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Energy scales of Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ by means of thermopower investigations

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We present the thermopower $S(T)$ and the resistivity $\rho(T)$ of Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ in the temperature range $3 < T < 300$ K. $S(T)$ is found to change from two minima for dilute systems ($x < 0.5$) to a single large minimum in pure YbRh$_2$Si$_2$. A similar behavior has also been found for the magnetic contribution to the resistivity $\rho_{\text{mag}}(T)$. The appearance of the low-$T$ extrema in $S(T)$ and $\rho_{\text{mag}}(T)$ is attributed to the lowering of the Kondo scale $k_B T_K$ with decreasing $x$. The evolution of the characteristic energy scales for both the Kondo effect and the crystal electric field splitting $\Delta_{\text{CEF}}$ are deduced. An extrapolation of $T_K$ to $x=1$ allows us to estimate the Kondo temperature of YbRh$_2$Si$_2$ to 29 K. For pure YbRh$_2$Si$_2$, $T_K$ and $\Delta_{\text{CEF}}/k_B$ lie within one order of magnitude and thus the corresponding extrema merge into one single feature.

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I. INTRODUCTION

YbRh$_2$Si$_2$ is a stoichiometric heavy-fermion (HF) metal with an extremely low antiferromagnetic ordering temperature of 70 mK.\textsuperscript{1} It crystallizes in the tetragonal ThCr$_2$Si$_2$ structure and has been investigated extensively due to its pronounced non-Fermi liquid (NFL) properties at low $T$. This behavior was attributed to a quantum critical point, which can be attained by application of a small magnetic field of 60 mT within the $ab$ plane.\textsuperscript{2} At intermediate temperatures ($10$–$300$ K), the properties of YbRh$_2$Si$_2$ are determined by a competition of crystal electric field (CEF) excitations and the Kondo interaction. A knowledge of the corresponding characteristic energy scales $k_B T_{\text{CEF}}$ and $k_B T_K$ is essential for an understanding of the low-temperature properties of the compound. The NFL behavior dominates the thermodynamic and transport properties up to 10 K. Notably, the electronic specific heat divided by $T$ exhibits a logarithmic increase upon cooling with a spin fluctuation temperature $T_0=24$ K.\textsuperscript{3} The corresponding entropy revealed a doublet ground state of the Yb$^{3+}$ ions with a Kondo temperature $T_K$ of approximately 17 K.\textsuperscript{3} The CEF level scheme of YbRh$_2$Si$_2$ was determined from inelastic neutron scattering: The $4f^{13}$ multiplet of the Yb$^{3+}$ is split into four doublets at energies corresponding to 0–200–290–500 K, respectively.\textsuperscript{4}

The strong interplay between Kondo effect and CEF splitting manifests itself in the transport properties of the system. The temperature dependencies of both resistivity\textsuperscript{5} $\rho(T)$ and thermopower\textsuperscript{5} $S(T)$ exhibit a single large extremum around 100 K, which was attributed to scattering on the full Yb$^{3+}$ multiplet. No signature corresponding to Kondo scattering on the ground-state doublet at $T_K$ has been found in $S(T)$ and $\rho(T)$. Such behavior was observed and theoretically predicted for compounds, where the energy scales $k_B T_{\text{CEF}}$ and $k_B T_K$ are of the same order of magnitude, i.e., for systems near the crossover from the HF to the intermediate-valent (IV) regime.\textsuperscript{7,9}

Upon applying pressure, the Kondo temperature of Yb-based HF systems is typically shifted to lower $T$, while the CEF levels are not affected significantly. For sufficiently small values of $T_K$, separate maxima in $\rho(T)$ due to Kondo effect on the ground state and on excited CEF levels are expected to occur. Such behavior was confirmed for YbRh$_2$Si$_2$ by means of resistivity investigations under pressure: Above 4 GPa, the single peak in $\rho(T)$ splits into three separate maxima. The two maxima at lower $T$ were attributed to Kondo scattering on the ground-state doublet with the onset of coherence and to Kondo scattering on thermally populated CEF levels. The origin of a third maximum remains unclear.

