MAGNETIC PROPERTIES OF SINGLE-CRYSTAL AND POLYCRYSTALLINE YTTRIUM

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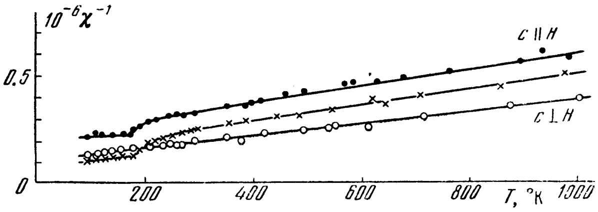
The magnetic properties of single-crystal and polycrystalline yttrium were investigated. It was found that the magnetic susceptibility was higher measured in a direction at right-angles to the c-axis than parallel to that axis. In both cases, the paramagnetic Curie point was negative.

1. It is well known that yttrium belongs to the palladium group and has one uncompensated spin in the 4d-band. Therefore, we can expect that the localization of the d-electrons in this metal is slight. The temperature dependence of the magnetic susceptibility of metallic yttrium has not yet been studied. The literature contains data on only the temperature dependence of the electrical resistance and specific heat.[1-3] An investigation of the magnetic susceptibility can give us new information on the role of the d- and s-electrons in the magnetic properties of weakly magnetic transition metals.

2. The magnetic properties of yttrium were investigated by us using both polycrystalline and single-crystal samples. An yttrium single crystal was prepared by the recrystallization annealing method[4] from the distilled metal. The original metal contained the following amounts of impurities: $\leq 0.004\%$ calcium, $\leq 0.07\%$ copper, $\leq 0.02\%$ iron, and $\leq 0.3\%$ other rare-earth metals.

A photomicrograph of the distilled yttrium showed fine grain boundaries free of nonmetallic occlusions. Before annealing, the yttrium was deformed—by static pressing—by 5—7%, which corresponded to the critical deformation of yttrium. The samples were annealed in vacuum at a residual pressure of 10^{-6} mm Hg; the annealing temperature did not exceed 1350—1400°C. Depending on the duration of the annealing, we were able to obtain single crystals of various sizes right up to $12 \times 10 \times 5$ mm. One-hundred-hour anneals were required to obtain large single crystals. The single crystals were oriented by the Laue method. From these two samples were cut in the shape of parallelepipeds of 1—2 mm cross section and 3—4 mm height. The samples were cut along and at right-angles to the c-axis. Then the surfaces of the samples were etched away by a solution of nitric acid and alcohol in order to remove the surface cold-work layers.

The temperature dependence of the magnetic susceptibility was measured between 77 and 1000°K by the Sucksmith method. First, we investigated a polycrystalline sample. The figure (the middle curve) shows that approximately between 300 and 1000°K the dependence of $1/\chi$ on T was linear. At low temperatures, in the region of 170°K, the dependence of $1/\chi$ on T exhibited a discontinuity.



The dependence of $1/\chi$ on T. The middle curve represents polycrystalline yttrium.

The magnetic properties of the yttrium single crystals were investigated along two directions: with the field parallel and perpendicular to the c-axis. Tests showed that the magnetic susceptibility measured at right-angles to this axis was considerably higher than along the axis. It should be noted also that in the former case the quantity $1/\chi$ varied strictly linearly with temperature over the whole investigated range.

In the latter case, i.e., when $H \parallel c$, the temperature dependence of the magnetic susceptibility exhibited a discontinuity, similar to that found for the polycrystalline sample. At temperatures below this discontinuity, the value of the susceptibility remained practically constant. The appearance of the discontinuity in the $1/\chi = f(T)$ curve may be due to various reasons, including the influence of impurities, particularly those of the rare-earth metals. Using the Curie-Weiss law, we determined the value of the paramagnetic Curie point Θ_p and the effective atomic magnetic moment P_p. It was found that $P_p = 1.34\,\mu_B$ and Θ_p was negative in all cases: $\Theta_{p\parallel} = -510°K$, $\Theta_{p\perp} = -330°K$ and $\Theta_{p.polycr} = -390°K$.

Thus, Θ_p obeys the relationship

$$\Theta_{p\ \mathrm{polycr}} = \tfrac{1}{3}\,\Theta_{p\parallel} + \tfrac{2}{3}\,\Theta_{p\perp}. \qquad (1)$$

A similar relationship was established earlier for the paramagnetic Curie point of neodymium[5] and scandium.[6] Our results show also that the magnetic susceptibility obeys the following relationships:

above room temperature

$$\chi_{\mathrm{polycr}} = \tfrac{1}{2}(\chi_{\parallel} + \chi_{\perp}), \qquad (2)$$

and at low temperatures

$$\chi_{\mathrm{polycr}} = \tfrac{1}{3}(\chi_{\parallel} + \chi_{\perp}). \qquad (3)$$

3. The results of the present investigation of the magnetic properties of yttrium show that its magnetic susceptibility depends weakly on temperature and $d\chi/dT < 0$. This temperature dependence of the susceptibility suggests that yttrium of the purity used in our tests has a high density of electron states and its Fermi energy should be close to the maximum of the energy dependence of the density of states. This is supported by measurements of the electronic specific heat of yttrium carried out by Montgomery and Pells.[1] Obviously, in metallic yttrium there are collective-state electrons of the d—s-band and electrons of the d-band, subjected to spatial localization, which determine, to a great extent, the temperature dependence of the susceptibility.

Our experimental results are in qualitative agreement with the general theoretical representations of the electronic structure of the transition metals. It is possible that an antiferromagnetic interaction exists in metallic yttrium because, according to our experiments, the paramagnetic Curie point is less than zero.

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