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Translated by R. T. Beyer

Magnetic properties of certain terbium alloys with CsCl structure

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(Submitted September 27, 1976)
Zh. Eksp. Teor. Fiz. **72**, 1540–1542 (April 1977)

The magnetic properties are investigated of solid solutions of the systems $TbCu_{1-x}B_x$ (B = Ag, Zn, Al). When the copper atoms are replaced by zinc and aluminum atoms, the Neel temperature is lowered and the magnetic Curie temperature Θ_p reverses sign at 16 at.% Al and 24 at.% Zn, with $\Theta_p > 0$ for alloys with larger contents of these metals, i.e., the configuration changes from antiferromagnetic to ferromagnetic. The antiferromagnetism is preserved in the solid solution $TbCu_{0.5}Ag_{0.5}$. The results are interpreted on the basis of the RKKY theory.

PACS numbers: 75.30.Kz, 75.50.Ee

To study the role of the conduction electrons in the mechanism of exchange interaction in metallic-conductivity solid solutions having antiferromagnetic or ferromagnetic order, we have investigated the magnetic properties of solid solutions of the system $TbCu_{1-x}B_x$ (where B stands for silver, zinc, or aluminum), where the nonmagnetic copper atoms are replaced by other nonmagnetic silver, zinc, or aluminum atoms, the magnetoactive-atom concentration and the lattice parameters remaining constant, the only change being in the number of the conduction electrons per magnetic atom.

The investigated alloys were prepared by arc melting in an atmosphere of pure argon under pressure and were subjected to a homogenizing annealing. An x-ray phase shift analysis of the obtained samples (CuK_α radiation with a nickel filter) has revealed that all the alloys are solid solutions and have a crystal structure of the CsCl type (see Table I). The magnetic properties were investigated with the aid of a pendulum balance in the temperature interval 78–300 K and in magnetic fields of intensity from 1 to 15 kOe.

The results of the investigations have shown that the Neel temperature Θ_N becomes lower with increasing zinc and aluminum content (Figs. 1 and 2), and antiferromagnetic ordering exists in the $TbCu_{1-x}Zn_x$ alloys in the concentration region up to 50 at.% zinc, while in the solid solutions, where the copper atoms are replaced by aluminum atoms, an antiferromagnetic transition is observed in the investigated temperature interval for samples containing 20 at.% aluminum (see the table). In the alloy $TbCu_{0.5}Ag_{0.5}$, where 50 at.% copper is replaced by silver atoms, Θ_N remains practically the same as in the TbCu compound. As to the paramagnetic Curie temperature Θ_p, in the systems $TbCu_{1-x}Zn_x$ and $TbCu_{1-x}Al_x$ at a definite zinc concentration (24 at.%) and aluminum concentration (16 at.%) it reverses sign and becomes positive ($\Theta_p > 0$), while in the alloy containing 50 at.% silver, just as in the TbCu compound, $\Theta_p < 0$ (Fig. 2). The effective magnetic moment μ_{eff} per terbium atom does not depend on the silver, zinc, or aluminum content and corresponds to the moment of the trivalent terbium ion in the ground state $^7F_6$. The table lists the values of Θ_N, Θ_p, and μ_{eff} for all the obtained solid solutions. Using the obtained values of Θ_N and Θ_p and the relations of the molecular-field theory,[1] we have estimated the exchange-interaction parameters J_1 and J_2, which characterize respectively the interaction between the nearest neighbors and the next-to-nearest neighbors. It turned out that $J_1 > 0$ and $J_2 < 0$ for all the investigated alloys (see the table), and the change of these parameters is faster with increasing aluminum content than that of zinc, with J_1 increasing and J_2 decreasing and tending to zero.

This variation of the exchange parameters as a function of the composition explains qualitatively the transition from the type-$\pi\pi 0$ antiferromagnetic configuration,

TABLE I.

Composition	a_0, Å	Θ_N, K	Θ_p, K	μ_{eff}	J_1, K	J_2, K
TbCu	3.480	116	—25	9.72	0.95	—1.1
$TbCu_{0.5}Ag_{0.5}$	3.533	114	—23	9.96	0.94	—1.04
$TbCu_{0.9}Zn_{0.1}$	3.490	112	—18	9.62	0.98	—1.02
$TbCu_{0.8}Zn_{0.2}$	3.501	107	—6	9.59	1.05	—0.88
$TbCu_{0.7}Zn_{0.3}$	3.510	98	13	9.68	1.16	—0.66
$TbCu_{0.6}Zn_{0.4}$	3.519	88	36	9.89	1.3	—0.41
$TbCu_{0.5}Zn_{0.5}$	3.524	76[2]	68	9.82	1.5	—0.04
$TbCu_{0.9}Al_{0.1}$	3.499	107	—12	9.60	1.0	—0.93
$TbCu_{0.8}Al_{0.2}$	3.518	95	11	9.56	1.14	—0.63
$TbCu_{0.7}Al_{0.3}$	3.540	—	42	9.56	—	—
$TbCu_{0.6}Al_{0.4}$	3.547	—	71	9.82	—	—
$TbCu_{0.5}Al_{0.5}$	3.549	—	98	9.39	—	—

