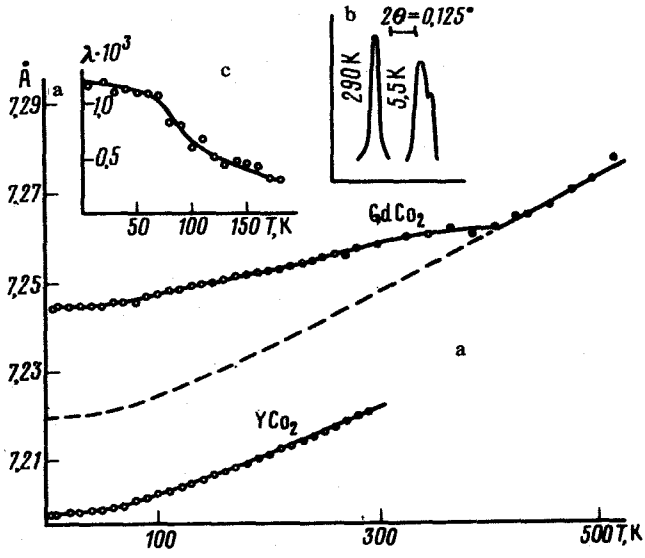

FIG. 1. a—Temperature dependence of the crystal lattice parameter $a \simeq \sqrt[3]{V_{el}}$ of $GdCo_2$ and YCo_2. The dashed line is the Debye dependence; b—the (440) x-ray reflection at $T = 290$ K and at $T = 5.5$ K; c—temperature dependence of the anisotropic magnetostriction λ_{100} of the compound $GdCo_2$.

to the ⟨100⟩ axes, which agrees with the results of magnetic measurements on the single crystal $GdCo_2$.[4] It is easy to show that the a and c parameters of the distorted tetragonal cell are related to the anisotropic magnetostriction constant λ_{100} by the relation $\lambda_{100} = \frac{2}{3}(c/a - 1)$. Figure 1c shows the temperature dependence of λ_{100} for $GdCo_2$. It is evident that at low temperatures the anisotropic magnetostriction of $GdCo_2$ attains the enormous value $\sim 1 \times 10^{-3}$, which is only three to four times lower than the giant anisotropic magnetostriction discovered in $R\,Co_2$ compounds, in which the rare earth has a nonzero orbital moment (R = Tb, Er, Ho, etc.).[2]

In order to clarify the nature of the anisotropic magnetostriction observed in $GdCo_2$, we performed x-ray diffraction measurements of the intermatallic compounds $GdNi_2$, $GdAl_2$, and $GdFe_2$, which have the same crystalline C15 structure as $GdCo_2$. It follows from the data obtained that at low temperatures the cubic structure of these compounds is not distorted. This indicates that the anisotropic magnetostriction of these compounds is at least an order of magnitude smaller than in $GdCo_2$. The conclusion that the anisotropic magnetostriction in $GdAl_2$, $GdNi_2$, and $GdFe_2$ is small is confirmed also by measurements of magnetostriction in an external magnetic field, which we performed on polycrystalline specimens of these compounds, and also in Ref. 5 on single crystals of $GdAl_2$. Thus, we conclude from our experimental results that the giant anisotropic magnetostriction in $GdCo_2$ is due to the cobalt, since it is observed in GdM_2 compounds only for M = Co.

The question as to the nature of the magnetostriction of $GdCo_2$ may be raised. To answer this question, we measured the magnetostriction of this compound in pulsed magnetic fields up to 230 kOe. Figure 2 shows the field dependence of the longitudinal and transverse magnetostriction of $GdCo_2$ at 4.2 K. It is evident that the magnetostriction saturates in comparatively weak fields (less than 20 kOe), while further increase in the field leads to a significant change in the magnetostriction and, in addition, $d\lambda_{\parallel}/dH = d\lambda_{\perp}/dH$. Since the change in volume is related to these quantities by the relation $d\omega/dH = (d\lambda_{\parallel}/dH + 2d\lambda_{\perp}/dH)$, it follows from the data obtained that in $GdCo_2$ at temperatures close to absolute zero there is a large bulk magnetostriction of the paraprocess. This indicates the band nature of the volume magnetostriction of $GdCo_2$. Indeed, if the magnetic moment is localized, then at absolute zero (this tem-

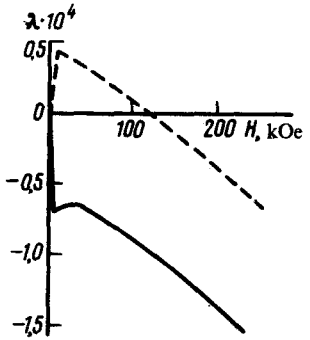

FIG. 2. Longitudinal (solid line) and transverse (dashed line) magnetostriction of the compound $GdCo_2$ at $T = 4.2$ K.

perature in this case is assumed to be 4.2 K) the magnetization is independent of the field and the magnetostriction of the paraprocess is zero. If, on the other hand, the magnetism has a band nature, then the external field changes the relative positions of the bands with "up" and "down" spins; this changes the magnetization and therefore leads to the appearance of magnetostriction of the paraprocess even at 0 K.

At the same time, it follows from our data that the anisotropic magnetostriction of $GdCo_2$ at low temperatures is nearly independent of the field

$$\left(\frac{d\lambda_{\text{anis}}}{dH} = \frac{2}{3}\left(\frac{d\lambda_{\parallel}}{dH} - \frac{d\lambda_{\perp}}{dH}\right)\right).$$

The fact that the anisotropic magnetostriction of this compound is determined by cobalt could indicate that cobalt has, in addition to the collectivized spin density, a localized spin density of $3d$ electrons, which has a considerable anisotropy. The conclusion that cobalt in $R\,Co_2$ compounds has a large anisotropic component of the magnetic moment follows from NMR studies of these compounds.[6]

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Translated by M. E. Alferieff
Edited by S. J. Amoretty