Pressure-induced magnetic instability in $Ce_2Rh_3Ge_5$

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A pressure-induced magnetic-nonmagnetic transition in an antiferromagnet $Ce_2Rh_3Ge_5$ has been investigated by the measurements of the resistivity ρ, magnetic susceptibility χ, and specific heat on a single crystal down to 0.3 K. With increasing pressure, the Néel temperature T_N is suppressed and disappears at $P_c=0.45$ GPa. For $P>P_c$, the deviation from the Fermi-liquid behavior is observed in both $\rho(T)$ and $\chi(T)$: $\rho(T)=\rho_0+AT^n$ ($n\cong1.45$) and $\chi(T)=\chi_0-DT^m$ ($m\cong0.27$). Even for $P>3P_c$ both n and m hardly change, i.e., no recovery of the Fermi-liquid state. This fact is in contrast with the recovery in many of Ce-based antiferromagnets at $P>2P_c$. The magnetization hardly decreases with pressure up to 1.2 GPa, suggesting that the cerium local moments still remain even far from the quantum critical point. Moreover, the Kondo temperature T_K increases weakly from 10 K at $P=0$ to 13 K at $P=0.57$ GPa. These findings indicate the important role of short-range magnetic correlations in the revised Doniach phase diagram.

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I. INTRODUCTION

The ground state of cerium-based heavy-fermion compounds is characterized by the proximity to a magnetic instability where the Kondo effect competes with the Ruderman-Kittel-Kasuya-Yoshida (RKKY) interaction. According to conventional Doniach phase diagram,[1] the characteristic temperatures T_{RKKY} and T_K are, respectively, proportional to $N_c|J|^2$ and $\exp(-1/N_c|J|)$, where N_c is the density of states of conduction electrons at the Fermi level and J is the exchange coupling constant between the $4f$ and conduction electrons. When a magnetically ordered compound is pressurized, $|J|$ increases by enhancement of the hybridization between $4f$ and conduction electrons, and then T_K increases exponentially with pressure, resulting in a reduced magnetic moment and transition temperature. However, Coqblin *et al.* have proposed a revised Doniach diagram that T_K for the Kondo lattice increases with $|J|$ more slowly than the one-impurity Kondo temperature.[2] At a critical pressure or concentration, there exists a second-order zero-temperature phase transition [quantum critical point (QCP)] that separates a magnetically ordered phase from one with no long-range order.[3]

In recent years, pronounced deviations from conventional Fermi-liquid behavior have been found in some Ce-based antiferromagnets near the QCP.[4–6] Anomalous temperature dependences of the specific heat C, magnetic susceptibility χ, and electrical resistivity ρ have been found: $C/T\propto-\ln T$, $\chi\propto(1-T^{0.5})$, and $\rho\propto T^n$ $(1\leqslant n<2)$. Different scenarios have been proposed in order to elucidate this anomalous behavior, so-called non-Fermi-liquid (NFL) behavior, at the QCP. The self-consistent renormalization (SCR) theory of spin fluctuations for itinerant antiferromagnetism[7] and Hertz-Millis spin-fluctuation theory[8,9] have been applied to describe the NFL behavior of $Ce_xLa_{1-x}Ru_2Si_2$ (Ref. 10), $CePd_2Si_2$ (Ref. 11), and $CeNi_2Ge_2$ (Ref. 12). Both models regard the quantum critical phenomena as a magnetic instability of the Fermi surface due to low-lying spin fluctuations. More recently, a local moment model has been proposed to interpret the results of neutron scattering and bulk magnetic susceptibility measurements for $CeCu_{6-x}Au_x$.[13] This approach regards the compound as a local moment system. Most interestingly, heavy-fermion superconductivity appears in the vicinity of the pressure-induced QCP in $CeCu_2Ge_2$ (Ref. 14), $CePd_2Si_2$ (Ref. 11), $CeRh_2Si_2$ (Ref. 15), $CeIn_3$ (Ref. 16), and $CeRhIn_5$ (Ref. 17).

