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de Haas van Alphen effect in Nd-based skutterudites

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The exotic behaviors of Pr-based skutterudites, such as heavy fermion state in $PrFe_4P_{12}$, metal-insulator transition in $PrRu_4P_{12}$ and heavy fermion superconductivity in $PrOs_4Sb_{12}$, have promoted intense research activities based on various experimental techniques. Recentry, several attractive features have been also found in Sm-based skutterudites, such as ferromagnetic Kondo lattice in $SmFe_4P_{12}$, octupole ordering in $SmRu_4P_{12}$ and heavy fermion state robust against magnetic fields in $SmOs_4Sb_{12}$. In contrast, the physical properties of the reference compounds, such as La- and Nd-based ones, have been poorly investigated despite those importance for understanding the unusual properties both of Pr- and Sm-based ones. Until now, from the magnetic and transport properties, it was found that most Nd-based skutterudites show a ferromagnetic transition at low temperature and several ones show unusual behaviors, such as Kondo like logarithmic temperature dependence of electrical resistivity far above the ferromagnetic transition temperature in $NdFe_4P_{12}$ and heavy fermion behavior in $NdOs_4Sb_{12}$. In the present work, we have succeeded in measuring the dHvA effect of $NdFe_4P_{12}$, $NdRu_4P_{12}$, $NdRu_4Sb_{12}$ and $NdOs_4Sb_{12}$, and investigated these electronic states systematically. One of the results of dHvA experiments is shown in fig. 1. The angular dependence of dHvA frequency in $NdRu_4P_{12}$ is close to that of $LaRu_4P_{12}$, indicating the closeness of the Fermi surfaces as expected from the localized nature of $4f$-electrons. The observed cyclotron effective mass up to 10.9 m_0 is extraordinary large as Nd-based compound.

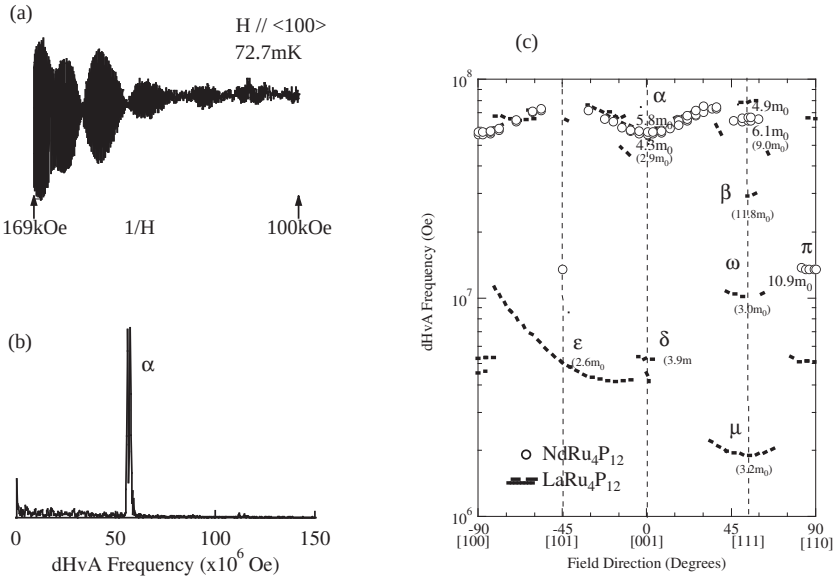

Figure 1: (a) Typical dHvA oscillation and (b) its FFT spectrum in $NdRu_4P_{12}$. (c) Comparison of the angular dependence of the dHvA frequencies between $NdRu_4P_{12}$(circles) and $LaRu_4P_{12}$(dashed lines).