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ORIGINAL PAPER

Coexistence of Superconductivity and Antiferromagnetism in Heavy-Fermion Intermetallic Compound $CeRhIn_5$

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Abstract An interference of heavy-fermion superconductivity (SC) and antiferromagnetism (AFM) has been studied in the framework of the periodic Anderson model with the superexchange interaction between localized electrons. It has been shown that pressure-induced energy change of the localized states leads to modifying antiferromagnetic and superconducting order parameters. Conditions have been found for the coexistence of SC and AFM in the model. Theoretical results of the pressure effects on the ground state character of the heavy-fermion systems are in good agreement with experimental data for a rare-earth intermetallic compound $CeRhIn_5$. The divergence of the effective electron mass produced by suppressing the long-range antiferromagnetic order has also been analyzed in the same framework.

Keywords Coexistence superconductivity antiferromagnetism · Periodic Anderson model · Heavy-fermion systems

1 Introduction

An interest to the competition between Copper pairing and antiferromagnetic ordering in unconventional superconductors has grown considerably since it was found that the application of pressure has a strong influence on the low-temperature phase transitions in the heavy-fermion intermetallides $CeIn_3$ [1], $CeRhIn_5$ [2]. For these materials, it has been shown that increasing pressure can induce a state in which the long-range antiferromagnetic order is conserved at the onset of SC [1, 3]. It has been concluded from the de Haas-van Alphen experiment for $CeRhIn_5$ [4] that the Ce $4f$-electron character is changed from localized to itinerant under pressure. In addition, the $4f$ electrons contribute both to the formation of antiferromagnetic and superconducting ordering [5].

2 Coexistence of SC and AFM in the PAM

The periodic Anderson model (PAM) is generally thought as a basis to describe the physical properties of heavy-fermion systems. The coexistence of AFM and SC within the slave-boson approximation of the PAM has been studied in [6]. However, the terms describing Cooper and antiferromagnetic instabilities were introduced by the phenomenological way in the mean-field approximation. Such an approach leaves open the question about the type of electron interaction, which is responsible for the coexistence of SC and AFM in the heavy-fermion systems. In the strong electron correlation regime, hybridization processes involving the states of the upper Hubbard localized level can be taken into account by the perturbation theory [7]. It is important to note that the derived low-energy Hamiltonian can lead to arising the long-range antiferromagnetic order due to the superexchange interaction in the subsystem of localized Hubbard fermions.

In this connection, the following Hamiltonian of the PAM has been considered for studying the coexistence of SC and

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