In this paper, we report the pressure dependence of electrical resistivity, magnetization, and specific heat of single-crystalline $Ce_2Rh_3Ge_5$, which orders antiferromagnetically below $T_N=5.5$ K.[18] This compound crystallizes in the $U_2Co_3Si_5$-type orthorhombic structure, which is an intergrowth of the $CaBe_2Ge_2$- and the $BaNiSn_3$-type structures.[19] From the specific-heat measurement for the polycrystalline sample, the Kondo temperature was estimated to be 6 K, which is close to T_N.[18] Therefore, we expected that the T_N is suppressed with low pressure, and thereby pressure-induced superconductivity may appear. By the present experiments, however, no evidence of superconductivity has been observed down to 0.3 K. Nevertheless, strong deviations from conventional Fermi-liquid behavior have been found in $\rho(T)$, $\chi(T)$, and $C(T)$. The non-Fermi-liquid behavior in $Ce_2Rh_3Ge_5$ is compared with that for certain Ce-based compounds such as Ce_7Ni_3 and CeM_2X_2 ($M=$transition metal, $X=$Si, Ge). We discuss the quantum critical phenomena for the present compound in terms of the spin-fluctuation theory.

II. EXPERIMENTAL PROCEDURE

Single crystals of $Ce_2Rh_3Ge_5$ were grown by the Czochralski method in a tetra-arc furnace. We used starting materials of Ce, Rh, and Ge with a purity of 99.99% (Ames Laboratory), 99.9%+, and 99.999%, respectively. The crystal of 4 mm in diameter and 20 mm in length was wrapped in Ta foil and annealed in an evacuated quartz tube at 900 °C

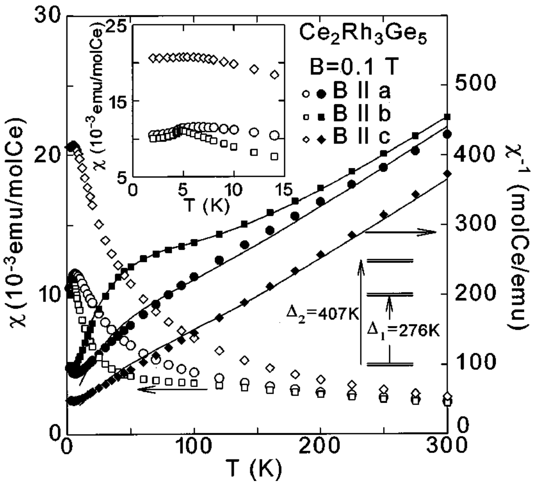

FIG. 1. Temperature dependence of magnetic susceptibility $\chi(T)$ and its inverse along the three principal axes of $Ce_2Rh_3Ge_5$. The solid lines and the level scheme show the results calculated with a crystal-field model. The inset shows $\chi(T)$ below 15 K.

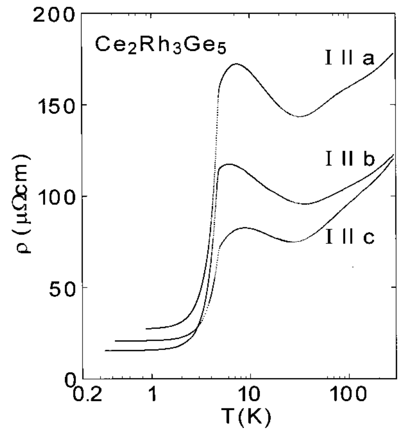

FIG. 2. Electrical resistivity of $Ce_2Rh_3Ge_5$ along the three principal axes.

for 3 weeks. The crystal orientation was determined by the backscattering Laue method.

The electrical resistivity under pressures up to 1.3 GPa was measured by an ac four-terminal method in the range $0.35 \leqslant T \leqslant 300\,\mathrm{K}$. A superconducting quantum interference device magnetometer (Quantum Design) was used for susceptibility measurements. The magnetization under pressures up to 1.2 GPa was measured by an extraction method with a clamp-type piston-cylinder pressure cell at the Institute for Solid State Physics, University of Tokyo.[20] The heat capacity under pressures up to 0.6 GPa was measured using an ac method.[21]

