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De Haas-van Alphen effect under pressure in heavy fermion systems

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When pressure P is applied to the cerium compounds with antiferromagnetic ordering such as $CeCu_2Ge_2$, $CeIn_3$ and $CePd_2Si_2$ [1,2], the Néel temperature T_N decreases, and a quantum critical point corresponding to the extrapolation $T_N = 0$ is reached at $P = P_c$. Surprisingly, superconductivity and/or the non-Fermi liquid nature appear around P_c. Similar pressure-induced superconductivity was reported for other compounds such as $CeRh_2Si_2$ [3], $CeRhIn_5$ [4] and UGe_2 [5]. The crossover from the magnetically ordered state to the non-magnetic state under pressure, crossing the quantum critical point, is currently the most interesting issue in the strongly correlated f-electron systems. Here we report the nature of f-electrons in $CeRh_2Si_2$, UGe_2, $CeRhIn_5$ and $CeIn_3$ studied by the de Haas-van Alphen (dHvA) experiments under pressure.

In $CeRh_2Si_2$, the detected dHvA frequencies clearly change at $P_c \simeq 1.06\,\mathrm{GPa}$, implying a first-order like phase transition. This indicates a discontinuous change of the Fermi surface from $4f$-localized to itinerant at P_c. In UGe_2, the dHvA experiments under pressure indicate that the dHvA branches are clearly observed from ambient pressure to P_c^*=1.2 GPa (in the strongly polarized phase) but are disappeared in the pressure region from P_c^* to P_c=1.5 GPa (in the weakly polarized phase). This is mainly due to an extremely large cyclotron mass of conduction electrons in the weakly polarized phase, which is expected to be about 100 m_0 from the specific heat data under pressure, and/or the due to large scattering rate of the conduction electrons. It is, however, remarkable that new dHvA branches with large cyclotron masses $m_c^* = 60\,m_0$ appear clearly in the paramagnetic region, $P > P_c$. A drastic change of the Fermi surface occurs at P_c, suggesting that the phase boundary at P_c is of the first-order like phase transition. On the other hand, the change of the Fermi surface in $CeRhIn_5$ and $CeIn_3$ at the critical pressure, where the magnetically ordered state changes to non-magnetic one, is not drastic compared to $CeRh_2Si_2$. The picture that the $4f$-electron changes from localized state to itinerant one at the critical pressure, which is in the case of $CeRh_2Si_2$, may not be applicable to the case of $CeRhIn_5$ and $CeIn_3$.

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