Strong electronic correlations in ytterbium intermetallics

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For the past few years there has been considerable interest in the physical properties of Yb-based intermetallic phases, which are usually considered as hole analogs to isostructural Ce-based compounds. It is commonly believed that the principal mechanism determining the ground state behavior in both these series is the interaction between 4f electrons of Ce or Yb, and s, p, d electrons of neighboring atoms. The 4f-ligand hybridization generally tends to reduce the mean occupation of the 4f electronic shell and thus destabilizes the magnetic $4f^1$ configuration in Ce^{3+} ions and the non-magnetic $4f^{14}$ configuration in Yb^{2+} ions. As a result, depending on the strength of these interactions, various unusual low-temperature phenomena may occur, like Kondo effect, heavy-fermion behavior, non-Fermi liquid properties, spin and valence fluctuations. Whereas such phenomena have been quite thoroughly investigated in many cerium systems, much less is known on their development in Yb-based materials.

In the course of our continuous search for new f-electron ternary compounds with strong electronic correlations, several such systems based on ytterbium have recently been found. Here, we give an overview on the structural, magnetic, electrical transport and thermodynamic properties of a few of them, studied down to very low temperatures and in strong magnetic fields. The main emphasis will be put on ternary compounds with high-symmetry crystal structures, like equiatomic YbTM compounds, crystallizing with cubic or hexagonal unit cells (where T stands for a d-electron transition metal and M is a p-electron element), and cubic Heusler-type phases $YbPd_2M$ (M = In, Sn, Pb, Sb, Bi).

To demonstrate the main features characteristic of Yb-based heavy fermion compounds that order magnetically at low temperatures we have chosen YbPtIn. This equiatomic compound crystallizes with a hexagonal structure of the ZrNiAl-type, which has a typical layered character. It has been described as a heavy fermion system with the characteristic temperature of the order of 4 K, which orders antiferromagnetically below 3.1 K, and undergoes a spin reorientation at 1.2 K. The latter effect is probably related to possible frustration of the Yb magnetic moments due to their triangular arrangement in the crystal lattice. It should be stressed that the main energy scale in the system, i.e. the magnetic exchange and Kondo interactions are here of nearly the same magnitude. Moreover, both of them are strongly influenced by crystal field effect, which makes quite difficult an unambiguous interpretation of some of the features observed in the antiferromagnetic state.

Similar difficulties in establishing heavy fermion behavior that come up because of the lack of clear separation between magnetic, Kondo and crystal field energy scales are frequently observed in Yb-based compounds crystallizing with cubic MgAgAs-type structure. To recall just one example from this series we discuss here YbPdBi. This cubic compound is a heavy fermion system with the characteristic temperature of 2.5 K. The latter value is very close to the magnitude of RKKY interaction, measured by the onset of magnetic order at 1 K. Moreover, the inelastic neutron data indicate a quite small crystal field splitting with the separation of the first excited state from the ground state of only 20 K. Apparently the physical behavior of YbPdBi is governed by valence instability of Yb ions, which exhibit below room temperature a valence lower that 3+ .

The crystal structure of $YbPd_2Sb$ is cubic of the $MnCu_2Al$-type. This Heusler phase behaves like a heavy fermion system with very low characteristic temperature of about 0.4 K. Its magnetic, electrical and thermodynamic properties can be successfully interpreted in terms of Kondo lattice, yet at present some other scenarios for the intriguing physics in this compound cannot be ruled out, as for example an idea of the formation at low temperatures of a spin liquid as proposed for the closely related compound YbPdSb. Quite surprisingly despite the presence of well-defined magnetic moments and very low Kondo temperature the compound does not order magnetically down to 12 mK. At the lowest temperatures one observes rather unusual properties that possibly may be related to some degree of structural disorder or/and frustration in triangular sublattice of Yb-ions, which both may result in a kind of spin-glass or cluster-glass phenomena.

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