III. RESULTS AND DISCUSSION

First, we present the magnetic susceptibility $\chi(T)$ and electrical resistivity $\rho(T)$ of a $Ce_2Rh_3Ge_5$ single crystal at ambient pressure. Figure 1 shows $\chi(T)$ and its inverse along the three principal axes. Above 150 K, the data follow a Curie-Weiss law with paramagnetic Curie temperatures $\Theta_P = -126$, -160, and -26 K for $B\|a$, $B\|b$, and $B\|c$, respectively. The large anisotropy in Θ_P may indicate anisotropic exchange interactions. The effective magnetic moments per Ce atom are, respectively, $2.81\mu_B$, $2.85\mu_B$, and $2.65\mu_B$, which are somewhat larger than the free Ce^{3+} ion value $(2.54\mu_B)$. The deviation of the data from the Curie-Weiss law below 150 K arises from a crystal-field (CF) effect, as described below.

We have analyzed the $\chi(T)$ data by using a CF model. In this analysis, the orthorhombic point symmetry for the Ce^{3+} ion was assumed instead of the monoclinic Cs point symmetry at the Ce site in the $U_2Co_3Si_5$-type structure to keep the number of the adjustable parameters in the CF Hamiltonian to a minimum. Following this procedure, the CF Hamiltonian is written in the Stevens parametrization scheme:[22]

$$H_{\mathrm{CF}} = B_2^0 O_2^0 + B_2^2 O_2^2 + B_4^0 O_4^0 + B_4^2 O_4^2 + B_4^4 O_4^4. \qquad (1)$$

We used the expression $\chi^{-1}(T) = \chi_{\mathrm{CF}}^{-1}(T) - \lambda$, where λ is the molecular-field term arising from intersite magnetic interactions. The solid lines in Fig. 1 represent the calculated curves using the parameters obtained by a least-squares fitting: $B_2^0 = 3.6\,\mathrm{K}$, $B_2^2 = 9.5\,\mathrm{K}$, $B_4^0 = 0.85\,\mathrm{K}$, $B_4^2 = 1.3\,\mathrm{K}$, $B_4^4 = -5.2\,\mathrm{K}$, and $\lambda = -19\,\mathrm{mol/emu}$. These parameters yield the CF-level scheme with two excited doublets at $\Delta_1 = 276\,\mathrm{K}$ and $\Delta_2 = 407\,\mathrm{K}$. The CF ground state is obtained as $0.422|\pm 5/2\rangle - 0.132|\pm 1/2\rangle + 0.897|\mp 3/2\rangle$, where the orthorhombic c axis was chosen as the quantization z direction because $\chi(T)$ is largest along the c axis. The ground state of $Ce_2Rh_3Ge_5$ consists mainly of $|\mp 3/2\rangle$, which is in contrast with some CeM_2X_2 systems such as $CeRh_2Si_2$ (Ref. 23) and $CeCe_2Ge_2$ (Ref. 24) with the ground state composed mainly of $|\pm 5/2\rangle$.

The inset of Fig. 1 shows the $\chi(T)$ data at low temperatures. The maximum in $\chi_a(T)$ and $\chi_b(T)$ at 4.9 K is attributed to the antiferromagnetic order. It is noteworthy that the easy-axis susceptibility $\chi_c(T)$ does not decrease below T_N, being at variance with a steep decrease for a conventional antiferromagnet, such as an isostructural compound $Ce_2Pd_3Ge_5$.[25] This fact suggests a complex magnetic structure for $Ce_2Rh_3Ge_5$.

Figure 2 displays $\rho(T)$ of $Ce_2Rh_3Ge_5$ along the three principal axes in the temperature range 0.3–300 K at ambient pressure. With decreasing temperature, $\rho(T)$ shows a broad hump around 80 K, which can be ascribed to the interplay between the CF effect and Kondo effect. On further cooling, $\rho(T)$ exhibits a minimum at around 30 K, passes through a maximum at around 8 K and then suddenly drops below $T_N = 4.9\,\mathrm{K}$. The rather large residual resistivity of 20–30 $\mu\Omega\,\mathrm{cm}$ might be attributed to a crystallographic disorder by a partial mixing of Rh and Ge atoms over their available lattice sites, as was found in URh_2Ge_2.[26]

