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Magnetism and superconductivity in heavy fermion compounds at high pressure

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Abstract

From high pressure transport measurements we compare the normal and superconducting properties of $CeCu_2Ge_2$ and $CeCu_2Si_2$. The pressure-induced enhancement of the superconducting transition temperature T_c up to about 2 K is correlated to several characteristics of the normal phase which all point to the possibility that charge fluctuations are involved in superconductivity. We also examine whether the transport properties of $CeRu_2Ge_2$ and $YbCu_2Si_2$ show deviation of the Fermi liquid behaviour in the vicinity of the magnetic to non-magnetic transition. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: High pressure; Superconductivity; Transport properties; Magnetic transition

1. Introduction

External pressure (P) is a powerful and clean control parameter for investigating the physics of strongly correlated electron systems [1]. Notably for heavy-fermion (HF) compounds, electronic correlations are very pressure-sensitive and various ground states, cooperative transitions and crossover regimes can be induced by pressure. In HF systems, electronic couplings, such as the Kondo and RKKY can be dramatically changed in a pressure range of the order of 20 GPa. But, as expected for extreme experimental conditions, the higher the pressure is, the less experiments become feasible. For instance, specific heat investigations are up to now limited to 1–2 GPa. Yet the transport properties, which are very sensitive to the HF phenomenon, provide unique opportunities. Indeed, e.g. the electrical resistivity can be simultaneously measured up to very high pressure, in high magnetic field and down to very low temperature where the most interesting HF physics develops.

Transport properties at high pressure may offer valuable information about some of the following topics: (i) the magnetic phase diagram, especially near the magnetic to non-magnetic transition at the critical pressure P_c, (ii) the occurrence of superconductivity at the verge of magnetism observed for an increasing number of Ce-based HF compounds, (iii) the deviation of Fermi-liquid (FL) behaviour near the magnetic instability or (iv) the role of the disorder. Challenging problems are, e.g. whether a spin fluctuation theory succeeds in describing the physics near P_c [2], the nature of superconductivity and the intriguing P-dependence of the superconducting transition of $CeCu_2Si_2$ [3]. In this paper, we will limit ourselves to the case of some Ce and Yb-based HF compounds.

The technique for measuring the transport properties at high pressure is discussed in Section 2 with emphasis on progress and limitations. In Section 3 we focus on the interplay of normal and superconducting properties of $CeCu_2Ge_2$ and $CeCu_2Si_2$. In Section 4, the P-dependence of the residual resistivity of several compounds is presented and Section 5 is devoted to the T-power relationship of resistivity and thermopower.

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2. Experiment

The technique to measure the resistivity and the thermopower at high pressure has been recently described [4]. Let us mention here only a few points. Pressure up to about 10 GPa or 30 GPa is generated between two Bridgman anvils made of tungsten carbide (WC) or sintered diamond, respectively. Because the magnetisation of the WC anvils is sufficiently low, an external magnetic field can be applied in this case. Upon cooling, the pressure is kept constant within a few percents. Between the flats of the anvils, a pyrophyllite gasket contains steatite which is used as pressure transmitting medium. The geometrical factor of a given sample is nearly P-invariant (neglecting the sample compressibility). Thus, not only the resistance but also the resistivity of a sample can be determined. In most cases, the main error source comes from the estimation of the sample thickness (20–30 μm) and the overall accuracy of resistivity data is within $\pm$ 5%. This experimental progress permits residual resistivity investigations or a better comparison between different pressure runs. A similar set-up is used for thermopower measurements but the measuring error is slightly larger [5].

With the miniaturization of the pressure cells and using up to eight measuring wires, samples of a few micrograms can be now probed at different places by resistivity [4]. The discrepancies detected in a sample on a length scale down to about 100 μm, reflect the pressure gradient ΔP in the cell, and in certain cases the sample inhomogeneity. The width of the superconducting transition of the Pb-manometer gives a local indication of the pressure gradient. One estimates that ΔP increases slowly with P from about 0.1 GPa at $P = 1$ to 2 GPa at $P = 30$ GPa. The tuning of electronic couplings of a given system is therefore blurred by the non-hydrostaticity of the steatite medium at very high pressure.

