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POSSIBLE HEAVY-FERMION BEHAVIOR IN A HEUSLER-TYPE COMPOUND $YbPd_2Sb$*

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Magnetic, electrical transport and thermodynamic properties of a novel Heusler compound $YbPd_2Sb$ have been studied down to 40 mK in applied magnetic fields up to 14 T. The results hint at a heavy-particle nature of the electronic ground state, with some features characteristic of systems being close to Doniach's magnetic–nonmagnetic instability.

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Rare-earth-based Heusler phases $RE\,Pd_2M$, where M = In, Sn or Pb, attracted in the past considerable attention because of their interesting magnetic and superconducting properties [1]. Most intriguing are obviously those systems in which superconductivity coexists with long-range magnetic ordering, as for example $YbPd_2Sn$ [2] and $ErPd_2Sn$ [3]. In these compounds the $4f$-electrons responsible for antiferromagnetism are moderately coupled to superconducting electrons [4], in contrast to systems like $RE\,Ni_2B_2C$, $RE\,Rh_4B_4$ or $RE\,Mo_6Y_8$ (Y = S, Se), where the two cooperative phenomena are spatially clearly isolated. This finding makes $RE\,Pd_2M$ Heusler phases an attractive subject for further investigations. In this paper we report for the first time on the magnetic, electrical transport and thermodynamic properties of a novel Heusler-type compound $YbPd_2Sb$, studied down to 40 mK in magnetic fields up to 14 T. A more comprehensive presentation and discussion of these data will be given elsewhere.

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The investigated sample of $YbPd_2Sb$ was single phase with a $MnCu_2Al$-type related crystal structure. The refined cubic lattice parameter is larger than the value expected from the lanthanide contraction [5], hence suggesting some instability of the Yb ion valence. Indeed, preliminary Yb L_{III}-edge spectroscopy studies yielded the effective valence slightly lower than +3.

Compatible with the above findings is the value of the effective magnetic moment $\mu_{eff} = 4.02\ \mu_B$, obtained from a Curie–Weiss fit of the magnetic susceptibility of $YbPd_2Sb$, made above 80 K. The calculated paramagnetic Curie temperature of −18 K manifests appreciable antiferromagnetic exchange interactions or/and Kondo effect. At low temperatures the susceptibility is featureless down to a temperature T^* below which $\chi(T)$ saturates at quite high values. In a field of 0.1 T, $T^* = 0.4$ K and $\chi(0) = 1.5$ emu/mole (see Fig. 1(a)). With increasing magnetic field the low-temperature susceptibility is suppressed and T^* gradually rises towards 12 K, the upper border of the region in which the susceptibility is field dependent. Interestingly, for $B > 0.1$ T the low-temperature susceptibility of $YbPd_2Sb$ scales perfectly well to the formula $\chi T^{0.75} = f\left(\frac{B}{T}\right)$, appropriate for strongly interacting spin fluctuations [6]. These findings indicate that the compound studied does not order magnetically, at least down to 40 mK, but it does exhibit some antiferromagnetic correlations with the characteristic energy scale $T^* = 0.4$ K.

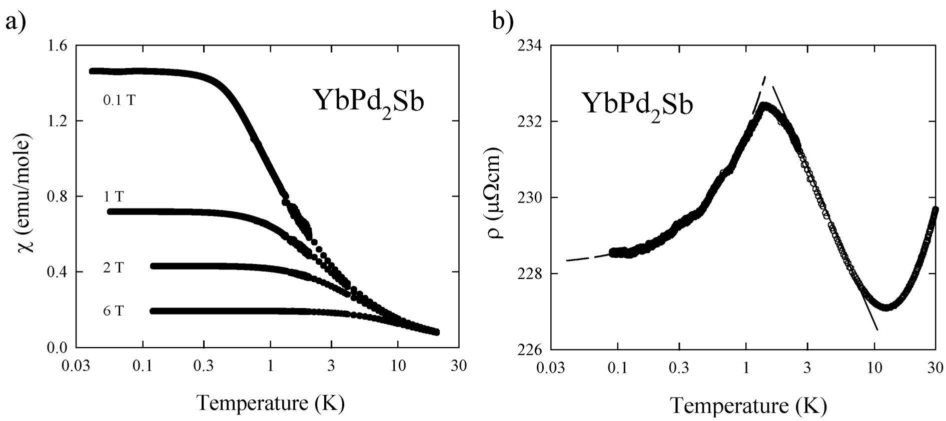

Fig. 1. Low-temperature magnetic susceptibility $\chi(T)$ (a) and electrical resistivity $\rho(T)$ (b) of $YbPd_2Sb$. Dashed and solid lines mark the proportionalities $\rho \sim T$ and $\rho \sim \ln T$, respectively.

