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MAGNETIC PROPERTIES OF GADOLINIUM-TERBIUM AND GADOLINIUM-ERBIUM ALLOYS

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The magnetic properties of Gd–Tb and Gd–Er alloys were investigated in the temperature range from 77 to 1100°K. Maxima, which depended on the concentration and the magnetic field intensity, were found in the $\sigma(T)$ curves. For Gd–Er alloys, a dependence of the effective magnetic moment and of the paramagnetic Curie point on the alloy composition was established.

1. The results of a study of the magnetic properties of a single crystal of Tb,[1] together with the data on neutron diffraction in this metal and in Tb–Y alloys[2] have established the existence in them of a helicoidal antiferromagnetic structure.

In the present paper, we report the results of a study of the magnetic properties of Gd–Tb and Gd–Er alloys. We investigated five Gd–Tb alloys containing 10, 30, 50, 70, and 90 wt.% Tb, and eight Gd–Er alloys containing 5, 20, 30, 50, 60, 70, 80, and 90 at.% Er. The purity of the primary metals was 99.2%. The main impurities were Ca, Nd, Sm, Ho, Tm, Th, and gaseous impurities.

The alloys were prepared in an arc furnace with a nonconsumable tungsten electrode in a cooled copper hearth in an atmosphere of purified helium. Each alloy was remelted three times, which ensured maximum uniformity of the compositions. After the remelting treatments, the alloys were annealed in vacuum for 50 hours at 800°C. The data of microstructure, x-ray diffraction, and thermal analyses, carried out at the A. A. Baĭkov Metallurgy Institute, indicated that at room temperature the primary metals formed a continuous series of solid solutions.

The magnetic properties were investigated by the standard ponderomotive method using a pendulum balance and a balance ring. To check the uniformity of the alloy composition, several samples of the same composition were investigated. The Gd–Tb alloys were investigated in the temperature range from 77 to 300°K, and the Gd–Er alloys from 77 to 1100°K, i.e., both in the ferromagnetic and paramagnetic regions. For all the samples, we measured the temperature dependence of the magnetization for various magnetic field intensities.

2. Figure 1 shows the dependence of σ on T for polycrystalline Tb and for the Gd–Tb alloys, plotted using our measurements. It is evident that the majority of the curves have characteristic maxima, which appear most clearly in weak fields. On increasing the magnetic field intensity, these maxima broaden gradually and disappear completely at some critical field H_c. Thus, for example, the maximum for the alloy with 90 wt.% Tb disappears in a field of 7550 Oe, while that for the alloy with 10 wt.% Tb disappears at 1500 Oe. The value of the critical field H_c decreases as the Gd content is increased.

It is especially necessary to mention that on increasing the Gd content the T_c maxima in the $\sigma(T)$ curves broaden and are barely noticeable in the alloy with 10 wt.% Tb. Obviously, in the Gd–Tb alloys the nature of the dependence $\sigma(T)$ is governed primarily by the Tb atoms. Hegland, Legvold, and Spedding[1] also detected maxima, which disappeared at 300 Oe, in the $\sigma(T)$ curve for a Tb single crystal. The neutron diffraction data[2] showed that a helicoidal antiferromagnetic structure exists in pure Tb. The Néel point was found to be 229°K. The same structure was detected in Tb–Y alloys. The results of these studies and our data form the basis for the suggestion that in pure terbium, as in Gd–Tb alloys with high Tb content, the antiferromagnetic structure coexists with the ferromagnetic, i.e., in the region of the existence of antiferromagnetism, the ferromagnetic ordering of spins does not disappear completely. This complicates the determination of the ferromagnetic Curie point and the Néel temperature in these substances. If the ferromagnetic Curie point is found from the curve $\sigma(T)$, then it is more convenient to do this in strong magnetic fields. The values of the Curie temperature determined in this way show that Θ_f