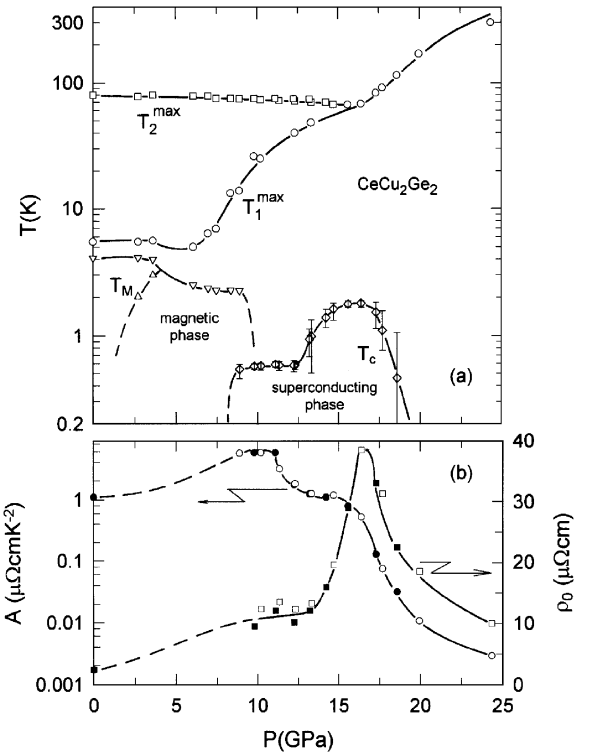

Fig. 1. (a) Pressure dependence of the temperatures of magnetic ordering T_M, superconducting transition T_c and maxima of the magnetic resistivity T_1^{max} and T_2^{max} for $CeCu_2Ge_2$ #1. Vertical bars indicate the width of T_c ($\Delta T_c = T_c^{10\%} - T_c^{90\%}$). (b) Pressure dependence of the residual resistivity ρ_0 and of the coefficient A in the relation $\rho = \rho_0 + AT^2$ for the same sample.

3. Normal and superconducting properties of $CeCu_2Ge_2$ and $CeCu_2Si_2$

In $CeCu_2Ge_2$ the RKKY interaction dominates the Kondo effect and the compound orders antiferromagnetically ($T_N = \sim 4.1$ K) at ambient pressure. The study of the high pressure resistivity of single crystalline $CeCu_2Ge_2$ [4,6] has allowed us to determine the magnetic ordering (T_M) and superconducting transition (T_c) temperatures as a function of P and to establish various links between properties of the normal and superconducting phase. At low pressure, the Kondo temperature (T_K) of $CeCu_2Ge_2$ is small in comparison to the crystal field (CF) splitting $\Delta_{CF} = 191$ K [7]. Therefore, as often observed in this situation for other compounds, the magnetic resistivity has two maxima at temperatures T_1^{max} and T_2^{max}, reflecting the Kondo scattering on the ground state and excited CF levels, respectively. In Fig. 1 a the P-dependence of these temperatures is plotted together with T_M and T_c. A strong P-variation of T_1^{max} is seen, whereas the almost constant T_2^{max} indicates that the CF splitting is nearly P-independent. At low pressure, T_1^{max} seems to be connected to T_M because both show the same behaviour. In the pressure range $7 < P < 25$ GPa, the rapid (nearly exponential) rise of T_1^{max} of about two orders of magnitude could correspond to an enhancement of the Kondo coupling which then dominates the indirect RKKY interaction. This is supported by the decrease of T_M and agrees well with Doniach's model [8]. However, the (T_M, P) magnetic phase diagram is complex. At low P, there is evidence of two magnetic transitions. Approaching $P_c \approx 9.4$ GPa, T_M seems to saturate at about 2 K. In fact, there is no sign of the existence of a quantum critical point. It could be possible that the already at ambient pressure reduced magnetic ordered moment $\mu = 0.74\mu_B$ [9] is further diminished with pressure and eventually leads to a non-magnetic phase.

Superconductivity suddenly emerges close to P_c, and the transition temperature $T_c \approx 0.6$ K remains constant up to ~ 13 GPa. Experimentally, the coexistence of the magnetism and the superconductivity at a microscopic level cannot be proved due to the pressure gradient in the cell and the sample inhomogeneity [4]. One can only state that signs of coexistence are observed (like for $CeCu_2$ [10], $CePd_2Si_2$ and $CeIn_3$ [2]) and that this situation agrees with a pairing mechanism mediated by antiferromagnetic spin fluctuations. The critical temperature increases above $P = 13$ GPa and reaches a maximum of almost $T_c = 2$ K at $P = 16$ GPa. At this pressure the temperatures T_1^{max} and T_2^{max} merge, indicating the entrance in an intermediate valence regime when the Kondo temperature T_K becomes of the order of the CF splitting. Thermopower measurements lead to the same conclusion [5].

