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Author(s)	Rajabi, Muhammad Zafur Abror
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Title of Doctoral Dissertation

Spin and bond-charge susceptibilities in a correlated electron model of antiferromagnetism and
superconductivity

(反強磁性相と超伝導相近傍でのスピンとボンド電荷揺らぎに関する理論研究)

We present a comprehensive study of dynamical spin and bond-charge susceptibilities on an equal footing by employing an effective model tailored for antiferromagnetism and superconductivity [1]. Motivated by electron-doped high-temperature cuprate superconductors, we choose appropriate parameters to mimic the typical Fermi surface and the phase diagram. In the paramagnetic phase, dynamical spin and bond-charge susceptibilities are computed within the random phase approximation in the plane of momentum and energy. We find that spin excitation spectra show a pencil-shaped structure around momentum transfer (π, π) in a low-energy region. Furthermore, magnetic excitations are also pronounced in a higher-energy region along the (π, π) -(0,0)- $(\pi, 0)$ direction. In the bond-charge sector, we obtain dominant d-wave bond-charge excitations along the (0,0)- $(\pi, 0)$ direction in a low-energy region as well as various bond-charge excitations around (π, π) . These features of bond-charge excitations are corroborated by the large-N theory of the t-J model, although strong correlations are not included in the present model.

The obtained features of spin and bond-charge excitations show a nice agreement with various experiments. The pencil-shaped structure is observed in neutron scatterings experiments. The magnetic excitations along the (π, π) -(0,0)- $(\pi, 0)$ direction capture the so-called paramagnon dispersions reported in electron-doped cuprates, which, however, may be interpreted as individual excitations rather than collective ones in the present theory. Furthermore, we find that the charge ordering tendency reported in electron-doped cuprates can be understood in terms of the d-wave bond-charge excitations.

We also perform a close inspection of the static spin susceptibility inside an antiferromagnetic phase when it shows the superconducting instability, yielding their coexistence at lower temperatures [2]. The calculations of the spin susceptibility inside a magnetically ordered phase become highly nontrivial due to the emergence of additional linear terms associated with the breaking of the spin rotational symmetry. This effect is frequently missed in literatures. We find a surprising finding that the spin susceptibility exhibits a jump at the superconducting instability inside the magnetic phase. This anomaly reflects a general feature of the longitudinal spin susceptibility due to the breaking of the rotational symmetry and thus can be expected not to depend on models nor approximations. We expect experimental tests of this finding in the future.

[1] M. Zafur and H. Yamase, to appear in Phys. Rev. B (2024).

[2] H. Yamase and M. Zafur. Phys. Rev. B **103**, 224527 (2021).