According to theoretical models, the lowering of $T_K$ is also expected to induce systematic changes in $S(T)$ (Ref. 8 and references therein). For systems with a thermopower as described for YbRh$_2$Si$_2$, the anticipated behavior upon application of a small pressure or weak lowering of $T_K$ is the appearance of a low-$T$ shoulder. With further decreasing $T_K$, two separate minima develop in $S(T)$, similar to the behavior of $\rho(T)$. The minimum at lower $T$, which reflects Kondo scattering on the ground-state doublet, is situated at $T_{\text{min,1}} \approx T_K$\textsuperscript{10,11} The high-$T$ minimum is caused by Kondo scattering on thermally populated CEF levels. For an excited CEF level at $\Delta_{\text{CEF}}$ above the ground state, it typically appears at $T_{\text{min,2}} \approx (0.3–0.6)\Delta_{\text{CEF}}/k_B$,\textsuperscript{8,12,13} Such evolution has been detected, e.g., for Yb(Ni$_{1-x}$Cu$_x$)$_2$Si$_2$ upon substitution (chemical pressure).\textsuperscript{14} The IV system YbCu$_2$Si$_2$ exhibits a single minimum in $S(T)$. As the Kondo temperature is reduced by Ni substitution on the Cu site, a shoulder appears at low $T$ already for the lowest Ni content studied ($x=0.125$). However, it remains unsolved, whether only a single minimum occurs, when the system is pushed to the HF regime for Ni concentrations $x<0.125$, or whether the appearance of the low-$T$ shoulder is directly related to the development of the HF state. YbRh$_2$Si$_2$ seems to be an appropriate system to address this problem, since it, being a HF metal, exhibits a single minimum in $S(T)$.

In order to change the effective coupling between the $4f$ and the conduction electrons, substitution on all crystallographic sites has been realized in YbRh$_2$Si$_2$, generally with

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the aim of lowering the antiferromagnetic ordering temperature. This, however, is connected with an increase in $T_K$ as observed in Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$.\cite{Ref1} I-type YbRh$_2$Si$_2$\cite{Ref2} and YbRh$_2$(Si$_{1-y}$Ge$_y$)$_2$.\cite{Ref3} Recent investigations on Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ indicate a weak lowering of $T_K$ upon replacement of Yb by the nonmagnetic Lu.\cite{Ref4} Additionally, the substitution on the Yb site leaves, in a first approximation, the chemical environment of the remaining Yb ions unchanged, thus reducing the influence of disorder on the magnetic moments. Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ therefore appeared a promising candidate for the observation of distinct anomalies in the thermopower due to Kondo interaction on the ground state and on excited CEF levels at ambient pressure, with the objective to determine the characteristic energy scales $k_BT_K$ and $k_BT_{CEF}$ of pure YbRh$_2$Si$_2$.

In this paper, we present thermopower and resistivity measurements of a number of Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ single crystals with Yb concentration $0 \leq x \leq 1$. The energy scales of Kondo interaction and CEF excitations as a function of the Yb concentration are deduced based on the thermopower and supported by the resistivity data. Finally, the evolution of $S(T)$ and $\rho(T)$ is discussed in comparison to other Ce- and Yb-based materials.

II. EXPERIMENTAL DETAILS

Single crystals of Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ ($0 \leq x < 1$) were grown from In flux, as described elsewhere.\cite{Ref4} The average (nominal) Yb content $x_{\text{nom}}$ of each batch was determined from susceptibility measurements and confirmed by microprobe analysis on selected crystals. However, our resistivity measurements suggest a moderate variation of the Yb concentration throughout a batch. The scaling analysis described below indicates deviations from $x_{\text{nom}}$ of up to approximately 5%. Specifically, the samples with $x_{\text{nom}}=0.15$ and $x_{\text{nom}}=0.49$ studied in $S(T)$ and $\rho(T)$ have an effective Yb concentration of $x=0.10$ and $x=0.44$, respectively. For all other samples, the nominal concentration has been confirmed, i.e., $x=x_{\text{nom}}$. In the following, the effective values $x$ are used.