We have measured $\rho(T)$ along the a and c axes of $Ce_2Rh_3Ge_5$ under various pressures. No significant difference was observed between the current directions along the a and c axes. The $\rho(T)$ along the c axis up to 1.27 GPa is shown in Fig. 3. With increasing pressure, the anomaly due to an antiferromagnetic order, as denoted by the arrow, shifts to lower temperatures and vanishes above 0.42 GPa. For P

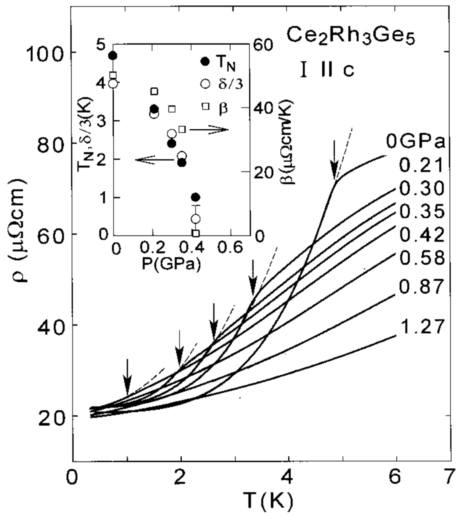

FIG. 3. Low-temperature resistivity of $Ce_2Rh_3Ge_5$ along the c axis for several pressures. The dashed lines are the fits by Eq. (2) given in the text. The inset shows the pressure dependence of the antiferromagnetic ordering temperature T_N, the spin-wave scattering weight β, and the spin-wave energy gap δ (see text).

$\geqslant$0.58 GPa, no anomaly was observed down to 0.35 K. The critical pressure P_c is estimated to be $P_c = 0.45$ GPa, as is shown in the inset.

We assume that $\rho(T)$ below T_N is described with the following form, which was used in the same context for the antiferromagnets $Ce_2Ni_3Ge_5$ (Ref. 27) and $U_2Rh_3Si_5$ (Ref. 28):

$$\rho(T) = \rho_0 + AT^2 + \beta T(1 + 2T/\delta)\exp(-\delta/T). \tag{2}$$

The first term ρ_0 is the residual resistivity, the second term AT^2 is the Fermi-liquid contribution, and the last term is the contribution of antiferromagnetic spin waves with a magnon scattering weight β and a gap of δ. The fit to the data is shown by the dotted lines in Fig. 3. The parameter A is 0.48 $\mu\Omega$ cm/K^2 at $P = 0$. The low-temperature specific-heat linear coefficient γ is obtained to be 220 mJ/mol K^2, as will be described later. Then, so-called Kadowaki-Woods ratio A/γ^2 is 0.99×10^{-5} $\mu\Omega$ cm K^2 (mol/mJ)^2, which is just the canonical value 1.0×10^{-5} $\mu\Omega$ cm K^2 (mol/mJ)^2.[29] The strong suppression of both δ and β with pressures is evident in the inset of Fig. 3. The vanishing of both δ and β at P_c is in contrast to the case of $CePd_2Si_2$,[11] where δ is constant with P up to P_c. Our findings suggest that the change of the spin-wave spectrum plays an important role as the driving mechanism to the QCP. To confirm the pressure dependence of δ and β, a neutron-scattering study is highly desirable.

Non-Fermi-liquid behavior in $\rho(T)$ of $Ce_2Rh_3Ge_5$ is observed in a wide pressure range above P_c as shown in Fig. 4. The resistivity follows a form $\rho(T) = \rho_0 + AT^n$ ($n = 1.45$) far below T_ρ where $\rho(T)$ exhibits a maximum or shoulder. The value of n is close to the exponent $n = 1.5$, which is obtained by the spin-fluctuation theory for a three-dimensional antiferromagnet just above the QCP.[7] It has been proposed that the temperature regime where the resistivity varies as T^n with an

