1 - 5 New Orientation of Cooper Pair Momentum in FFlO State

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Due to the anisotropic pairing interaction in asymmetric two component D-wave pairing systems, the pairing gap and quasiparticle spectrum are also anisotropic. When Cooper pair momentum are considered, the FFLO state is nondegenerate for the orientation of the Cooper pair momentum $2\mathbf{q}$ and some special directions of $2\mathbf{q}$ are local stable. Reference [1] points out only two special orientations [orthogonal and parallel orientations respect with the symmetry axis of angle-depend gap (ADG)[2]] of $2\mathbf{q}$ are found. However, different from the result in Ref. [1], for moderate asymmetry the favored direction of $2q$ is between the orthogonal and parallel orientations.

We exhibit the condensate $\varDelta$ of all the possible stable states (such as FFLO-ADG-O and FFLO-ADG-P states) for the system with fixed chemical potential asymmetry in Fig. 1. The values of $\varDelta$, scaled by its value $\varDelta_0$ in the corresponding symmetric system with $\delta\mu = 0$, vary as a function of the chemical potential difference $\delta\mu$ scaled by $\varDelta_0$ too at $\tilde{V}_l = 0.5, \Lambda = 4$ and $T/\epsilon_F = 0$. The ground states are also marked with the thick lines i.e., the uniform ADG state is stable in the region $0 < \delta\mu/\varDelta_0 < 0.748$, while the FFLO-ADG-O, FFLO-ADG-B and FFLO-ADG-P states become ground states in the regions $0.748 < \delta\mu/\varDelta_0 < 0.843$, $0.843 < \delta\mu/\varDelta_0 < 0.906$ and $0.906 < \delta\mu/\varDelta_0 < 1.37$, respectively. Two points should be emphasized here. First, except for the two special orientations of $2\mathbf{q}$ (parallel and orthogonal to the symmetry axis of ADG) first studied in the Ref. [1], the Cooper pair momentum $2\mathbf{q}$ can locate between the two special orientations in the windows $0.843 < \delta\mu/\varDelta_0 < 0.906$. Second, when the Cooper pair momentum is considered for D-wave paring, the superfluid state can exist up to $\delta\mu/\varDelta_0 \approx 1.37$, which is much larger than that of S-wave paring[3].

For the system with a fixed density asymmetry, by comparing the free energy of all possible ground state [such as ADG, FFLO-ADG-P and FFLO-ADG-O states], we can get the ground state which are shown in Fig. 2. The ground states are the uniform ADG state in the region $0 < \alpha < 0.0625$, while the FFLO-ADG-O, FFLO-ADG-B and FFLO-ADG-P states become ground states in the regions $0.0625 < \alpha < 0.145$, $0.145 < \alpha < 0.177$ and $0.177 < \alpha < 0.272$. It is obviously form Fig. 2 that the transitions from FFLO-ADG-O state to FFLO-ADG-B state, FFLO-ADG-B state to FFLO-ADG-P state are of the first order while the transition from FFLO-ADG-P state to normal state is of the second order. Moreover, being different from the result in Ref. [1], the transition from ADG state to FFLO-ADG-O state is of first order.

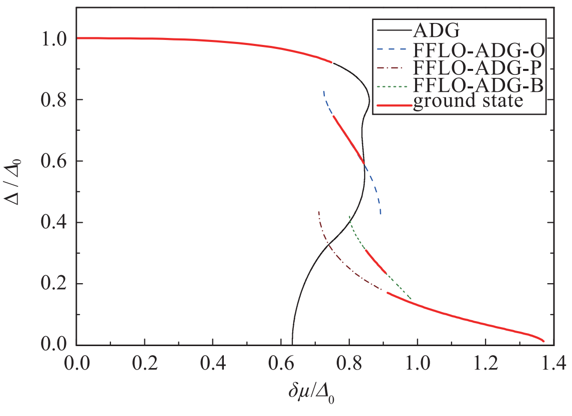

Fig. 1 (color online) The scaled gap $\varDelta/\varDelta_0$ as a function of the scaled chemical potential difference $\delta\mu/\varDelta_0$ at $\tilde{V}_l = 0.5, \Lambda = 4$ and $T/\epsilon_F = 0$. The black solid, blue dashed, wine dash-doted and olive short dashed lines correspond to the ADG, FFLO-ADG-O, FFLO-ADG-P and FFLO-ADG-B state, respectively. The red thick lines indicate the real ground states in different regions .

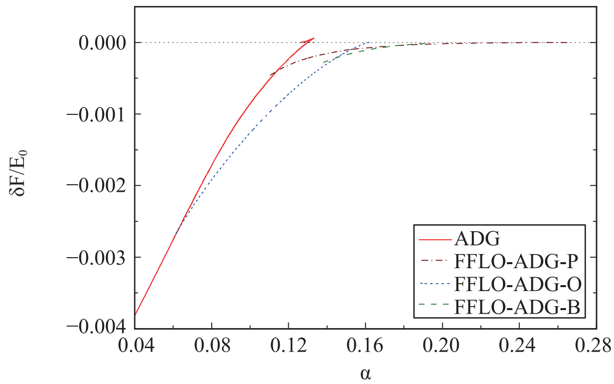

Fig. 2 (color online) The phase diagram as a function of number asymmetry α. The red solid, blue short dashed, olive dashed and wine dash dotted lines correspond to ADG, FFLO-ADG-O, FFLO-ADG-B and FFLO-ADG-P states, respectively.

References

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[3] L. He, M. Jin, P. Zhuang, Phys. Rev. B, 73(2006)214527.