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New Types of Phase Transitions in Magnetic Materials

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The present paper reviews the recent work on the quantum effective-field theory by M.Suzuki (in Physica B, 1994). This new theory is shown to be very useful in studying new types of phase transitions in strongly correlated systems and in quantum magnetic systems.
KEYWORDS: effective field, phase transition, electron system and magnetic system

1. Introduction

Since the discovery of high-T_c superconductors, the study of strongly correlated electron systems has been one of the challenging problems in theoretical and experimental physics. As one of the theoretical approaches to such problems, we explain here the basic idea of the quantum effective-field theory[1,2].

2. Basic Idea of the Quantum Effective-Field Theory

Up to now, electron systems have been studied mainly using momentum space approximations such as the RPA. However, the real space approach, namely cluster effective-field approximations will be useful in studying strongly correlated electron and spin systems. It is crucial in this scheme to take into account the hopping effect of electrons between inside and outside of the relevant cluster. For this purpose, we introduce the following quantum effective field

$$\mathcal{H}_{\rm qm} = \sum_{j\in\partial\Omega} (\lambda_j^\dagger c_j + \lambda_j c_j^\dagger), \tag{1}$$

where $c_j^\dagger$ and c_j denote Fermi creation and annihilation operators at site j, respectively. The symbol $\partial\Omega$ denotes the boundary of the relevant cluster Ω. The operators $\lambda_j^\dagger$ and λ_j are quantum fields conjugate to $c_j^\dagger$ and c_j. These quantum effective-fields $\lambda_j^\dagger$ and λ_j are determined by the condition that $< \mathcal{H}_{\rm qm} >=< \mathcal{H}_{\rm original} >$, where $\mathcal{H}_{\rm original}$ denotes the original transfer term in the Hamiltonian of the system.

3. Some Applications

The above quantum effective-field theory can be applied to the Hubbard model. The cluster effective-field Hamiltonian $\mathcal{H}_{\rm eff}$ is expressed by the sum of the following three terms

$$\mathcal{H}_{\rm eff} = \mathcal{H}_\Omega + \mathcal{H}_{\rm mf} + \mathcal{H}_{\rm qm}, \tag{2}$$

where $\mathcal{H}_\Omega$ denotes the original cluster Hamiltonian and $\mathcal{H}_{\rm mf}$ the mean-field interaction to describe the ordering of the relevant system. An explicit application of this scheme to the three-dimensional Hubbard model has been presented in Ref.3. It has been shown to be very useful in fairly small clusters. We have obtained phase diagrams which are consistent with those of other authors.

4. Discussion

The present effective-field theory is quite different from the decoupling scheme[4-6]

$$a_j^\dagger a_k + h.c. \rightarrow a_j^\dagger < a_k > + h.c., \tag{3}$$

because in this scheme the average $< a_k >$ appears only below the transition point. On the other hand, the present effective fields are non-vanishing even above the transition point.

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