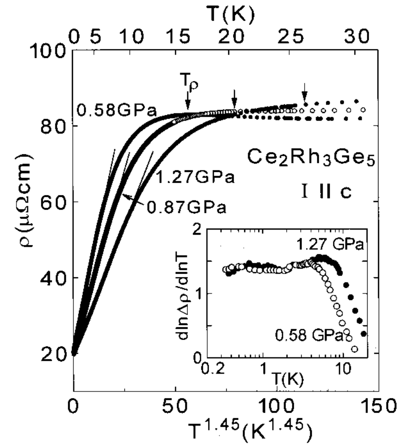

FIG. 4. Resistivity of $Ce_2Rh_3Ge_5$ along the c axis as a function of $T^{1.45}$ under various pressures above 0.58 GPa. Here T_ρ is the temperature where the resistivity exhibits a maximum or shoulder. The inset shows the temperature dependence of $d\ln\Delta\rho/d\ln T$, where $\Delta\rho = \rho - \rho_0$, at 0.58 and 1.27 GPa.

anomalous exponent, $1 \leqslant n \leqslant 1.5$, depends on the amount of disorder.[30] Indeed, n is close to 1.5 for a dirty sample of $CePd_2Si_2$ with rather low residual resistivity ratio (RRR $\cong 5$).[12] For $Ce_2Rh_3Ge_5$, therefore, the value of $n = 1.45$ may be related to the low RRR$\cong$6. With increasing pressure, T_ρ moves to higher temperatures, and the range of $T^{1.45}$ dependence becomes wider as shown in the inset of Fig. 4. However, it is noteworthy that n hardly changes even for $P = 1.27$ GPa$> 3P_c$, as is reported for $CeNiGa_2$.[31] This fact is in contrast with the recovery of the Fermi-liquid state at $P > 2P_c$ for many Ce-based antiferromagnets such as Ce_7Ni_3.[32]

The magnetic susceptibility $\chi(T)$ for $B \| c$ of $Ce_2Rh_3Ge_5$ under pressures is shown in Fig. 5. We note that the pressure dependence of $\chi(T)$ above 50 K is much less than that of Ce_7Ni_3 (Ref. 32) and $CeRh_2Si_2$ (Ref. 33). Furthermore, as shown in the inset of Fig. 5, the magnetization at 9 T for $P = 1.2$ GPa$\cong 3P_c$ is still 60% of that at $P = 0$, while the magnetization of Ce_7Ni_3 at $P = 3P_c$ is only 10% of that at P

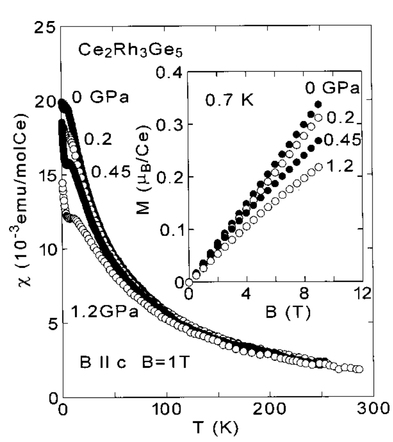

FIG. 5. Temperature dependence of magnetic susceptibility of $Ce_2Rh_3Ge_5$ for $B \| c$ under various pressures. The inset shows the isothermal magnetization curves at 0.7 K under pressure.

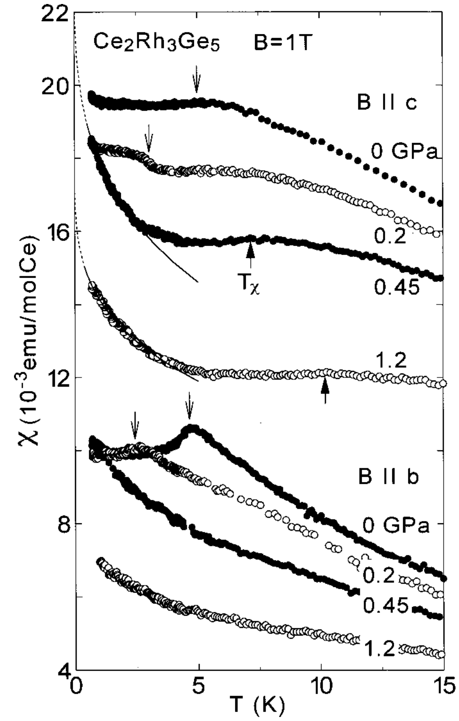

FIG. 6. Temperature variations of magnetic susceptibility of $Ce_2Rh_3Ge_5$ for $B\|b$ and $B\|c$ below 15 K under pressure. The solid lines represent the fit with $\chi(T)=\chi_0-DT^m$.