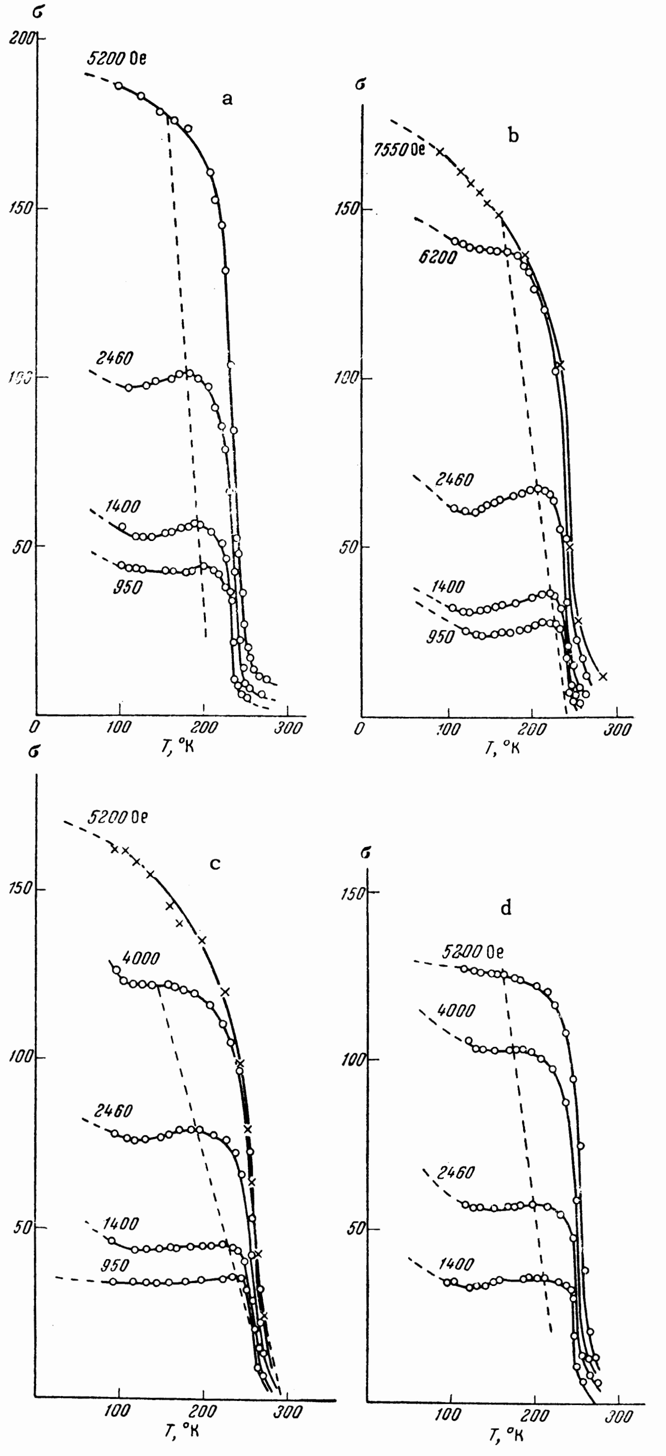

FIG. 1. Dependence of σ on T: a) Tb polycrystal; b) Gd--90 wt.% Tb alloy; c) Gd--50 wt.% Tb alloy; d) Gd--70 wt.% Tb alloy.

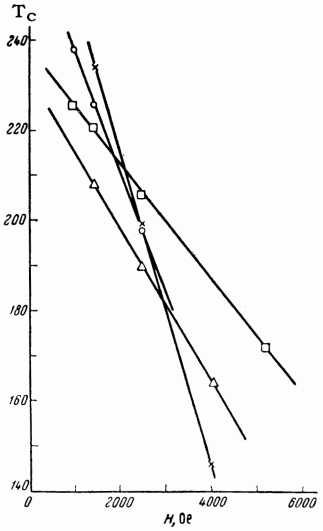

FIG. 2. Dependence of the temperature T_C on the magnetic field intensity for Gd--Tb alloys: × – 30 wt.% Tb; ○ – 50 wt.% Tb; △ – 70 wt.% Tb; □ – 90 wt.% Tb.

varies linearly with the alloy composition. In Fig. 1, dashed lines join the maxima of the σ(T) curves. It is easily seen that the temperature of the maximum, T_C, becomes displaced toward lower temperatures. This displacement of T_C is a linear function of the magnetic field, as shown clearly in Fig. 2.

We also determined the σ(T) dependence for the Gd–Er alloys (up to 50 at.% Er). It was found that these σ(T) curves also had maxima. However, in this case the maxima were sharpest for the alloys with high gadolinium content (Fig. 3).

A further investigation that we carried out involved the determination of the temperature dependence of the paramagnetic susceptibility of the Gd–Er alloys up to 1100°K. Figure 4 shows the temperature dependence of the reciprocal of this

