**Research Article**



# Role of f electrons in rare-earth and uranium intermetallics - an alternative look at heavy-fermion phenomena.

*R. J. Radwanski**

*Center of Solid State Physics; $S^{nt}$Filip 5, 31-150 Krakow, Poland*

(cond-mat/9911292, 18 November 1999; published 30 March 2007)

PACS: 75.10.-b, 71.70.Ch
Keywords: Heavy fermion, Crystal Field, spin-orbit coupling, magnetism, $5f$ compounds



The origin of the large specific heat and the non-magnetic state observed at low temperatures in some $f$ intermetallic compounds with uranium called heavy-fermion (h-f) compounds is discussed. Different existing theoretical models are briefly overviewed but it will be proposed to discuss the h-f compounds in terms of physical concepts worked out for rare-earth intermetallics [1]. To remind, the magnetic and electronic properties of rare-earth intermetallics are understood by considering a few, two in the simplest but quite adequate approach, electronic subsystems i.e. the $f$ electronic subsystem and conduction-electron subsystem (the individualized-electron model). These two subsystems are described by essentially different theoretical approaches referring to the localized and band magnetism.

In the discussion if the non-magnetic state observed in h-f compounds do refer to the local scale (single-ion) or to a collective many-body state some arguments will be given for the on-site effect. Namely, it can be rigorously proven that charge interactions via the Stark effect can produce the non-magnetic state of the localized $f^n$ electronic subsystem also in case of the Kramers system (n is an odd number) [2]. The full suppression of the local moment is attained by highly anisotropic charge distribution at the vicinity of the f-shell electrons. This highly anisotropic charge distribution is visualized by CEF parameters with significant values for higher-order terms. The charge mechanism for the

* http://www.css-physics.edu.pl; Email: sfradwan@cyf-kr.edu.p

formation of the non-magnetic state of the $f$ magnetic ion is compared with other known mechanism like the Kondo-compensation mechanism (the spin type) and the hybridization, of $f$ and conduction electrons, mechanism.

In view of the individualized-electron model the large specific heat originates from low-energy excitations between doublet levels of the Kramers state of the fn electronic subsystems that are slightly split due to exchange interactions. These excitations are many-electron excitations in contrary to single-electron excitations in the conduction-electron subsystem. It will be shown that magnetic and electronic properties of intermetallic systems with the $f$-electronic subsystem in a quasi-nonmagnetic Kramers state exhibit properties observed in h-f compounds. One can say that the h-f compounds are compounds with Kramers $f$ ions that have difficulties, due to exotic ground state and weakness of exchange interactions, to form the well-established magnetic order. However, the system has to release the Kramers entropy before reaching zero temperature as is experimentally observed by the entropy value of R ln2.

These phenomena will be discussed for some uranium h-f compounds with the hexagonal symmetry. For instance, the temperature dependence of the specific heat of $UPd_2Al_3$ with a $\lambda$-type of peak at $T_N$ of 14 K and a Schottky-type of peak above $T_N$ has been very well reproduced by the $U^{3+}$ ($5f^3$) configuration [3].

Presented at European Conference Physics of Magnetism 93, **21-24** June 1993, Poznan, Poland (Committee: J. Morkowski, R. Micnas, S. Krompiewski)

[1] R. J. Radwanski, N. H. Kim-Ngan, F. E. Kayzel, J. J. M. Franse, D. Gignoux, D. Schmitt, F. Y. Zhang, J. Phys.: Condens. Matter **4**, 8853 (1992).

[2] R. J. Radwanski, Physica B **182**, 209 (1992).

[3] R. J. Radwanski and J. J. M. Franse, in: *Physics of Transition Metals, Conf. Darmstadt 20-24.07.1992*, P. M. Oppeneer and J. Kubler, eds. (World Scientific, 1993) p. 38 (1993).