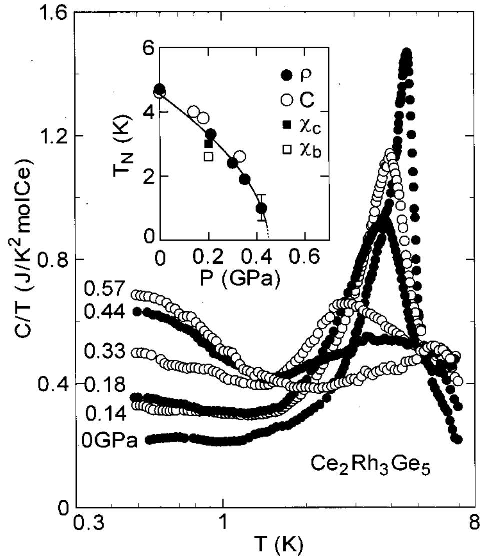

FIG. 7. Specific heat divided by temperature C/T as a function of T for $Ce_2Rh_3Ge_5$ under various pressures. The inset shows the pressure dependence of magnetic transition temperature T_N.

$=0$.[32] These facts suggest that the local moments remain at high pressures far above P_c in $Ce_2Rh_3Ge_5$, and its spin fluctuations play an important role in the non-Fermi-liquid behavior.

Figure 6 shows the pressure variations of $\chi(T)$ for $B\|c$ and $B\|b$. For both directions, the anomaly in $\chi(T)$ at 5 K for $P=0$ shifts to $\cong$2.5 K for $P=0.2$ GPa. For $P>P_c$, however, $\chi(T)$ shows an upturn at low temperatures. A similar upturn in $CeNi_2Ge_2$ at ambient pressure[34] was phenomenologically explained by a model assuming a density of states with a peak in the vicinity of the Fermi energy.[35] To analyze the data of $\chi(B\|c)$ for $Ce_2Rh_3Ge_5$, we assumed the form $\chi(T)=\chi_0-DT^m$ (D is constant), as was predicted by SCR theory of spin fluctuations.[36] The exponent m for 0.45 GPa and 1.2 GPa is, respectively, 0.27 and 0.28, which are close to the theoretical one, $m=0.25$. The solid lines in the figure are the fitting result. The pressure independence of m even for $P=1.2\,\text{GPa}\cong 3P_c$ corresponds to the constant exponent $n=1.45$ in resistivity for $P=1.27$ GPa. For $B\|c, \chi(T)$ at $P=0.45\,\text{GPa}>P_c$ has a shallow maximum at $T_\chi\cong 7$ K. This behavior might be attributed to short-range magnetic correlations,[37] as observed in $CeRu_2Si_2$.[38] The maximum shifts to higher temperature and reaches 10 K with increasing pressure up to 1.2 GPa.

The temperature dependence of the specific heat divided by temperature, C/T, under pressures is displayed in Fig. 7. The peak due to the antiferromagnetic order shifts to lower temperatures and becomes broader with increasing pressure. The pressure dependence of T_N determined from $\rho(T)$, $C(T)$, and $\chi(T)$ is plotted in the inset of Fig. 7. We took the temperature of the maximum in $d\rho/dT$ and C/T as T_N. Other points for T_N were taken from the maximum in $\chi(B\|b)$ and the sudden change in $\chi(B\|c)$. Assuming the form $T_N\propto|P-P_c|^\varepsilon$, the parameters P_c and ε were estimated to be 0.45(3) GPa and 0.54(8), respectively. The solid line in the inset is the fitting curve. The exponent ε is somewhat smaller than 2/3, which was predicted for a three-dimensional antiferromagnet by Millis.[9]

Upon application of pressure, the value of C/T increases significantly at low temperatures. This increase is attributed to the enhancement of low-lying spin fluctuations near the magnetic instability as found in $CeRh_2Si_2$.[39] The C/T value in the vicinity of P_c tends to be constant as T approaches 0 K. This behavior is consistent with the prediction of the SCR theory for a three-dimensional antiferromagnet. In more detail, however, the data of C/T do not follow the predicted $T^{1/2}$ dependence. Instead, at $P=0.44\,\text{GPa}\cong P_c$, a broad maximum appears at around 3 K, which shifts to higher temperature for $P=0.57$ GPa. The maximum might be due to the development of a short-range magnetic correlation as mentioned above.[38] Therefore, the $T^{1/2}$ dependence of C/T may be hidden by the contribution of the short-range magnetic correlation.

