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KONDO EFFECT IN YCe UNDER PRESSURE

M. Dietrich and W. Gey

Institut für Experimentelle Kernphysik der Universität
und des Kernforschungszentrums Karlsruhe, Germany

and

E. Umlauf

Zentralinstitut für Tieftemperaturforschung der Bayerischen,
Akademie der Wissenschaften, Garching b. München, Germany

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The decrease of the electrical resistivity minimum in Y 1 at.% Ce with pressure is shown to be due to a monotonic shift of the Kondo anomaly to higher temperatures. At pressures at which the resistivity minimum has practically disappeared (30 kbar), the magnitude of the anomaly does not differ from its zero pressure value. Thus the concept of a magnetic–nonmagnetic transition of the Ce impurities in this pressure regime must be abandoned.

IN AN EARLIER paper we have shown that the Kondo temperature T_K of <u>La</u>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 YCe 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 <u>La</u>Ce and also for <u>Cu</u>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. Y 1 at.% Ce is advantageous because of its absence of superconductivity in the pressure regime used and its relatively high Kondo temperature at zero pressure, which permits the use of standard cooling techniques.

The measurements were taken using a piston-cylinder technique in a pair-of-tongs apparatus described earlier.[9] It is sensitive to ± 100 bar at zero pressure and can be cycled repeatedly up to 45 kbar. The use of steatite has proved to be a sufficiently hydrostatic medium.[10] Nevertheless to avoid excessive cold work on the samples, pressure was always applied at room temperature. Samples of pure yttrium (purity 99.9%, residual resistivity ratio $R_{300K}/R_{4K} = 7.8$) and Y 1 at.% Ce ($R_{300K}/R_{4K} = 3.1$) were mounted in series in the pressure cell and fed by the same current of 10.000_5mA. Voltages were measured with a Yokogawa Digital Voltmeter with a $\pm 0.1\mu$V sensitivity. The <u>Y</u>Ce alloy was prepared from a master alloy by induction melting on a cooled copper substrate in an atmosphere of high purity argon. Suitable sample sizes were obtained by cutting these slabs with a grinding wheel and polishing by hand to the desired thickness. The resistivity of the materials was determined from larger pieces of the same alloy. The dimensions were determined by means of a travelling microscope and micrometer and controlled by weighing the samples with an electronic microbalance. The resistivities of Y and Y 1 at.% Ce at 4.2 K are $11.8\mu\Omega$cm and $31.6\mu\Omega$cm, respectively.

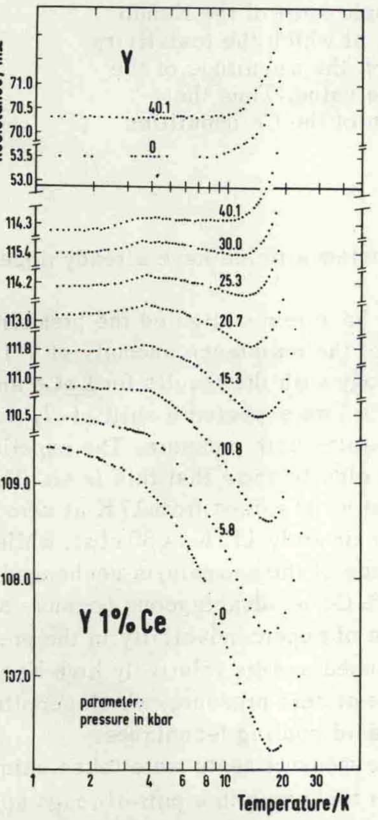

FIG. 1. Low temperature electrical resistance of Y and Y 1 at.% Ce vs. temperature at various pressures.

Figure 1 shows the resistance vs. ln T for both Y and YCe as obtained directly in the low temperature regime. The Y sample shows normal behaviour at all pressures up to 40 kbar with measurable phonon resistivity beginning near 9 K. At low temperatures the phonon dependence is $T^{4.0}$ for all pressures. Only data for 0 and 40 kbar are given. The increase of residual resistivity from 0 to 40 kbar is large because of repeated pressure cycling between these pressures after a continuous run from 0 to 25.3 kbar.

The decrease with pressure of the depth of the resistivity minimum in <u>Y</u>Ce is qualitatively in accord with the results of Maple and Wittig.[5] The difference in the relative depth for 25 kbar is remarkable and may be due to a different pressure quotation. At zero pressure $\rho(1\text{K}) - \rho(10\text{K})$ is $0.58\mu\Omega$cm in our measurements in accord with measurements of Sugawara and Yoshida[11] (normalized to 1 at.% Ce) but differing from the corresponding value of about $0.9\mu\Omega$cm in reference 5. The minimum is shifted with pressure to lower temperatures. It is barely noticable at 30 kbar and has completely disappeared at 40 kbar. These pressure quotations are about half of those of Maple and Wittig. Similar to Y the low temperature resistivity plateau for YCe rises slightly with pressure. The value for 40.1 kbar is low because of a five days annealing at 300 K under this pressure. This indicates imperfections introduced during the application of pressure. Except for the starting zero pressure run, all curves show a kink near 3.8 K with a slightly depressed resistivity below 3.8 K. It is still observed after complete removal of pressure from 25.3 kbar, although the remaining low T part of the curve is practically identical with the starting zero pressure run (not shown). Magnetic ordering upon application of mechanical stress may be suspected.

The gradual disappearance of the resistivity minimum with pressure and its shift to lower temperatures has actually led Maple and Wittig 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