The lattice constants of the stoichiometric systems LuRh$_2$Si$_2$ and YbRh$_2$Si$_2$ were determined from x-ray diffraction measurements on powdered material. The ThCr$_2$Si$_2$ crystal structure has been confirmed within the doping series. No additional peaks have been resolved in the pattern. The fraction of foreign phases can thus be excluded to be higher than 2%. The microprobe analysis has indicated no free elemental nor binary phases in the studied samples. Due to the extremely small change of the unit-cell volume $V_0$ of ($0.41 \pm 0.12$)% with respect to YbRh$_2$Si$_2$ a linear dependence of $V_0(x)$ is assumed for the crystals with partial substitution. The tiny variation in the lattice constant is not expected to significantly influence the relative position of the CEF levels.

Investigations of the thermopower $S$ and the electrical resistivity $\rho$ were performed within the $ab$ plane of the crystals with a typical size of $4 \times 1 \times 0.05$ mm$^3$. Both quantities were measured in the temperature range from 3 to 300 K in a commercial device (Physical Property Measurement System from Quantum Design) using the same contacts. Measurements of $\rho$ were extended down to 0.4 K using a $^3$He insert. The resistivity was determined with a four-point ac technique. For the thermopower, a relaxation-time method with a low-frequency square-wave heat pulse utilizing two thermometers was used. The determination of $S$ implies an average over the contact area of both the voltage and the temperature gradient. In our setup, due to the small crystal size, the contact size was not negligible compared to the sample dimensions. However, data sets obtained from repeated measurements on the same specimen but with different contacts can be scaled on top of each other. In particular, the position of the minimum in $S(T)$ remained unaffected. The absolute values of $S$ could be reproduced within $\pm 8\%$. The thermopower data for the pure Yb compound are taken from Ref. 6.

III. RESULTS

The thermopower $S(T)$ of Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ ($0 \leq x \leq 1$) is plotted semilogarithmically in Fig. 1(a) ($x=0.08$ not shown for the sake of clarity). Figure 1(b) displays the low-$T$ behavior of the same curves on a linear temperature scale. The
thermopower of the reference compound LuRh₃Si₂ is smaller than 1 μV/K in this T range and therefore omitted.

LuRh₃Si₂ exhibits a small positive thermopower, which is typical for normal metals with hole-like charge carriers. The thermopower comprises mostly a diffusion part of light nonmagnetic charge carriers. A strong phonon drag contribution leading to an enhancement around 20 K has not been resolved. By contrast, the thermopower of YbRh₂Si₂ is negative in the whole temperature range 3 ≤ T ≤ 300 K with large absolute values. It shows a single broad minimum around 80 K, as typically found in valence-fluctuating Yb compounds such as YbCu₅Si₂. However, for the HF system YbRh₂Si₂, the observed behavior was attributed to a combination of Kondo interaction and CEF effects. With decreasing Yb concentration, the temperature dependence of the thermopower changes qualitatively. The samples with x = 0.75 and x = 0.62 exhibit a minimum at 80 K and a shoulder at low temperatures, which may be seen on a linear scale [Fig. 1b)]. For Yb concentrations of x ≤ 0.44, the thermopower minimum around 80 K clearly splits into two separate features. While the position of the high-temperature shoulder remains almost concentration independent, the low-temperature shoulder shifts to lower T upon further decreasing x. Simultaneously, the absolute values of the minimum structure at elevated temperatures are significantly reduced. For samples with x ≤ 0.44, a sign change in S(T) appears below room temperature, which is shifted to lower T with decreasing Yb concentration. This indicates a stronger relative influence of the nonmagnetic contribution to the thermopower in these samples.

The electrical resistivity of Lu₁₋ₓYbₓRh₃Si₂ was measured on the same samples as the thermopower. In addition, a specimen with x = 0.02 has been investigated, which was too small to measure S(T). The results of ρ(T) are in agreement with Ref. 18. The resistivity of LuRh₃Si₂ takes a value of about 30 μΩ cm at 300 K and decreases linearly from room temperature to 10 K, below which it reaches a constant value of 1.25 μΩ cm. The magnetic contribution ρₘₐ₇ was calculated by subtracting the data of the reference compound LuRh₃Si₂ and a sample-dependent disorder term ρᵣᵣₑᵦ. The results normalized to the Yb concentration are shown in Fig. 2. For most samples scaling of the data at elevated temperatures was achieved by using the value of the nominal concentration. As already mentioned above, adjustment of the effective concentration was necessary for xₑᵣᵦ = 0.15 to x = 0.1 and for xₑᵣᵦ = 0.49 to x = 0.44 to ensure scaling of the high-T data above 100 K.

