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CHARACTERISTIC TEMPERATURES IN THE HEAVY-FERMION SYSTEM $U(Pt,Pd)_3$

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A summary is presented of the characteristic temperatures in the series of $U(Pt,Pd)_3$ heavy-fermion compounds as derived from thermodynamic and transport measurements.

1. INTRODUCTION

The heavy-fermion system $U(Pt,Pd)_3$ is an outstanding example in which many ingredients that are characteristic for heavy-fermion behaviour in cerium and uranium intermetallics are found to be present: a strongly correlated electron gas leading to large values for the electronic coefficient in the specific heat, spin-fluctuation and/or Kondo-type of behaviour in the resistivity, superconductivity, long-range antiferromagnetic order, short-range antiferromagnetic correlations etc. (1), see fig.1. Each of these phenomena can be represented by a characteristic temperature. These characteristic temperatures are well defined for the transition to an ordered state but are less established for the other phenomena. In this contribution values for these characteristic temperatures are collected as they can be deduced from mostly published data on the thermomagnetic and transport properties of the $U(Pt,Pd)_3$ system.

2. CHARACTERISTIC TEMPERATURES

Heavy-fermion systems are well known for their anomalous low-temperature behaviour in the specific heat that becomes prominent below a certain temperature. In general, the coefficient of the linear term in the specific heat is considered to be inverse proportional to the characteristic temperature, T^*, of the strongly interacting electron gas. Since no proper theory for describing the heavy-fermion part in the specific heat is available at present, the definition of this temperature on the basis of the specific heat results is rather ambiguous. One way to arrive at a value for this temperature is by adopting the result for a single-ion (spin-1/2) Kondo model: $\lim_{T\to 0} c/T = 0.68\ R/T_K$, where R is the gas constant and T_K the Kondo temperature (2). Identifying the characteristic temperature T^* with this Kondo temperature will lead in case of UPt_3 with $\lim_{T\to 0} c/T = \gamma^*$ equal to 420 mJ/mol K^2, to a value of 13.2 K. This identification, however, is not justified because of the coherence effects that dominate the low-temperature phenomena. Nevertheless, we shall use the specific-heat data that are available for the 1, 2, 5, 7, 10 and 15 at % Pd in order to derive in the above-given way the change in the characteristic temperature T^* with Pd content. There is an additional difficulty to study the variation of the heavy-fermion effect in the $U(Pt,Pd)_3$ system in this manner because of the long-range antiferromagnetic order below 6 K that sets in for Pd concentrations between 1 and 10 at %. The specific-heat anomaly associated with this long-range antiferromagnetic order is still present at temperatures down to 1.5 K and hampers the evaluation of the remaining heavy-fermion contribution to the specific heat.

Another method to follow in deriving a value for T^* is to separate the heavy-fermion contribution to the specific heat from the remaining contributions on the basis of an experimental approach. The method that has been followed for UPt_3 and $U(Pt_{0.95}Pd_{0.05})_3$ is the evaluation of the heavy-fermion part to the specific heat by applying a Grüneisen analysis (3). This analysis is most successful in compounds where different contributions with largely different values for the corresponding Grüneisen parameters are present. Extremely large values for the electronicGrüneisenparameter is a typical feature of most heavy-fermion compounds. In

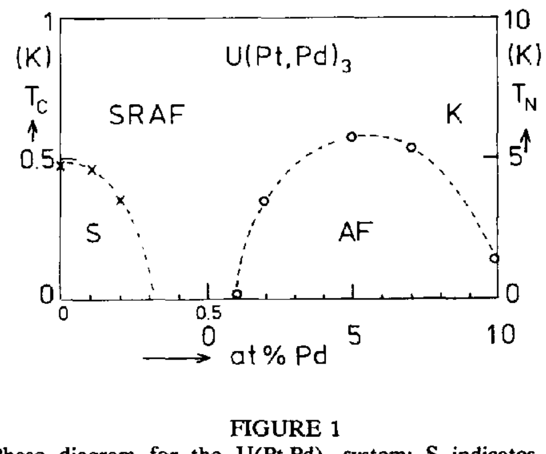

FIGURE 1
Phase diagram for the $U(Pt,Pd)_3$ system: S indicates the superconducting phase, AF the long-range antiferromagnetically ordered state, K the Kondo regime and SRAF the region where the short-range antiferromagnetic correlations are most pronounced.

