論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Effect of Magnetic Field and Hydrostatic Pressure on Low Temperature Phase Diagram of Non-Kramers System PrRh2Zn20
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出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第10403号, 授与年月日:2017年3月26日, 学位の種別:課程博士, 審査員:井澤 公一,田中 秀数,吉野 淳二,大熊 哲,古賀 昌久,楠瀬 博明
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第10403号, Conferred date:2017/3/26, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

専攻： Department of	物性物理学 専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	（ 理学 ）
学生氏名： Student's Name	吉田太地	指導教員（主）： Academic Advisor(main)		井澤公一
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Generally, three types of fundamental internal degrees of freedom of electron, i.e., charge, spin, and orbital, play a crucial role in forming low temperature electronic states in strongly correlated f electron systems. Especially in the system that the spin degree of freedom is predominantly active, namely in a Kramers system, a rich variety of exotic phenomena are realized on the basis of competition between the RKKY interaction and the Kondo effect. Based on many intensive studies which have been performed for the Kramers systems, the Doniach phase diagram has been constructed in order to provide a universal framework to understand systematically these exotic phenomena with respect to a single parameter, namely strength of hybridization between conduction electrons and localized *f* electrons (*c-f* hybridization). The Doniach phase diagram has been a significant base and contributed to investigations of low temperature properties of the Kramers systems.

On the other hand, few studies have been performed for clarification of exotic phenomena arising from orbital (multipole) degrees of freedom. Only the multipole order, which is a reflection of the localized character of multipole with weak *c-f* hybridization, has been well discussed so far, but in contrast, the phenomena reflecting the itinerant character of multipole with strong *c-f* hybridization have not been entirely unclear, although the quadrupole Kondo effect has been theoretically proposed. This is because most of the compounds which undergo the multipole order transition possess a dipole (spin) degrees of freedom as well as high-rank multipoles and consequently the electronic states are too complicated to clarify when the *c-f* hybridization is very strong. It is not necessarily trivial whether the electronic states arising from the multipole degrees of freedom can be understood on the analogy of the Doniach phase diagram for the Kramers systems. For clarification of multipolar properties with strong *c-f* hybridization, a system with only the high-rank multipoles, namely a non-Kramers system, has been highly required.

In this study, I focus on the non-Kramers system $PrRh_2Zn_{20}$, which belongs to the so-called Pr 1-2-20 family $PrTr_2X_{20}$ (Tr = Ir, Rh, V, Ti, X = Zn, Al). The Pr 1-2-20 family is known to possess a non-Kramers twofold degeneracy with active quadrupoles at the crystal electric field (CEF) ground state, which is well isolated from the first excited CEF state by several tens of kelvin. In addition, *f* electrons of Pr ions have many opportunities to hybridize with conduction electrons because of a high coordination number of a Pr^{3+} ion with *f* electrons. Therefore, the Pr 1-2-20 family is regarded as a suitable stage to clarify the quadrupolar properties with strong *c-f* hybridization. In fact, the quadrupolar properties have been successively unveiled on the basis of the recent studies which have observed as an anomalous non-Fermi liquid behavior, novel heavy-fermion, and coexistence of quadrupole order and superconductivity. However, it is still an open question whether these phenomena emerge in non-Kramers systems commonly or in only a specific compound. In order to progress the clarification of the quadrupolar properties with strong *c-f* hybridization, here I measure the electrical resistivity and the Seebeck coefficient under magnetic field and hydrostatic pressure. Since the transport coefficients can detect the electronic states of itinerant electrons, they are powerful tools to investigate the phenomena reflecting the itinerant character of quadrupole with strong *c-f* hybridization.

Based on the results of resistivity measurements under magnetic field, I first revealed that a low temperature phase diagram of $PrRh_2Zn_{20}$ is divided into four characteristic regions I, II, III, and IV. In the region I, the temperature dependence of resistivity shows a non-Fermi liquid (NFL) behavior which can be reproduced by a theoretical expression based on the quadrupole Kondo lattice model. By using the characteristic temperature T_0 estimated from the expression, the NFL behaviors can be successfully scaled on the unique curve. These facts strongly suggest that the electronic state in the region I is derived from a physics with the single energy scale T_0, namely the quadrupole Kondo effect. In the region II, an antiferro-quadrupole (AFQ) order occurs. The phase boundary can be roughly reproduced by the mean-field calculation, implying that the ordered state can be argued from the viewpoint of only the localized character of quadrupole because this calculation does not include the *c-f* hybridization effect which describes the itinerant character of quadrupole. In the region III, the temperature dependence of resistivity shows a Fermi liquid (FL) behavior in sharp contrast to the region I. The estimated A coefficient of the FL behavior $\rho - \rho_0 = AT^2$ is strongly enhanced in the region III, suggesting that a novel heavy-fermion (HF) state is realized. In the region IV, the resistivity is almost independent of temperature. Considering that the non-Kramers doublet is lifted by magnetic field via the first-excited magnetic state, the electronic state in the region IV is similar to a simple metallic state caused by quenching of the quadrupole degrees of freedom by magnetic field. Interestingly, from the analyses for the anisotropy of the phase diagram against applied field, I found that the electronic states in these four regions are characterized by an energy splitting of the non-Kramers doublet by magnetic field $\delta(B)$. From the fact that these features for the phase diagram of $PrRh_2Zn_{20}$ are common with those of $PrIr_2Zn_{20}$, I proposed a possible universal B-T phase diagram for non-Kramers systems with a single control parameter $\delta(B)$.

Under hydrostatic pressure, these characteristic electronic states composed of the B-T phase diagram of $PrRh_2Zn_{20}$ are observed as well as under ambient pressure, but the energy scales or transition temperatures for these states are enhanced within applied pressures in this study. This feature can be roughly interpreted in terms of enhancement of the *c-f* hybridization by pressure, and thus it is expected that the low temperature electronic states of $PrRh_2Zn_{20}$ under hydrostatic pressure are characterized by the *c-f* hybridization. On the other hand, a tendency to decrease the transition temperatures of the AFQ ordered state and the HF state are observed around the highest pressure of this study. It is quite nontrivial what kind of states emerge under higher pressures. To unveil the overall features of $PrRh_2Zn_{20}$, further high pressure experiments are necessary.