The magnetic resistivity ρₘₐ₇(T) of the series reflects the evolution from a diluted to a dense Kondo system, as, e.g., demonstrated in Ce₁₋ₓLaₓCu₆. At temperatures T > 100 K, ρₘₐ₇ of all samples increases logarithmically with decreasing T. Subsequently, samples with low Yb concentrations x = 0.23 exhibit a plateau around 60–100 K, followed by a further increase in ρₘₐ₇ to lower T. At T < 4 K, the magnetic resistivities of these specimens saturate. On the other hand, the magnetic resistivities of the concentrated Yb samples with x ≥ 0.62 pass through maxima around 70–100 K and then drop toward lower temperatures. The plateau or maximum at elevated T is attributed to the presence of a CEF splitting in the system. The depopulation of excited levels upon cooling and the associated lowering of the scattering rate leads to a reduction of ρₘ₇ in this temperature range. Toward lower T, the differences between the diluted and the dense Yb systems become evident. While Kondo scattering on the ground-state doublet gives rise to a second increase as −ln T and a saturation at lowest T for x = 0.23, the onset of coherence promotes a further decrease in the magnetic resistivity in samples with x = 0.62. The sample with Yb concentration x = 0.44 is situated close to the crossover between the two regimes. It shows an only weak decrease in ρₘ₇ toward low T and a saturation at a relatively large residual value.

**IV. DISCUSSION**

For a quantitative analysis of the thermopower, the magnetic contribution Sₘ₇ is usually determined by use of the Gorter–Nordheim rule: Sₘ₇ρₘ₇ = Sᵦ − Sᵦₑᵦρᵦₑᵦ. Sᵦₑᵦ and ρᵦₑᵦ are generally taken as the thermopower and (total) resistivity of the nonmagnetic reference compound. The resistivity ρᵦₑᵦ may be approximated by a sum of a phononic contribution ρᵦₑᵦ and a residual resistivity ρᵦᵦ due to impurities. It is assumed that ρᵦᵦ does not change significantly upon chemical substitution. The disorder induced by doping, however, affects the residual resistivity, and ρᵦₑᵦ has to be replaced by the x dependent disorder contribution ρᵦᵦ(ₓ) of the alloys. Since ρᵦᵦ(ₓ) cannot be determined accurately, an exact evaluation of Sₘ₇ is almost impossible. For the presented data, the overall behavior of Sₘ₇, and especially the position of the shoulders, is not expected to strongly deviate from that of S. At low temperatures (T < 50 K), at which the thermopower and the resistivity of LuRh₃Si₂ are small, the difference between S and Sₘ₇ is negligible. Just below room temperature, the calculation of Sₘ₇ mainly implies a correction for the diffusion thermopower of light charge carriers. The features below 100 K remain basically unchanged. For the discussion of the data, we therefore analyze S ≈ Sₘ₇.
T\text{iplet} states. Thus, the corresponding characteristic temperature of the CEF ground state,20 in agreement with results of inelastic neutron scattering, which revealed doublets at 0–200–290–500 K.4 We therefore conclude that the large thermopower minimum around 80 K is caused by Kondo scattering on the full Yb\textsuperscript{3+} multiplet.

Figure 3(b) shows the position of the low-T minimum \(T_{\text{low}}^S=\frac{T_K}{S_{\text{CEF}}/k_B}\) of the samples with \(x<0.5\) vs \(x\). For higher Yb concentrations, a determination of \(T_{\text{low}}^S\) was not possible with satisfactory precision. The data sets for low \(x\) clearly reveal an increasing \(T_K^S\) with rising Yb concentration. A linear extrapolation of \(T_{\text{low}}^S(x)\) yields a Kondo temperature of 29 K for YbRh\textsubscript{2}Si\textsubscript{2}. The fit is shown as a line in Fig. 3(b). This value is about a factor 1.5 larger than the one obtained from the entropy of the system, namely, \(T_K^S=17\) K.3 However, the model used in Ref. 3 for calculating \(T_K\) based on the entropy\textsuperscript{21} yields a temperature dependence of \(c_p\), which deviates significantly from that of the NFL compound YbRh\textsubscript{2}Si\textsubscript{2}. Its application to this system is therefore somewhat questionable. Furthermore, a determination of \(T_K\) from different experimental probes usually yields different values, however, always of the same order of magnitude.