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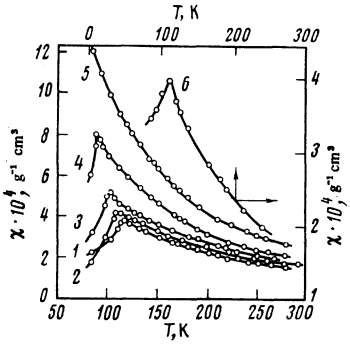

FIG. 1. Dependence of χ on T for the alloys $TbCu_{1-x}Zn_x$ at $x = 0.1$ (curve 1), $x = 0.2$ (curve 2), $x = 0.3$ (curve 3), $x = 0.4$ (curve 4), $x = 0.5$ (curve 5), and $TbCu_{0.5}Ag_{0.5}$ (curve 6).

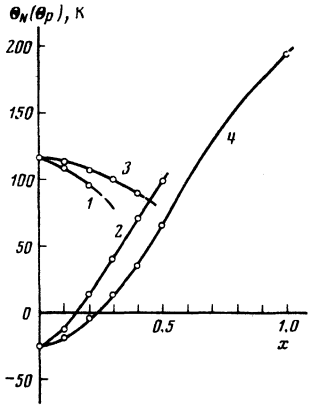

FIG. 2. Dependence of $\Theta_N(1, 3)$ and $\Theta_p(2, 4)$ on the composition for the alloys $TbCu_{1-x}Zn_x$ (3, 4) and $TbCu_{1-x}Al_x$ (1, 2). The value of Θ_p for $x = 1.0$ is taken from[5].

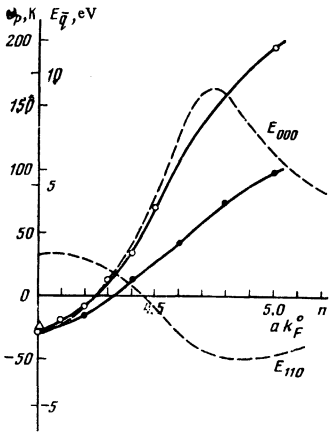

FIG. 3. Dependence of Θ_p on n (solid curves) and of $E_{\bar{q}}$ on ak_F^0 (dashed) for the alloys $TbCu_{1-x}Zn_x$ (○) and $TbCu_{1-x}Zn_x$ (●). Δ—value of Θ_p for the alloy $TbCu_{0.5}Ag_{0.5}$. The dashed lines show the sections of the theoretical Mattis curves.[3]

which neutron-diffraction investigations show to exist in the TbCu compound,[2] into the ferromagnetic configuration that appears in the solid solutions with increasing zinc and aluminum contents. This is also indicated by the reversal of the sign of the paramagnetic Curie temperature Θ_p. As to the alloy $TbCu_{0.5}Ag_{0.5}$, its values of Θ_N and Θ_p and of the parameters J_1 and J_2 remain practically unchanged in comparison with the TbCu compound. Thus, the character of the exchange interaction in the investigated solid solutions depends on the concentration of the conduction electrons.

Mattis,[3] using the RKKY theory, has determined the dependence of the energy of the magnetic configuration $E_{\bar{q}}$ on ak_F^0 (k_F^0 is the wave vector for the free electrons and a is the lattice constant) for cubic lattices and found in the case of a primitive lattice that the node of the theoretical curve for the energy of the ferromagnetic configuration corresponds to $ak_F^0 = 4.23$. According to our experimental data, on the other hand, Θ_p of the investigated solid solutions $TbCu_{1-x}Zn_x$ and $TbCu_{1-x}Al_x$ reverses sign at $ak_F^0 = 5.0$ ($n = 4.24$) and $ak_F^0 = 5.04$ ($n = 4.33$), respectively (see Fig. 3), as follows from the relation $n = (8\pi/3)(ak_F^0/2\pi)^3$,[3] where n is the number of conduction electrons per magnetic atom. If it is recognized, however, that the wave vector k_F in the investigated solid solutions differs from k_F^0 and is equal to $0.85k_F^0$ in the $TbCu_{1-x}Zn_x$ system and $0.84k_F^0$ in the $TbCu_{1-x}Al_x$ system,[4] then we find that Θ_p reverses sign at ak_F values close to theoretical. An estimate of the values of ak_F for solid solutions at different contents of zinc and aluminum has also shown that the obtained values of ak_F agree with those sections of the theoretical curves on which the ferromagnetic and antiferromagnetic states should be realized.

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