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J. Kappler, G. Nieva, J. Sereni, J. Souletie. STATIC SCALING IN THE CePd3Bx KONDO SYSTEM. Journal de Physique Colloques, 1988, 49 (C8), pp.C8-725-C8-726. 10.1051/jphyscol:19888329 . jpa-00228504

HAL Id: jpa-00228504

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Submitted on 1 Jan 1988

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JOURNAL DE PHYSIQUE
Colloque C8, Supplément au n° 12, Tome 49, décembre 1988

STATIC SCALING IN THE $CePd_3B_x$ KONDO SYSTEM

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Abstract. – The static scaling hypothesis for continuous transitions, extended to cases where $T_c < 0$, has appropriate features to describe heavy fermions. We present here the application of this model to the specific-heat and susceptibility anomalies for the concentrated Kondo system $CePd_3B_x$ ($x = 0.4$ and 1).

1. Introduction

The specific heat and the susceptibility of many Kondo systems can be rationalized in the framework of a model [1] which extends to negative values of the critical temperature T_c ($T_c = -T_K$) the same hypotheses which are currently used with $T_c > 0$ to describe the static properties of a second order transition. Within the model we write the Gibbs potential in dimension d as

$$G/t = \xi^{-d} g\left(\xi^{\bar{d}} H/T\right) \text{ with } \bar{d} \leq d \qquad (1)$$

in terms of a correlation length ξ of the form $\xi = t^{-\nu}$ with $t = 1 + T_K/T$ and ν the critical exponent.

The application of standard thermodynamic leads to the following expressions for the specific heat C_p and the susceptibility χ [1, 2]:

$$C_p T^2 = A\left(1 + T_K/T\right)^{-\alpha} \text{ with } \alpha > 2 \qquad (2)$$

$$\chi T = C\left(1 + T_K/T\right)^{-\gamma} \text{ with } 2 - \alpha < \gamma < \alpha - 2. \qquad (3)$$

If the multiplet which is undergoing the Kondo condensation is known we have $C = g^2 \mu_B^2 S\left(S+1\right)/3k_B$ and $A = \Delta S\left(1-\alpha\right)\left(2-\alpha\right) T_K^2$ where $\Delta S = R \ln\ (2S+1)$ so that the specific heat and the susceptibility are completely determined by the specification of two points [1]. Another method to know the parameters for a good fit with equations (2) and (3) is to check the differential form of these equations:

$$P_{C_pT^2} = -\Delta \ln T/\Delta \ln \left(C_p T^2\right) = \left(T_K + T\right)/\alpha T_K \qquad (4)$$

$$P_{\chi T} = -\Delta \ln T/\Delta \ln \left(\chi T\right) = \left(T_K + T\right)/\gamma T_K. \qquad (5)$$

The plots of $P_{C_pT^2}$ and $P_{\chi T}$ *vs.* T should produce straight lines which extrapolate to the same T_K and whose intercepts with the y axis are the inverses of the corresponding exponents (Fig. 1).

We have applied this method to the analysis of the low T anomaly in $CePd_3B_{0.6}$ and $CePd_3B$ [3] for which we found $T_K = 0.95$ K and 0.8 K respectively with the exponents $\alpha = 4$ and $\gamma = 1.4$ in both systems. The figure 1 shows the plot for the $CePd_3B_{0.6}$ case. For

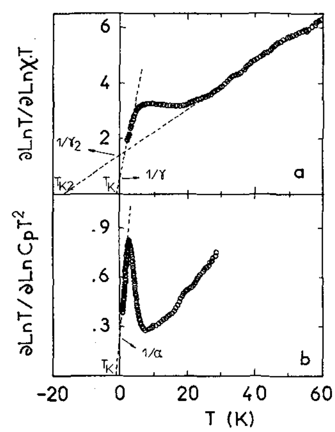

Fig. 1. – Plot of a) $-\Delta \ln T/\Delta \ln\ (\chi T)$ and of b) $-\Delta \ln T/\Delta \ln \left(C_p T^2\right)$ *vs.* temperature. For both the susceptibility χ and the specific heat C_p there is a linear regime at low temperature from which the Kondo temperature T_K and the critical exponents α and γ are deduced.

