Reprinted from: LOW TEMPERATURE PHYSICS-LT 13, VOL. 2
Edited by K. D. Timmerhaus, W. J. O'Sullivan, and E. F. Hammel
Book available from: Plenum Publishing Corporation
227 West 17th Street, New York, New York 10011

Kondo Effect in *Y*Ce under Pressure

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Introduction

In an earlier paper we showed that the Kondo temperature T_K of *La*Ce increases upon application of pressure.[1] This result was derived from the pressure dependence of the superconducting transition temperature by applying the theory of Müller-Hartmann and Zittartz.[2] It was independently derived from the temperature dependence of the resistance R at different pressures and the variation of R with pressure at constant temperature, using the calculation of Hamann.[3]

Similar measurements have been reported by other authors, who instead interpreted their results in terms of a magnetic–nonmagnetic transition of the Ce impurities at pressures at which both the slope $dR/d(\ln T)$ and the superconducting pair-breaking effect decrease.[4] Particularly, the disappearance of the resistance minimum of *Y*Ce under pressure has been presented as an argument for the vanishing magnetic moment of the cerium impurities.[5] This explanation has become widely accepted in the literature; review articles have already appeared.[6,7]

We have reinvestigated the pressure dependence of the resistance anomaly of Y 1 at.% Ce. In analogy with the results for *La*Ce and also for *Cu*Fe,[8] we expected a shift of T_K to higher temperatures with pressure. The experimental results clearly show that this is so. The Kondo temperature is raised from 17°K at zero pressure to approximately 110°K at 30 kbar, while the magnitude of the anomaly is unchanged.

Results

Measurements were taken using a piston-cylinder technique in a pair-of-tongs apparatus described earlier.[9] It is sensitive to $\pm$ 100 bar at zero pressure and can be cycled repeatedly up to 45 kbar. Steatite has proved to be a sufficiently hydrostatic medium.[10] Samples of pure yttrium and Y 1 at.% Ce were mounted in series in the pressure cell and fed by the same current.

Figure 1 shows the resistance vs. ln T for both Y and *Y*Ce as obtained directly in the low-temperature regime. The Y sample shows normal behavior at all pressures

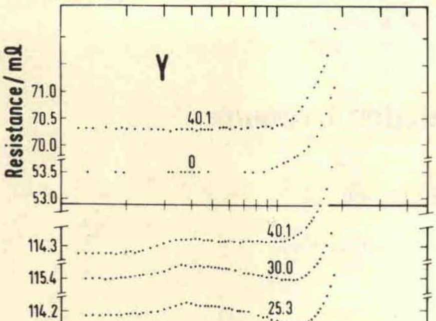

Fig. 1. Low-temperature electrical resistance of Y and Y 1 at. % Ce vs. temperature at various pressures.

up to 40 kbar. At low temperatures the phonon dependence is $T^{4.0}$ for all pressures. Only data for 0 and 40 kbar are given.

The decrease with pressure of the depth of the resistivity minimum in *Y*Ce is qualitatively in accord with the results of Maple and Wittig.[5] It led these authors to conclude that the magnetic moment of the Ce impurity vanishes in this pressure regime. In contrast, our results show that this is due to an increase of the Kondo temperature. In order to see this, it is necessary to isolate the magnetic part of the temperature-dependent resistivity from the phonon part at higher temperatures. This can be achieved as follows: Near room temperature the magnetic part of the resistance is negligibly small, at least at low pressure, i.e., low Kondo temperatures. Thus the slope of a R_Y vs. R_{YCe} plot near 300°K determines the geometric factor *m* between both samples. This factor does not change by more than 0.8 % for all pressures up to 25.3 kbar. Assuming the constancy of the residual resistance up to room temperature (i.e., Matthiessen's rule) and that the *T* dependence of the phonon part of the resistance is identical for *Y*Ce and Y, one obtains the magnetic resistance anomaly.

Figure 2 shows the result of this procedure. The main physical result is that an

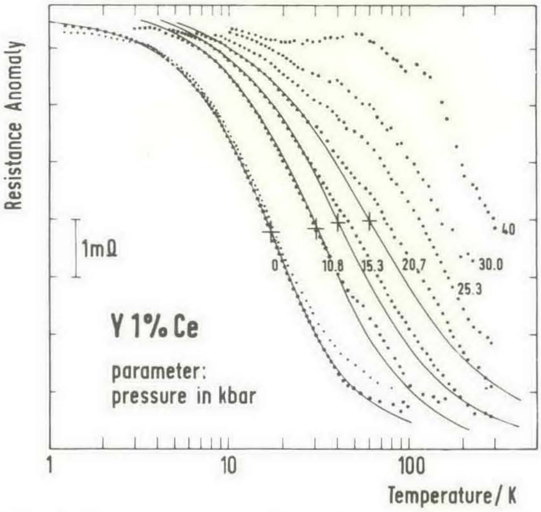

Fig. 2. The magnetic part of the resistance of Y 1 at.% Ce at various pressures and some fitted curves (solid lines) calculated from Hamann's equation.

application of pressure shifts the Kondo anomaly rather drastically to higher temperatures. One notes that for zero pressure the resistance anomaly is rather well described by Hamann's function for $\rho_m(T)$ over two decades of temperature (solid lines). The smaller dots represent zero-pressure data, which were obtained after removal of pressure from 25.3 kbar. With increasing pressure a deviation from the Hamann-type behavior starts to develop above 30°K, which may be due to a deviation from Matthiessen's rule, as suggested by Loram *et al.* for *Cu*Fe, *Au*Fe, and *CuAu*Fe alloys.[11] Hamann fits for higher pressures were thus obtained from the curvature of the data between 8 and 30°K. The fit parameters are given in Table I. While the magnitude of the anomaly $\rho_m(0)$ stays close to 8 mΩ (2.3 μΩcm) up to 30 kbar, the Kondo temperature rises to approximately 110°K.

In conclusion, a monotonic shift of T_K, but no magnetic transition, was observed. The results strongly support our earlier results on *La*Ce.

Table I

p, kbar	T_K, °K	S	$\rho_m(0)$, μΩ-cm
0	17 ± 0.3	0.11	2.26
5.8	21 ± 1	0.14	2.44
10.8	31 ± 1	0.16	2.46
15.8	40 ± 2	0.20	2.46
20.7	60 ± 3	0.25	2.44
25.3	80 ± 5	0.20	2.55
0	17 ± 0.5	0.11	2.26
30	110 ± 15	0.20	2.32
40	(140 ± 40)	(0.20)	2.32

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