Research Article

Formation of the heavy-fermion state - an explanation in a model traditionally called localized♠

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In contrary to widely spread view about the substantial delocalization of f electrons in heavy-fermion (h-f) compounds it is argued that h-f phenomena can be understood with localized f electrons. Then the role of crystal-field interactions is essential and the heavy-fermion behaviour can occur for the localized Kramers-doublet ground state.

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In the proposed explanation compounds exhibiting heavy-fermion (h-f) behaviour are considered - in analogy to normal rare-earth intermetallics - within a few electronic subsystems. For the understanding of the h-f behaviour it is essential to distinguish f electrons from conduction electrons. These two subsystems are independent as far as the direct electron hopping from one to other subsystem does not occur. The f subsystem is a highly correlated f^n electronic system. The proposed model takes advantage of two recent findings: i) crystalline-electronic-field (CEF) interactions of the f shell can produce a non-magnetic ground state even in case of the Kramers system (the analytical proof exists, at present, for the f^3 system in the hexagonal symmetry [1]) and ii) the f^n localized states for an intermetallic compound containing an f atom always lie at the specific-heat probing level (the virtual Fermi level) as the f^n states are many-body states in contrary to single-electron states within the conduction-electron band. The different nature of excitations allows for independent contributions of these two subsystems to magnetic and electronic properties. The CEF state:

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$$\Gamma_9 = \frac{\sqrt{3}}{2} \mid \pm 3/2> + \frac{1}{2} \mid \mp 9/2>$$

given for the f^3 subsystem in the hexagonal CEF interactions is a Non-Magnetic Kramers doublet because expectation values for J_x J_y, and J_z, of the total angular momentum are equal zero. In ref. [1] this state has been proved to be realized as the ground state. In compounds exhibiting the heavy-fermion behaviour, the ground state of the *f*-electron subsystem tends to the N-M Kramers doublet. Then one has in the single-ion picture enhanced but finite susceptibility at 0 K and a normal Curie-Weiss behaviour at higher temperatures exactly as is experimentally observed. The N-M Kramers doublet ground state of *f* electrons behaves like a half-filled band at the Fermi level (2 states and 1 f^n particle) allowing for a "delocalization" of the *f* electrons and, in particular, for a many low-energy excitations detected as an enormous specific heat at lowest temperatures. In the presented model correlations between *f* electrons and conduction electrons proceed via electrostatic in interactions. The heavy-fermion state results from competition between CEF and antiferromagnetic interactions.

Some further implications of the model will be discussed.

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[1] R. J. Radwanskl, Physica B **182**, 209 (1992).