UPt_3, this parameter takes a value of 71 to be compared with values of about two for the lattice and normal electronic contributions. In such a situation a combined analysis of specific-heat and thermal-expansion data can lead to a splitting of the heavy-fermion part and the lattice and normal electronic contributions to specific heat and thermal expansion. As a result of this analysis, a heavy-fermion contribution to the specific heat is obtained in a phenomenological way that shows some resemblance with the spin-1/2 single-ion Kondo specific heat. The entropy of this contribution turns out to saturate above 100 K and reaches a saturation value of almost exactly R ln 2. The heavy-fermion contribution has its maximal value around 12 K, not far from the temperature of 13.2 K deduced above. The Grüneisen analysis is more complicated in case of the $U(Pt_{0.95}Pd_{0.05})_3$ compound where long-range antiferromagnetic order sets in below 6 K. Analysing the data above 6 K, however, a clear shift of the heavy-fermion curve to lower temperatures is found, resulting in a three times smaller value for the temperature where the maximum in the heavy-fermion part of the specific heat is expected (4). This temperature (4.4 K) is given in fig.2 as well. Other

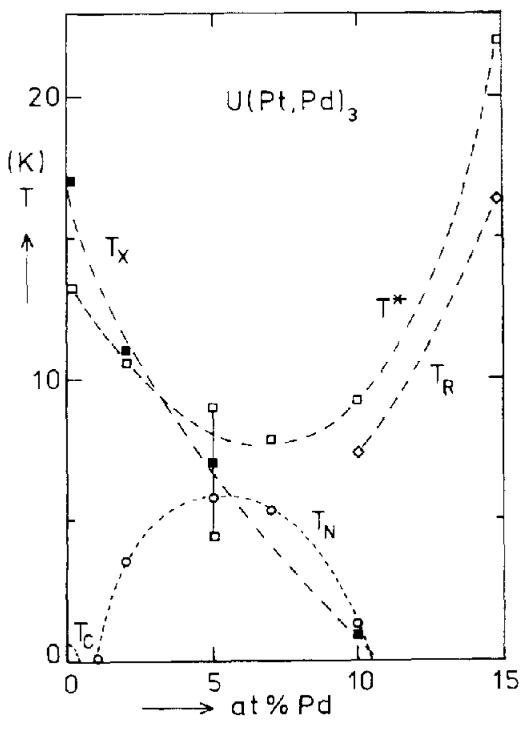

FIGURE 2
Characteristic temperatures for the $U(Pt,Pd)_3$ system: T^* from the specific heat, T_X from the susceptibility, T_R from the resistivity; T_C and T_N are the superconducting transition and the Néel temperature, respectively; data from ref.5.

characteristic temperatures are the superconducting transition temperature, T_C, and the Néel temperature, T_N, as deduced from the peak in the specific heat of the relevant compound. Two other characteristic temperatures remain to be discussed: the temperature T_X, reflecting the temperature where a maximum in the susceptibility is found in the hexagonal plane and the temperature T_R, a temperature characterising the temperature dependence of the resistivity. This latter temperature is rather badly defined because of the change-over from spin-fluctuation to Kondo-type of behaviour in the resistivity curves. An appropriate definition of T_R for UPt_3 is the temperature where the temperature derivative of the resistivity takes its maximum. Going from pure UPt_3 to the 10 at % Pd alloy, however, the quadratic temperature dependence at the lowest temperatures changes into a typical Kondo curve with increasing resistivity values for decreasing temperatures. For the 10 and 15 at % Pd alloys, T_R is best defined by the maximal (negative) slope in the ρ vs T curve. Only these results for T_R are shown in fig.2.

3. CONCLUDING REMARKS

At higher Pd concentrations, the characteristic temperatures T^* and T_R both increase with increasing Pd content, whereas T_N decreases, leading to a loss of antiferromagnetism above 10 at % Pd. This behaviour fits into a general picture in which the Kondo interactions become dominant over the RKKY interactions for larger values of the exchange coupling constant. It is tempting to deduce from this result an increase in the exchange constant with increasing Pd content.

At low Pd concentrations, the large values for T_X indicate strong short-range antiferromagnetic correlations. These correlations are weaker in the compounds where long-range antiferromagnetic order exists. These short-range correlations certainly contribute to the specific heat and consequently to the value of T^*. It must be concluded for that reason, that the T^* values within this range of Pd concentration are not directly comparable. This conclusion is supported by the change in sign of the initial field dependence of the coefficient γ^* between 7 and 10 at % Pd.

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