$1\text{ K} < T < 4$ K the indications of the susceptibility are consistent with those of the specific heat: i.e. the data in figure 1 align along two lines which extrapolate to the same T_K. (For $CePd_3B$ the susceptibility exhibits a plateau below $T = 1$ K (see Fig. 3) which cannot be analysed consistently with the specific heat using the same plot (Eq. (5)). In this range the zero field cooling and field cooling susceptibilities are different and may be we are not dealing with equilibrium values.) With T_K known, by plotting $\ln \left(C_p T^2\right)$ and $\ln\ (\chi T)$ *vs.* $\ln\ (1 - T_c/T)$ we obtained (see Fig. 2) the values $C = 0.4$ emu K/mol and $\Delta S \sim R \ln 2$. This entropy is consistent with a $S = 1/2\,(\Gamma_7)$ ground state.

The straight line in the $P_{\chi T}$ *vs.* T plot (Fig. 1) for the high temperature region yields $\gamma_2 = 0.7$ and $T_{K_2} = 17$ K. With these values we can obtain (Fig. 2) $C_2 = 0.78$ emu K/mol that is in good agreement with the Curie constant of the total $J = 5/2$ multiplet. For the specific heat there is not a clear straight line in the $P_{C_pT^2}$ *vs.* T plot for the high temperature re-

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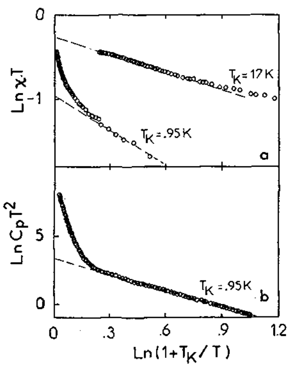

Fig. 2. – Plot of a) ln (χT) and b) ln $\left(C_pT^2\right)$ *versus* ln $(1 + T_K/T)$, where T_K is the Kondo temperature determined figure 1. The intercepts with the y axis yield the values for the Curie constant C and the entropy ΔS.

gion. Nevertheless a good fit of these data is obtained with $\alpha = 8$ and $T_{K_2} = 7.4$ K. This T_{K_2} has not the physical meaning of a Kondo temperature because we have to consider the interplay between the Kondo effect and the thermal population of the excited states in the cristal field scheme [3].

Altogether equations (2) and (3) show a remarkable aptitude to account for the experimental evidence over a wide range of temperatures in a Kondo system providing parameters T_K, C, ΔS in reasonable agreement with expectation. Equations (4) and (5) permit to reach these parameters very directly and unambiguously. It remains to know whether (like for classical transitions with a positive T_c) there is still a regime where universality applies when $T \to 0$ and the correlation length diverges. Up to now we have found $\alpha = 3$ in $CeCu_2$ und UPt_3, $\alpha = 3.5$ in $CeRu_2Si_2$ and UBe_{13} [1, 2] and $\alpha = 4$ in $CePd_3B_x$.

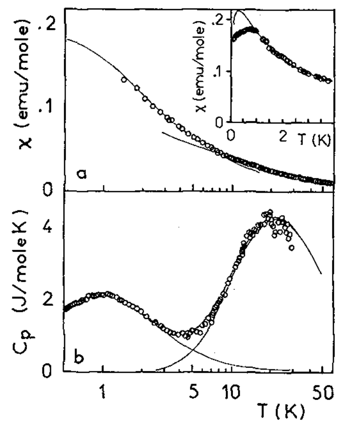

Fig. 3. – a) Plot of χ *vs.* T showing the susceptibility data for $CePd_3B_{0.6}$ and the prediction of equation (3) for $T_K = 0.95$ K, $\gamma = 1.4$ and $C = 0.4$ emu K/mol in the low temperature region and $T_{K_2} = 17$ K, $\gamma_2 = 0.7$ and $C_2 = 0.78$ emu K/mol in the high temperature region. The insert shows the susceptibility data for $CePd_3B$ and the prediction of equation (3) for $T_K = 0.8$, $\gamma = 1.4$ and $C = 0.4$ emu K/mol. b) Plot of C_p *vs.* T showing the specific heat of $CePd_3B_{0.6}$ and the prediction of equation (2) for $T_K = 0.95$ K, $\alpha = 4$ and $\Delta S = R \ln 2$ in the low temperature regime and with $T_K = 7.4$, $\alpha = 8$ and $\Delta S = R \ln 3$ in the high temperature region. The sum of the theoretical expressions for the low and the high temperature regions is also shown.

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