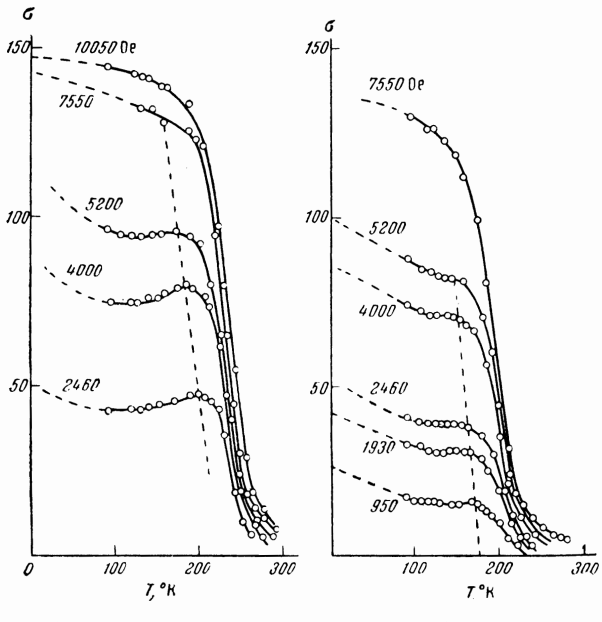

FIG. 3. Dependence of σ on T for Gd–Er alloys: a) 30 at.% Er; b) 50 at.% Er.

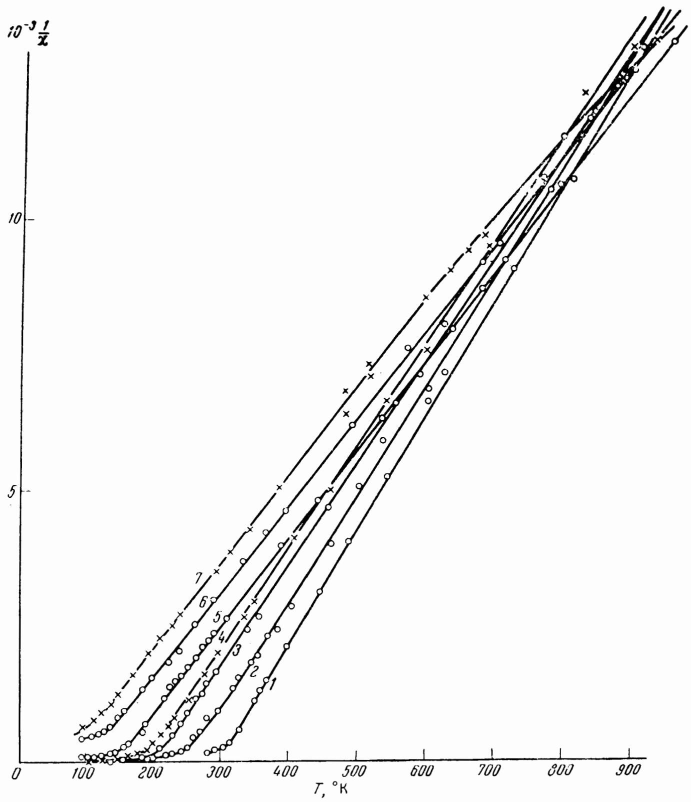

FIG. 4. Dependence of the reciprocal of the specific susceptibility on temperature for Gd–Er alloys: 1) Gd; 2) 30 at.% Er; 3) 50 at.% Er; 4) 60 at.% Er; 5) 70 at.% Er; 6) 90 at.% Er; 7) Er.

specific magnetic susceptibility for all the investigated alloys. It is evident from this figure that for the alloys containing more than 60% Gd the dependence of $1/\chi$ on T is linear over the whole investigated range of temperatures, i.e., the Curie-Weiss law in the form $\chi = C/(T - \Theta_p)$ is obeyed. For the remaining alloys, we have the law $\chi = C/(T - \Theta_p) + \chi_k$, where χ_k is the susceptibility component independent of temperature. The addition of Er to Gd also reduces the magnetic susceptibility and its temperature dependence, i.e., the curves $1/\chi(T)$ for these alloys are less steep than the curve for pure gadolinium. From the rectilinear portions of the $1/\chi(T)$ curves, we determined the effective magnetic moment P_p and the paramagnetic Curie point Θ_p. The magnetic moments of these alloys increase with increase of the Er content from 7.95 μ_B for pure Gd to 9.52 μ_B for Er. The paramagnetic Curie point shifts to lower temperatures when the erbium content is increased but remains positive at all concentrations of erbium.

3. The results of the studies of the magnetic properties of Gd–Tb and Gd–Er alloys have shown that the dependence of these properties on temperature is complex. This is particularly so in the ferromagnetic region where the ferromagnetic and antiferromagnetic structures coexist.

In conclusion, the authors express their gratitude to Prof. E. I. Kondorskiĭ for discussing the results of the present work and for his valuable comments.

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[1] Hegland, Legvold, and Spedding, Phys. Rev. **131**, 158 (1963).

[2] Koehler, Child, Wollan, and Cable, J. Appl. Phys. **34**, 1335 (1963).

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