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Unconventional superconductivity of $NpPd_5Al_2$

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The 5f electrons in actinide compounds has an intermediate character between the 4f-localized state and the 3d-itinerant state. This leads to a variety of exotic phenomena, such as non-Fermi liquid behavior, multipole ordering, hidden order state and unconventional superconductivity. The discovery of superconductivity in $PuCoGa_5$ and $PuRhGa_5$ with high critical temperatures provides a new perspective on the physics of actinide compounds. It is generally believed that Np compounds have more 5f-itinerant characteristic features like d-electron metals compared with U compounds. In fact, the results of dHvA experiments in Np-115 compounds are in good agreement with the 5f-itinerant band model. However, the complicated magnetic properties in Np-115 are well explained by the mean field theory including the orbital ordering based on the 5f-localized model. This indicates the dual nature of 5f electrons. $NpPd_5Al_2$ is the first Np-based heavy fermion superconductor with the $ZrNi_2Al_5$-type tetragonal structure. The superconductivity was found below $T_{sc} = 5\,K$. The non-Fermi liquid behavior and the large specific heat coefficient ($\gamma = 200\,mJ/K^2mol$) were detected. The upper critical field H_{c2} at $0\,K$ is large and highly anisotropic: $37\,kOe$ for $H \parallel [100]$ and $143\,kOe$ for $H \parallel [001]$. H_{c2} is strongly suppressed by the magnetic field in the H_{c2}–T phase diagram for both field direction, indicating the strong Pauli paramagnetic effect. The d-wave spin-singlet superconductivity is most likely realized. The large specific heat jump $\Delta C/\gamma T_{sc} = 2.33$ suggests the superconductivity with strong coupling. The results are compared with the well known heavy fermion superconductor $CeCoIn_5$.