Furthermore, the maximum in $T_c(P)$ seems to be correlated to the peak in ρ_0 and to the drop of the T^2 coefficient A of the low T resistivity (see Fig. 1b). For a non-magnetic HF ground state the A coefficient is related to the effective mass m^* by $A \propto (m^*)^2$. As can be seen in Fig. 1 b, the $A(P)$ dependence above P_c can be divided in two parts. In the pressure range $P_c < P < \sim 16$ GPa, a smooth decrease is found whereas for $P > \sim 16$ GPa, A drops by more than two orders of magnitude. This becomes even more clear, if the A coefficient is plotted versus T_1^{max} as shown in Fig. 2, where results for three single crystals of $CeCu_2Si_2$ are also included. Two temperature regions for T_1^{max} are found where the usual scaling $A \propto (T_1^{max})^{-2}$ holds. The drop of A is likely due to the change of the ground state degeneracy when the system crosses from the Kondo lattice state towards the intermediate valence state. A clear change of the scaling $A \propto (T_1^{max})^{-2}$ has been reported for $CeCu_6$ [11] whereas in $CeAl_3$ and $CeInCu_2$ [12] no deviation from the scaling was detected. Obviously, the occurrence of a valence transition as found by X-ray measurements of $CeCu_2Si_2$ [13] may also play a role. The scaling $A \propto (T_1^{max})^{-2}$ observed in Fig. 2 supports that T_1^{max} is closely related to the Kondo temperature T_K ($T_1^{max} \propto T_K$) which appears as the single energy scale of the system. The fact that close to the pressure of the $T_c(P)$ maximum, T_1^{max} and T_2^{max} merge, ρ_0 has a peak and the A coefficient drops, strongly suggest that valence fluctuations are connected or even are the origin of the T_c enhancement as proposed in this proceedings [14].

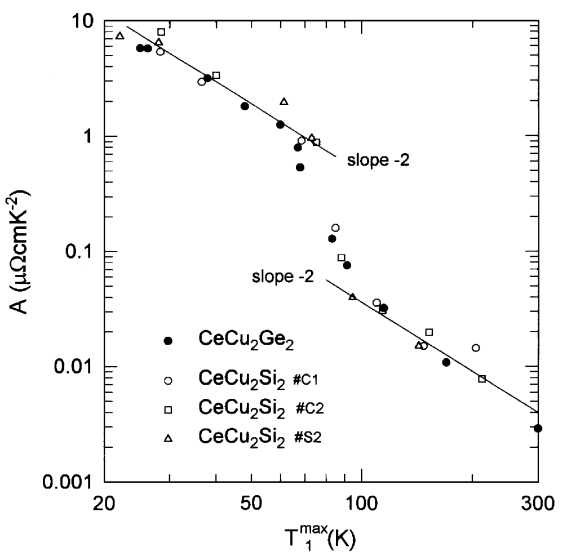

Fig. 2. The Fermi-liquid coefficient A versus temperature T_1^{max} of the magnetic resistivity maximum for $CeCu_2Ge_2$ #1 and different $CeCu_2Si_2$ samples.

Measurements of the upper critical field H_{c2} under pressure (from $\rho(T, B)$-data) should be another way to follow the pressure dependence of the large effective mass m^* in HF superconductors. For $CeCu_2Si_2$, such investigations have been recently performed on various samples [15]. They mainly differ by their residual resistivity ρ_0. For all samples, although $T_c(P)$ varies strongly under pressure, $H_{c2}(T/T_c)/T_c$ is weakly pressure dependent. The principal difficulty of the interpretation of H_{c2} is to find a model consistent with the normal phase properties. It appears that a good framework for the analysis is a strong coupling model in the dirty limit [16] and that for samples with the lowest ρ_0 values an intermediate regime between the clean and dirty limit is still better adapted. The strong coupling parameter λ is of the order of 1 and decreases slowly under pressure. Up to 4.5 GPa, i.e. the pressure of the $T_c(P)$ maximum in $CeCu_2Si_2$, we found a satisfying agreement between the pressure-induced decrease of m^* deduced either from H_{c2} or from the A coefficient. At higher pressure however, the abrupt drop of A has no clear corresponding effect in H_{c2}. This discrepancy might indicate that above 4.5 GPa the total conductivity is increased by the formation of an additional band of lighter carriers which do not participate in superconductivity.

