Thermal expansion of thulium in the 2-300 °K temperature range

N. S. Petrenko and V. P. Popov

Khar'kov State University

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The thermal expansion of Tm (∾ 99.9% purity) is investigated by the dilatometric technique at low temperatures. The anomalies in the thermal expansion observed at 56, 32, and 10 °K can be ascribed to magnetic transformations at these temperatures.

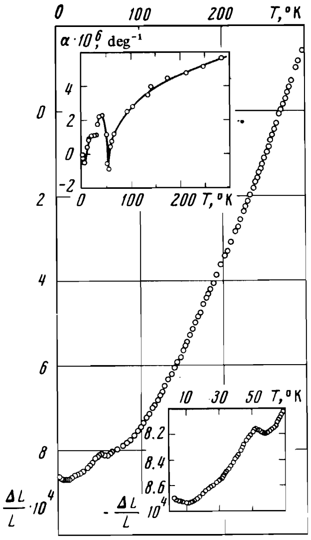
The thermal expansion of Tm at temperatures below 90° K was not investigated before. Yet according to neutron-diffraction studies[1,2] it is precisely in this temperature that unique magnetic transformations occur in Tm. Consequently a study of the thermophysical properties of this rare-earth metal at low temperatures is of considerable interest.

Neutron diffraction studies[1,2] have shown that Tm goes over at 56° K from a paramagnetic into an antiferromagnetic state with a complex developed structure of the "static longitudinal spin wave" type (LSW). This structure is preserved down to 38° K. Below 38° K, a unique antiphase-domain structure is produced and can be described in first order as an alternation of magnetic moments oriented parallel and antiparallel to the c axis. For each four moments parallel to the c axis there are three antiparallel moments. This gives grounds for assuming that Tm is ferrimagnetic in this temperature region. At the same time, a ferromagnetic component in the magnetic structure of Tm was observed at 32° K[2]. An investigation of a number of physical properties of polycrystalline Tm (specific heat[3], magnetic susceptibility[4], resistivity[5]) has revealed the presence of anomalies at approximately the same temperatures.

The purpose of the present paper is to study the thermal expansion of Tm in the temperature interval 2—300° K. To measure the relative elongations ($\Delta L/L$) of the sample we used a procedure that did not differ in principle from that described earlier[6]. The error in the measurement of $\Delta L/L$ was $\leq 2\%$ in the entire temperature interval. The temperature was measured with a copper—ZLZh-999 thermocouple (in the interval 2—25° K) with accuracy ±0.2° K, and with a platinum resistance thermometer (in the interval 15—300° K) with accuracy 0.01° K. The investigations were performed on polycrystalline Tm (grade "0") of purity ~99.9%. The sample was a plane-parallel plate measuring 1 × 2 × 50 mm.

The measurement results are shown in the figure. In the paramagnetic region ($T > 56°$ K), the thermal expansion has a normal character, although the coefficient of thermal expansion is lower than that of most previously investigated heavy rare-earth metals.

We call attention first to the anomaly observed at 56° K (T_N). The presence of an inflection on the $\Delta L/L = f(T)$ curve and the negative λ anomaly of the linear-expansion coefficient α (upper insert¹⁾) are typical of second order phase transitions. The sign of the anomaly indicates, that in accordance with the Landau theory of phase transitions[7] we have $\Delta\alpha = (\Delta c_p/VT)dT/dp$ and the transition temperature should decrease following hydrostatic compression. Incidentally, a negative value of dT_N/dp is typical of transitions observed in all other heavy rare-earth metals[8]. The change in the $\Delta L/L = f(T)$ curve at 32° K (see the lower insert) confirms that a magnetic transformation LSW—antiphase domain structure takes place at this temperature. The jump of α at this temperature is $\sim(6 \pm 0.6) \times 10^{-7}$ (see the upper insert). The measurement accuracy, however, is insufficient for a reliable assessment of the character of the phase transition at this temperature.



The change in the sign of the thermal-expansion coefficient α at 10° K is very instructive and confirms the assumption, previously based on magnetic measurement data[9], that the spin orientation becomes further realigned at this temperature. We note that no changes were observed in the specific heat of Tm[10] at 10° K.

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¹⁾The data were obtained by graphically differentiating the $\Delta L/L = f(T)$ curve.

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