The Lu-Yb substitution leads to a change in the unit-cell volume \(V_{\text{uc}}\). In order to evaluate the relevance of this effect for the observed change in \(T_K\), a comparison to results from experiments under pressure \(p\) are of interest. Using the bulk modulus\textsuperscript{22} of YbRh\textsubscript{2}Si\textsubscript{2} of 189 GPa and assuming a linear relation of \(V_{\text{uc}}\) vs \(x\), we can compare our results with investigations under pressure. The Kondo temperature \(T_K^p(p)\) of YbRh\textsubscript{2}Si\textsubscript{2} determined from resistive pressure studies\textsuperscript{23} is shown as a dashed line in Fig. 3(b), where the pressure axis is scaled to the same unit-cell volume change. It is seen that the lowering of \(T_K\) under pressure is somewhat weaker than upon substitution. This reflects the relevance of additional effects beside the variation of \(V_{\text{uc}}\). Chemical substitution induces a change in the band structure of the system, which may influence the effective coupling between the 4f and conduction electrons even at constant \(V_{\text{uc}}\). However, the relatively small difference between the evolution of \(T_K\) under pressure and upon Lu substitution underlines a dominating influence of the unit-cell volume in Lu\textsubscript{1−}\textsubscript{Yb}\textsubscript{3+}Rh\textsubscript{2}Si\textsubscript{2}. This is ascribed to the unchanged chemical environment of the 4f moments as a result of the substitution on the rare-earth ion site. Furthermore, due to the small radius of the 4f shell, Lu and Yb behave chemically very similar. The 4f electrons together with the nucleus act as an “effective nucleus.” Therefore, Lu-Yb substitution is expected to have a minor influence on the band structure. Yet, the integer valence \(\nu\) of the Lu ions compared to the slightly reduced value for the Yb ions (Lu\textsuperscript{3+} vs Yb\textsuperscript{3+} with 2.95 ≈ \(\nu\) ≈ 3.00)\textsuperscript{24} might have a...
small effect on the charge-carrier concentration.

The large values usually found for the thermopower of 4f systems have been related to the likewise enhanced electronic contributions to the specific heat. In the zero temperature limit, the ratio $S/\gamma T$ of several correlated compounds takes a quasiuniversal value. For metals, the dimensionless quantity $q = N_A e S/\gamma T$ with the Avogadro number $N_A$, and the electron charge $e$ is close to $\pm 1$, whereas the sign depends on the type of charge carriers. This relation can be derived within Fermi-liquid theory assuming impurity scattering as the relevant scattering process. In the present system, the thermopower $S \times T$ is only found for $T < 5$ K and $x < 0.5$, due to both the low Kondo temperature of the order of 10 K and the NFL behavior of the pure system YbRh$_2$Si$_2$. The calculated $q$ values ranging from $-0.63$ to $-0.85$ are in line with that expected for hololike charge carriers of $-1$.

The change in the behavior of $S(T)$ from a single minimum at $x=1$ to a double-peak structure for small $x$ is correlated to the lowering of $T_K$ upon decreasing Yb concentration. YbRh$_2$Si$_2$ with a Kondo temperature of approximately 20 K and a first excited CEF level around 200 K seems to be situated near the critical ratio $T_{CEF}/T_K$ where the two minima of Kondo scattering on the ground state and thermally populated CEF levels in $S(T)$ merge into a single feature. A slight reduction of $T_K$ on the other hand allows for a separation of both effects.

A similar behavior is found in the magnetic contribution to the resistivity $\rho_{\text{mag}}(T)$ of Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$. The similarities are best seen for the two samples with Yb concentrations at the crossover from a single large minimum in $S(T)$ to two clearly separated shoulders. Figure 4 shows a comparative plot of $S(T)$ as well as $\rho_{\text{mag}}(T)$, which were determined on the same specimens with $x=0.44$ and 0.62. The curves for thermopower and magnetic resistivity strongly resemble each other. For the sample with $x=0.44$, two clearly separated shoulders are seen in both quantities, situated at the same temperatures, as indicated by the vertical lines. By contrast, the sample with $x=0.62$ exhibits only one large extremum in $S(T)$ and $\rho_{\text{mag}}(T)$ around 80 K. The double-peak structure is well tracked by both the thermopower and resistivity for $x<0.5$, whereas larger concentrations $x>0.5$ exhibit a single peak.