In respect to $CeCu_2Si_2$ the P-dependencies of all the measured properties of the homovalent compounds $CeAu_2Si_2$ [17] and $CeCu_2Ge_2$ are almost quantitatively identical if pressure shifts of ~ 18 and ~ 10 GPa are taken into account, respectively. Considering these P-shifts, for example, $T_M(P)$ and $T_1^{max}(P)$ of $CeAu_2Si_2$ and $CeCu_2Ge_2$ are quite similar as well as $T_c(P)$ of $CeCu_2Ge_2$ and $CeCu_2Si_2$. These similarities emphasise that the properties mainly depend on the unit-cell volume, and in particular, results concerning the superconducting phases of $CeCu_2Si_2$ and $CeCu_2Ge_2$ are complementary. For other compounds of the CeM_2X_2 family, where M is a d transition metal and X = Si or Ge, and more generally for Ce-based compounds, the comparison is less and less straightforward but some features of Fig. 1 remain.

For example, $CeNi_2Ge_2$ [18] seems to correspond to $CeCu_2Ge_2$ at 16 GPa, i.e. far above P_c when $T_1^{max} \approx 80$ K and T_c is maximum. Another example is the T_1^{max} minimum of $CeCu_2$ for $P < P_c$ [10] which appears to be qualitatively similar to that of $CeCu_2Ge_2$ in Fig. 1. Additionally, the profound unity between metallic Ce-based HF compounds is reflected by their thermopower behaviour [5]. It is, e.g. striking that a strong resemblance between the thermopowers of $CeRu_2Si_2$ at ambient P and $CeCu_2Si_2$ at 4 GPa is found although the resistivities are different.

Unusual resistive transitions of certain samples of $CeCu_2Ge_2$ and $CeCu_2Si_2$ at pressures of the $T_c(P)$ maximum gives further hints about the enhancement of superconductivity. In Fig. 3, sample #1 of $CeCu_2Ge_2$ shows a standard transition at $T_c \approx 1.8$ K. For $T < 1.4$ K, its resistivity has dropped below our threshold detection level of 10^{-4} μΩcm. Thus, in comparison to the normal phase resistivity, a drop of ρ by more than five decades is observed. Sample #2 which has been cut from the same crystallite has a different behaviour. Below ~1.8 K, the drop of ρ is modest until $T_c \sim 0.55$ K, where superconductivity sets in. The ohmic response of sample #2 to very different excitation currents suggests that below 1.8 K the ρ-drop is not due to superconducting traces. Without any other results, the change of slope of ρ near 1.8 K would be interpreted as a sign of magnetic ordering.

The resistive transition of $CeCu_2Si_2$ can also exhibit surprising structures as shown in Fig. 3 for two $\rho(T)$-curves of $CeCu_2Si_2$ in zero field and in $B = 3$ T. The main transition in zero field is located at $T_c \approx 2.4$ K, but at lower T a very small ohmic contribution remains down to ~1.5 K (see inset Fig. 3). In a magnetic field this contribution shifts to lower T as the main transition does. These observations do not necessarily reflect the sample imperfection and tend to indicate that the superconductivity is likely different when T_c is enhanced. It might be possible that the T_c enhancement occurs in a small part of the sample volume. Finally, one can note that the higher ρ_0 value of $CeCu_2Si_2$ the less pronounced pressure-induced T_c enhancement seems. For high ρ_0 values, T_c increases only up to 1.2 K.

4. Residual scattering in HF compounds

Analysis of $\rho(T)$-data are most often done according to several hypotheses which are seldom discussed. For example, although not always independent, various scattering mechanisms are assumed to give additive contributions to ρ. For a real crystal, the residual resistivity ρ_0 ascribed to the disorder (all types of defects: impurity, vacancy, etc.) is considered as temperature independent. Fig. 4 shows that in various HF compounds ρ_0 varies considerably between the magnetic and non-magnetic regions or in the P-interval where $T_c(P)$ changes. It appears that ρ_0 strongly depends on electronic correlations present in the systems considered. The structures in $\rho_0(P)$, with very different magnitudes, are not necessarily centered at P_c, as observed for $CeAl_3$ single crystals [19] and their origin seems to be divers. At pressures close to the $T_c(P)$ maximum, the magnitude of the ρ_0-peak of $CeCu_2Si_2$ and $CeCu_2Ge_2$ is very sample dependent [4,15]. The occurrence of this peak can be associated to

