THERMAL CONDUCTIVITY OF Tm, Yb, *AND* Lu *AT LOW TEMPERATURES*

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The thermal conductivity of Tm, Yb, and Lu was investigated in the temperature range 2—100°K. It was found that the antiferromagnetic–paramagnetic transition affected the thermal conductivity of Tm at 53°K. At 4.2°K, the Lorenz numbers calculated for Yb and Lu, which were not magnetically ordered, were higher than the theoretical values. The Lorenz number for Tm, which was magnetically ordered, was anomalously high. It is suggested that at 4.2°K Yb and Lu samples still exhibited, in addition to the electronic component of the thermal conductivity, a considerable lattice component, while Tu also had a magnetic component.

INTRODUCTION

INVESTIGATIONS of the thermal conductivity of the transition metals Ti, Zr, V, Hf, Mn, Ce,[1,2] Sc, Yt[3] have shown that, in the residual resistance region ($\rho = \rho_0$), the Lorenz numbers, defined as the ratio $L_0 = K\rho_0/T$, where K is the thermal conductivity, are higher than their theoretical values. These high values ($3—3.5 \times 10^{-8} V^2/deg^2$) have been ascribed to the presence, in addition to that of the electronic component, of the phonon component in the total thermal conductivity of these metals, with the latter component still playing a considerable role at quite low temperatures.

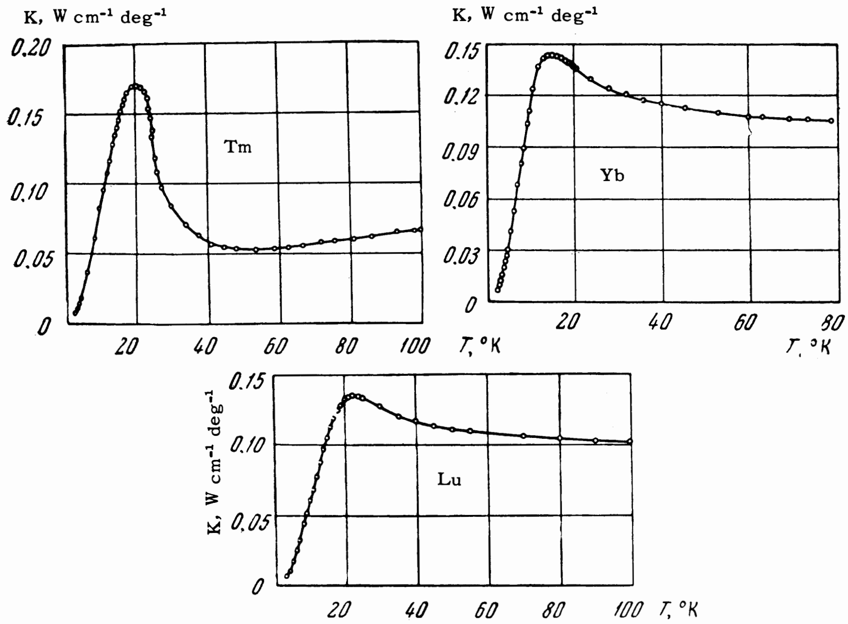
From recent investigations of the thermal conductivity of rare-earth metals (REM), it follows that the Lorenz numbers of Gd, Dy, and Tb[4-6] are anomalously high ($7—10 \times 10^{-8} V^2/deg^2$). Similar values were obtained by us for Gd and Tb,[7] Ho and Er.[8] Compared with the theoretical value of the Lorenz number, equal to $L_0 = 2.45 \times 10^{-8} V^2/deg^2$, they were so high that it was hardly possible to explain them by the presence of only two types of heat carriers, electrons and phonons. Therefore, we suggested that in the investigated samples the thermal conductivity could have a magnon component, in addition to the electron and phonon components. It should be mentioned that the magnon component should appear only in metals having magnetically ordered states. In REM having a closed 4f-shell and no magnetic moment, the magnon thermal conductivity should be absent. In view of this, it is interesting to investigate the thermal conductivities of such metals and to compare them with those of other REM, having magnetically ordered states. In the present work, we investigated for the first time the thermal conductivities of three consecutive elements in the series of heavy REM: Tm, which has a complex magnetic structure, and Yb and Lu, which exhibit no magnetic ordering.

RESULTS OF MEASUREMENTS AND DISCUSSION

We measured the temperature dependence of the thermal conductivity of 99.99% pure polycrystalline samples, in the form of strips 0.25 mm thick, in the temperature range 2—100°K for Tm and Lu and 2—80°K for Yb. We measured also the electrical resistivity of these samples at room temperature and at 4.2°K. All the samples were annealed in a stream of helium vapor. The temperature and duration of annealing and the electrical resistivities of the samples are listed in the table.

Samples	Annealing Temperature, °C	Duration of annealing, hr	$10^6\rho$, Ω cm	
			$T = 239$ °K	$T = 4{,}2$ °K
Tu	650	3	79	12.7
Yb	450	2.5	27	5.56
Lu	600	3	79	12.3

The temperature dependences of the thermal conductivity of the samples are shown in the figure. All three curves have the form typical of the thermal conductivity of pure metals: the conductivity increases sharply with temperature at low temperatures, passes through a maximum near $T = \Theta_D/10$ (Θ_D is the Debye temperature), and decreases rapidly at higher temperatures, becoming finally almost independent of temperature in the case of Yb and Lu. The nature of the thermal



Temperature dependence of the thermal conductivity of Tm, Yb, and Lu.

conductivity curve of Tm resembles the corresponding curves for REM investigated earlier: at 53°K, the magnetic order disappears[1)] and the thermal conductivity begins to rise markedly as the temperature increases through the paramagnetic region. The magnetic transition at the point $T_C = 22$°K is not reflected in the thermal conductivity curve of Tm.

The Lorenz numbers for the investigated samples of Tm, Yb, and Lu were found to be, respectively, 7.30, 3.17, and 3.40 (all in units of $10^{-8} V^2/deg^2$). It was characteristic that for Tm this number was again high, as in other REM exhibiting magnetic ordering at low temperatures, while the Lorenz numbers of Yb and Lu had values similar to those of transition d-metals. Since the anomalously high values of the Lorenz number are observed only in REM having magnetically ordered states at low temperatures, it is natural to assume that the third carrier of heat (in addition to electrons and phonons), is in the form of thermal perturbations in the system of ordered moments, i.e., magnons. The special role played by these quasiparticles in heat transfer in REM is obviously associated with the fact that a system of ordered magnetic moments in these metals is easily excited (low values of T_C). The low values of T_C and of Θ_D of these metals result in the fact that even at very low temperatures they contain a sufficient number of magnons and phonons taking part in the process of heat transfer. The quantitative separation of the contributions of electrons, phonons, and magnons to the thermal conductivity is not yet possible.

1)Tm is paramagnetic above 53°K, antiferromagnetic between 53 and 22°K, and below 22°K it has a complex structure in the basal plane with an uncompensated magnetic moment.[9]

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184