We now discuss the pressure dependence of the characteristic energy, i.e., the spin-fluctuation temperature or the Kondo temperature T_K. The magnetic entropy S_{mag} was calculated by subtracting the phonon contribution that was estimated from the specific heat of $La_2Rh_3Ge_5$.[18] The phonon part of the entropy is less than 1% of the total entropy at 5 K. For $P=0$, S_{mag} at $T_N=4.9$ K reaches $0.48R\ln 2$. This significant reduction of S_{mag} was ascribed to the Kondo effect.[18] If any short-range order is absent, the deficiency of the $S_{\text{mag}}(T_N)$ is due to the fact that the twofold magnetic degeneracy is partially exhausted above T_N by the presence of

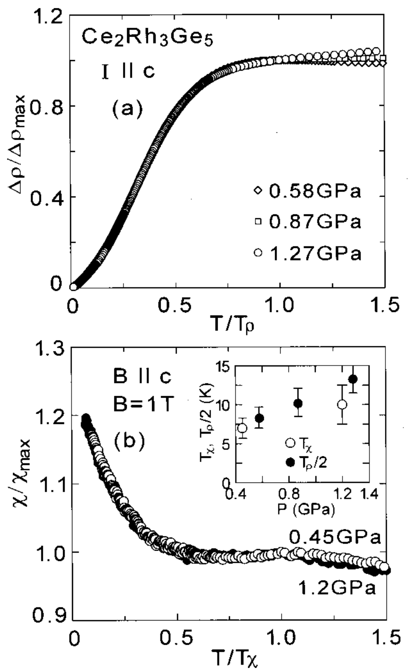

FIG. 8. Normalized resistivity (a) and susceptibility (b) as a function of the normalized temperature. The inset shows the pressure dependence of characteristic temperatures T_χ and T_ρ.

Kondo effect. This leads to the relation $S_{\rm mag}(T_N) = S_K(T_N/T_K)$, where $S_K(T_N/T_K)$ is Kondo entropy at T_N,[40] provided that $\Delta_1 \gg k_B T_N$ and $\Delta_1 \gg k_B T_K$, where Δ_1 is the energy from the ground state to the first excited state. Using $\Delta_1 = 276$ K for $Ce_2Rh_3Ge_5$, we obtain T_K to be 10 K. This value is somewhat larger than the previous estimation $T_K = 6$ K in Ref. 18, because the short-range order was ignored. For $0 < P < P_c$, it is difficult to estimate T_K by this method, because the anomaly in $C(T)$ at T_N becomes broader. The entropy at 4.9 K for $P = 0.57$ GPa decreases to only 80% of that at $P = 0$. This fact implies the significantly weak increase of T_K. If we apply the relation $\gamma = \pi R/3T_K$ predicted by the spin-1/2 single-impurity Kondo mode,[41] T_K at $P = 0.57$ GPa is estimated to be 13 K from $\gamma = 0.68$ J/K^2 molCe. This value of T_K just above QCP is much smaller than T_K at $P \cong P_c$ for $CeRh_2Si_2$(54 K) (Ref. 42), $CeRu_2Ge_2$(24 K) (Ref. 43), and $CePd_2Si_2$($\sim$100 K) (Ref. 12). Although the increase of T_K is thought to be the driving force to QCP in these compounds, it is not the case for $Ce_2Rh_3Ge_5$.

