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Fulde-Ferrell-Larkin-Ovchinnikov state in quasi-low-dimensional superconductors

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The Fulde-Ferrell-Larkin-Ovchinnikov (FFLO or LOFF) state, which has been predicted in clean type II superconductors, is favored in quasi-low-dimensional systems for the following two reasons. (1) The orbital pair-breaking effect can be suppressed by orienting magnetic field to any direction parallel to the conductive layer. For such a direction of the magnetic field, the upper critical field can reach a value near the Pauli paramagnetic limit, where the FFLO state may occur. (2) The FFLO state is stabilized by a Fermi-surface effect which is analogous to the Fermi surface nesting effect in spin density wave (SDW) and charge density wave (CDW). Such an effect is most pronounced in the nearly one-dimensional system, but the nesting condition for SDW and CDW is also perfectly satisfied in such a system. Hence, taking into account the competition with the SDW and CDW instabilities, quasi-two-dimensional superconductors would be the best candidates for the FFLO state to occur. In particular, quasi-two-dimensional heavy fermion superconductors would be favorable for the FFLO state, since the orbital pair-breaking effect is suppressed also due to the heavy effective mass in addition to the effects mentioned above. Some of the organic superconductors can also be good candidates. We also discuss the competition between the vortex state and the FFLO state in quasi-two-dimensional systems. For example, the FFLO state can be regarded as the vortex state with infinite Landau level index n. In the systems with sufficient three dimensionality, the center-of-mass momentum $\mathbf{q}$ of the FFLO state is oriented to the direction of the magnetic field as found in Gruenberg and Gunther's theory. In contrast, in the two-dimensional system in exactly parallel magnetic field, $\mathbf{q}$ is oriented to the direction for which the Fermi-surface effects are maximized. These two states in the opposite limits must be continuously connected by the vortex states with higher Landau level indexes.