The electrical resistivity of $YbPd_2Sb$ is characteristic of systems exhibiting an interplay of Kondo and crystal field interactions. A broad shoulder in $\rho(T)$ at about 70 K gives an estimate for crystal field splitting. Around

12 K $\rho(T)$ shows a minimum, and in the range $2 < T < 9$ K a logarithmic increase in the resistivity is observed (see Fig. 1(b)). Then $\rho(T)$ goes through a maximum at $T^{\rm LT}_{\rho\,\max} = 1.4$ K, and eventually it displays a nearly linear T-dependence. Upon applying magnetic field the resistivity decreases in a Kondo-like manner. The magnetoresistivity reaches -7% at $T = 1.8$ K and $B = 14$ T. For temperatures $T > 2$ K a single-ion Kondo scaling $\rho(B)/\rho(0) = f\left(\frac{B}{T+T^*}\right)$ is fulfilled with $T^* = 0.4$ K, as found from the magnetic data.

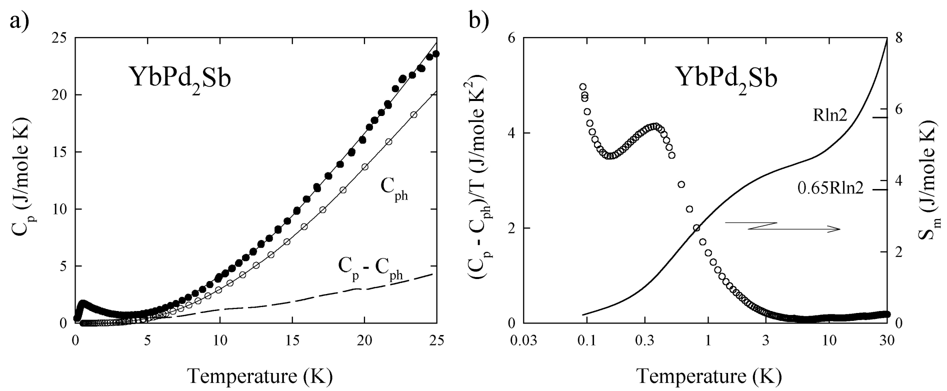

Fig. 2. (a) Low-temperature specific heat $C_{\rm p}(T)$ of $YbPd_2Sb$, its phonon component $C_{\rm ph}(T)$, approximated by $C_{\rm p}(T)$ of $LuPd_2Sb$, and non-phonon component $\Delta C(T) = C_{\rm p} - C_{\rm ph}$. (b) ΔC over temperature and entropy $S(T)$ in $YbPd_2Sb$.

The temperature variation of the specific heat of $YbPd_2Sb$ reveals a broad anomaly at $T^* = 0.4$ K but no feature at $T^{\rm LT}_{\rho\,\max} = 1.4$ K (see Fig. 2). Approximating the phonon contribution $C_{\rm ph}(T)$ by the measured specific heat of $LuPd_2Sb$ one obtains the non-phonon part, $\Delta C(T) = C_{\rm p} - C_{\rm ph}$ which can be qualitatively described by the Coqblin–Schrieffer model for the effective spin $s = 1/2$ and $T^* = 0.4$ K [7]. The Sommerfeld coefficient interpolated from the region 4–10 K, *i.e.* where the high-temperature tail of the $T^* = 0.4$ K anomaly is negligible, is equal to 112 mJ/K^{2}mole. At the lowest temperatures the ratio $C_{\rm p}/T$ strongly rises and attains at $T = 0.09$ K a huge value of about 5 J/K^{2}mole. The entropy derived from the $\Delta C(T)$ *versus* T data is very small. It shows some tendency to saturate in between 2 K and 9 K, *i.e.* in the range where $\rho \sim \ln T$, at a value that is larger than the Bethe ansatz solution for $s = 1/2$ but considerably reduced with respect to the value expected for a doublet ground state with no Kondo interactions (see Fig. 2(b)). Upon applying external magnetic field the broad peak in $C_{\rm p}(T)$ shifts to higher temperatures, thus reflecting an increase in the Zeeman splitting of the crystal field ground state. From the field dependence of this anomaly one concludes that the lowest energy CEF level in $YbPd_2Sb$ is probably the Γ_6 doublet. Another effect of magnetic field is suppression of the low-temperature tail in $C_p(T)$. In high fields ($B > 4$ T) a Fermi liquid behavior of the specific heat is observed with strongly enhanced values of $\gamma(0)$.

In summary, despite the presence in $YbPd_2Sb$ of rather large magnetic moments, carried by almost trivalent ytterbium ions, no long-range magnetic order has been found down to 40 mK. Instead, some features characteristic of short-range antiferromagnetic correlations are observed in the magnetic, electrical and thermodynamic properties, which altogether define the characteristic energy scale $T^* = 0.4$ K. The electrical resistivity of $YbPd_2Sb$ is governed by the interplay of crystal field and Kondo interactions. Likewise, the low-temperature specific heat can be interpreted in terms of Kondo effect. At the lowest temperatures the compound exhibits clear deviations from the Fermi liquid behavior, typical for systems being close to Doniach's magnetic–nonmagnetic instability. Our on-going investigations attempt to address questions relevant to the nature of the electronic ground state in $YbPd_2Sb$, including the issue of the role played by possible atomic disorder that is commonly present in Heusler–type phases.

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