Next, we proceed to analyze the pressure dependence of the characteristic temperature in the paramagnetic region for $P > P_c$. When the temperature is scaled with T_ρ and T_χ, both sets of data $\Delta\rho(T) = \rho(T) - \rho_0$ and $\chi(T)$ at different pressures, respectively, can be mapped onto a single curve as shown in Figs. 8(a) and 8(b). This simple scaling behavior suggests that the energy of the spin fluctuations related to the non-Fermi-liquid behavior of $Ce_2Rh_3Ge_5$ is given by a universal function of a characteristic temperature. Indeed, in many paramagnetic Ce compounds, T_ρ and T_χ empirically correspond to the Kondo temperature or the spin fluctuation temperature. Therefore, the pressure dependence of T_ρ and T_χ allows the determination of the Grüneisen parameter Γ.[44] Both T_ρ and T_χ increase with pressure in a similar fashion as shown in the inset of Fig. 8. This dependence gives a value of $\Gamma \cong 60$ by assuming a bulk modulus $B \cong 100$ GPa, which is the typical value for CeM_2X_2 such as $CeRu_2Si_2$ ($B = 122$ GPa) (Ref. 45) and $CeNi_2Ge_2$ ($B = 87$ GPa) (Ref. 46). We note that the value of Γ for $Ce_2Rh_3Ge_5$ is smaller than that for $CeRu_2Si_2$ ($\Gamma = 185$) (Ref. 45), $CeNi_2Ge_2$ ($\Gamma = 90$) (Ref. 46), and Ce_7Ni_3 ($\Gamma = 100$) (Ref. 47). This small Γ may be responsible for the no recovery of the Fermi-liquid state in the present system.

The weak increase of T_K with pressure below and above P_c contradicts the exponential increase derived from the conventional Doniach model. Recently, Coqblin *et al.* have proposed a revised model where T_K of the Kondo lattice above P_c becomes smaller than that for the single-impurity model because of short-range magnetic correlations.[2] This model explained the pressure independence of T_K for $CeRh_2Si_2$ (Ref. 42) derived from specific-heat and resistivity measurements. In the case of $CeRu_2Si_2$ and $CeCu_6$ at ambient pressure, short-range magnetic correlations manifest themselves in the broad maximum of $\chi(T)$ and $C(T)$, as observed in $Ce_2Rh_3Ge_5$ at $P > P_c$. Therefore, the weak increase of T_K with pressure for this compound is attributed to the magnetic correlations. In order to gain insight into the magnetic correlations, a neutron-scattering study is highly desirable.

IV. CONCLUSION

The magnetic susceptibility $\chi(T)$, resistivity $\rho(T)$, and specific heat $C(T)$ for single crystals of an antiferromagnet $Ce_2Rh_3Ge_5$ with $T_N = 4.9$ K were measured in the temperature range $0.3\,{\rm K} < T < 300$ K and pressure range $0 \leqslant P < 1.3$ GPa. For $P = 0$, the crystal-field and Kondo effects manifest in $\chi(T)$ and $\rho(T)$. From the analysis of $\chi(T)$ by the CF model, we obtained the CF-level scheme with two exited doublets at $\Delta_1 = 276$ K and $\Delta_2 = 407$ K.

With increasing pressure, the anomaly in $\rho(T)$, $\chi(T)$, and $C(T)$ due to the antiferromagnetic order disappears at $P_c = 0.45$ GPa. For $P > P_c$, non-Fermi-liquid behavior is observed in both $\rho(T)$ and $\chi(T)$: $\rho(T) = \rho_0 + AT^n$ ($n \cong 1.45$) and $\chi(T) = \chi_0 - DT^m$ ($m \cong 0.27$). Both n and m are close to the theoretical exponents $n = 1.5$ and $m = 0.25$ derived from the self-consistent renormalization theory of spin fluctuations in the vicinity of QCP.[7,36] Even for $P > 3P_c$, both n and m hardly change; therefore, Fermi-liquid state does not recover. This fact is in contrast with the recovery of the Fermi-liquid behavior for $P > 2P_c$ in many Ce compounds such as Ce_7Ni_3. Furthermore, little decrease of the magnetization with pressure suggests that local moments still remain even far from the QCP. The analysis of the specific heat indicated the Kondo temperature T_K to be 13 K at $P = 0.57$ GPa just above P_c. This value of T_K is much lower than that for the CeM_2X_2 systems at their P_c's. We conclude that the weak increase of T_K in $Ce_2Rh_3Ge_5$ results from short-range magnetic correlations as was proposed by the revised Doniach phase diagram.[2]

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