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Pauli Limiting, First Order Superconducting Phase Transition, and a Possible Fulde-Ferrell-Larkin Ovchinnikov Inhomogeneous Superconducting State in $CeCoIn_5$

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We report specific heat and thermal conductivity measurements of the heavy fermion superconductor $CeCoIn_5$ in the vicinity of the superconducting critical field H_{c2}, with magnetic field in the plane of this quasi-2D compound and at temperatures down to 50 mK. The superconducting phase transition changes from second to first order for field above 10 T, as evident from a sharp peak in specific heat and a jump in thermal conductivity, indicating the importance of the Pauli limiting effect in $CeCoIn_5$. In the same range of magnetic field we observe a second specific heat anomaly within the superconducting state. We interpret this anomaly as a signature of a Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) inhomogeneous superconducting state. In addition, the thermal conductivity data as a function of field display a kink at a field H_k below the superconducting critical field, which closely coincides with the low temperature anomaly in specific heat, tentatively identified with the appearance of the FFLO superconducting state. Our results indicate that the thermal conductivity is enhanced within the FFLO state, and call for further theoretical investigations of the real space structure of the order parameter (and in particular, the structure of vortices) and of the thermal transport within the inhomogeneous FFLO state.