It appears remarkable that the effects of Kondo scattering on the ground-state doublet and on thermally populated CEF levels cannot be separated for $x>0.5$ in $S(T)$ and $\rho(T)$, although the corresponding energy scales differ by approximately one order of magnitude. This observation can be understood in view of the relatively large temperature range, which is affected by the thermal population of an excited CEF level as apparent, e.g., from a Schottky contribution to the specific heat. A significant population of an excited CEF level and, consequently, an enhanced scattering from CEF excitations sets in at temperatures well below the splitting of $\Delta_{CEF}/k_B$. Thus, in Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$, for $x>0.5$, the crossover from scattering solely on the ground-state doublet to that on all CEF level may not be resolved. Instead, the observed single large extremum in $S(T)$ and $\rho(T)$ is caused by scattering on the full Yb$^{3+}$ multiplet. On the other hand, in samples with $x<0.5$, the reduced Kondo scale allows a separate observation of scattering on the ground-state doublet at low $T$, while thermal population of the three excited levels gives rise to a second broad extremum at elevated temperatures.

The disappearance of the low-$T$ minimum in the thermopower of Yb(Ni$_{1-x}$Cu$_x$)$_2$Si$_2$ for $x=0$ is connected with a crossover to the valence-fluctuating regime. A qualitatively similar behavior has been frequently observed in Ce systems under pressure and upon substitution, e.g., in CeRu$_2$Ge$_2$ (Ref. 27) or Ce(Ni$_{1-x}$Pd$_x$)$_2$Si$_2$. In contrast to Yb compounds, Ce-based HF systems generally exhibit maxima in $S(T)$ due to the preponderance of electronlike charge carriers. Likewise, the crossover from two maxima to a single maximum is usually taken as an indication that $T_K$ lies in the order of the CEF splitting and the system enters the valence-fluctuating regime. However, in x-ray absorption measurements of the L-III absorption edge of the Yb ion in Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$, no significant contribution from Yb$^{2+}$ could be resolved at 5 K. Taking into account the resolution of the method, the valence $v$ has been estimated to be $2.95 \leq v \leq 3.00$. A strong intermediate-valent character is therefore excluded for this system. Thus, Lu$_{1-x}$Yb$_x$Rh$_2$Si$_2$ appears to be a rare example, for which the two extrema in $S(T)$ merge, while the system is still in the HF regime. The coalescence of both features corresponding to $T_K$ and $\Delta_{CEF}$ can be observed in detail in this series since the Lu substitution induces an extremely small change of the unit-cell volume connected with a very weak lowering of $T_K$. 

FIG. 4. (Color online) Comparison between thermopower and magnetic contributions to the resistivity for two Yb concentrations $x=0.44$ and $x=0.62$. 

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V. SUMMARY

The temperature dependence of the thermopower of \( Lu_{1-x}Yb\text{Rh}_2\text{Si}_2 \) qualitatively changes upon substitution from a single large minimum in \( S(T) \) for the pure Yb compound to two well separated minima for \( x < 0.5 \). A similar evolution is found in the magnetic contribution to the resistivity. This change in the overall behavior of \( S(T) \) and \( \rho_{\text{mag}}(T) \) is ascribed to a lowering of \( T_K \) upon decreasing Yb content. For high Yb concentrations \( x > 0.5 \), the extrema of Kondo scattering on the ground state and thermally populated CEF levels merge into one single feature. A slight reduction of \( T_K \) due to the substitution of Yb by Lu on the other hand allows for a separation of both effects in the transport properties of the series for \( x < 0.5 \). The evolution of the Kondo temperature upon substitution can be understood mainly from the change in the unit-cell volume. In addition, modifications in the band structure may be relevant. Due to the extremely small overall change in \( T_K \), \( Lu_{1-x}Yb\text{Rh}_2\text{Si}_2 \) displays the crossover from two minima in \( S(T) \) to one minimum upon increasing \( x \) without entering the valence-fluctuating regime. The Kondo temperature of \( \text{YbRh}_2\text{Si}_2 \) has been estimated to be around 29 K.

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