

Ubiquity of Odd-Frequency Superconductivity in Coexistence Phase with Magnetic order with Gapless Collective Modes

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Odd-frequency superconductivity (OF-SC) is stabilized by the pairing interaction with strong retardation effect in general. Such an interaction arises at around quantum critical point (QCP) of one form or another. However, it is not whether the OF-SC wins the anisotropic even-frequency SC (EF-SC) at around antiferromagnetic (AF) QCP. In Ref. [1], we have shown that the p-wave spin-singlet OF-SC can win the *conventional* d-wave spin-singlet EF-SC at AF-QCP and in the AF ordered state that has the gapless spin wave mode, which is consistent with gapless nature of SC observed in $\text{CeCu}_2(\text{Si}_{1-x}\text{Ge}_x)_2$ [2] and CeRhIn_5 [3] in the coexistence phase with magnetic orders. After that, the gapless nature of SC has been observed in a series of compounds, $\text{CeRh}_{0.55}\text{Ir}_{0.45}\text{In}_5$ [4], CaFe_2As_2 [5], etc.. In the talk, the following crucial points will be also discussed.

- 1) Gapless nature of OF-SC is nontrivial because $\Delta(-i\varepsilon_n)=-\Delta(i\varepsilon_n)$ in the Matsubara world does not necessary means that $|\Delta(\varepsilon+i\delta)|=0$ after the analytic continuation $i\varepsilon_n \rightarrow \varepsilon+i\delta$. [1]
- 2) Stability of OF-SC: Necessity of path-integral formulation. [6]
- 3) Stability against the reentrant behavior of OF-SC. [1,7]
- 4) Strong coupling effect on the stability of OF-SC. [8]
- 5) Effect of impurity scattering on OF-SC. [9]

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