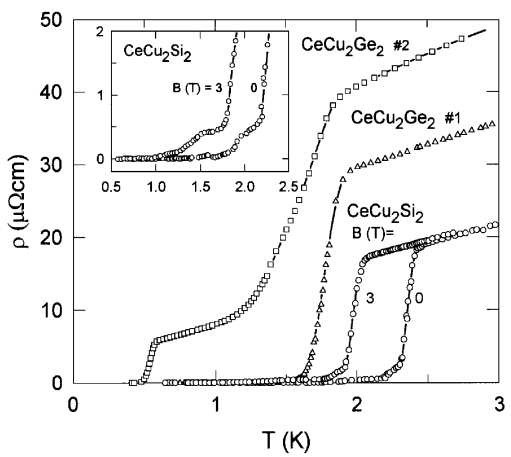

Fig. 3. The superconducting transition of $CeCu_2Si_2$ and $CeCu_2Ge_2$ #1 and #2 close to the $T_c(P)$ maximum. For $CeCu_2Si_2$ data recorded in a magnetic field of 3 T are included. The transition is shown in detail in the inset.

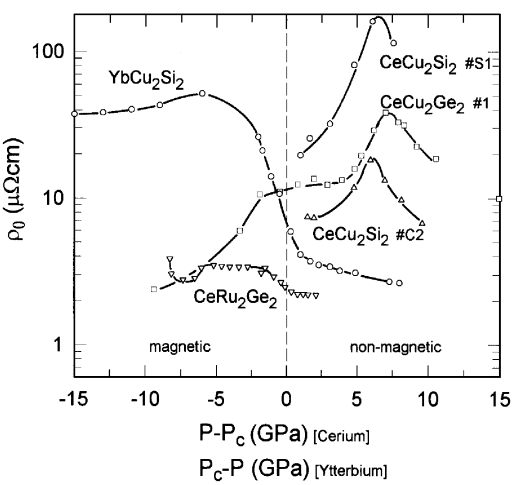

Fig. 4. Residual resistivity of different HF compounds. The critical pressure P_c(GPa) = 8, 8.7, 9.4 and −1 for $YbCu_2Si_2$, $CeRu_2Ge_2$ $CeCu_2Ge_2$ #1 and $CeCu_2Si_2$, respectively.

charge fluctuations [14] or even to a valence transition. For $YbCu_2Si_2$ only one part of the Yb ions orders magnetically [20] at $P_c \sim 8$ GPa and then the $\rho_0(P)$ maximum may correspond to full ordering at higher P.

Even in the case of relatively low ρ_0 value, as for e.g. $CeRu_2Ge_2$ [21] or polycrystalline $CeAl_3$ [22], large residual magnetoresistivity effects show that the magnetic contribution to ρ_0 is not negligible at all in comparison to the static disorder contribution. Furthermore, other observations indicate that a part of ρ_0 is caused by various scattering centres such as Kondo hole [23,24], uncompensated spin [25] or magnetic cluster [26] and their contribution should decrease with increasing temperature. For example, approaching P_c, in the non-magnetic region, the rise of $\rho_0(P)$ for $YbInAu_2$ (like that of $YbCu_2Si_2$ in Fig. 4) is correlated with the appearance of $\rho(T)$ minimum at low T [27]. An analogous minimum (and even $\rho \propto -AT^2$) has been observed at low T for $CeCu_2Si_2$ # S1 under pressure when ρ_0 is large [4]. This effect can also explain why at low P, the AT^2 term of $CeCu_2Si_2$ #S1 is lower than that of $CeCu_2Si_2$ #C2 or even why around 20 GPa $CeCu_2Ge_2$ shows $\rho \propto T^n$ with $n \sim 2.3$, i.e. $n > 2$ (see below). Finally, there is little evidence that the disorder can be reduced to an independent temperature term ρ_0. It is more likely that only one part of ρ_0 due to static disorder can be subtracted from the total resistivity according to the Matthiessen rule.

5. Deviation from Fermi liquid behaviour

In spite of the aforementioned considerations which will limit the interpretation, the fit of the relation $\rho = \rho_0 + AT^n$ to the data up to a temperature $T_A^{(n)}$ provides valuable information on the pressure dependences of the exponent n and temperature $T_A^{(n)}$. In principle such investigation should show if an unconventional $\rho(T)$ behaviour develops in the vicinity of a quantum critical point. However, fits are not always conclusive because they are obviously limited by the measurement errors or data are sometimes not taken at sufficiently low temperature in order to really probe the ground state excitations. For example, minor deviations from a quasi-linear $\rho(T)$ variation observed in a wide temperature interval were often not considered at low temperature.

Fig. 5 shows the exponent n of the power law $\rho = \rho_0 + AT^n$ as a function of $(P - P_c)$ for $CeRu_2Ge_2$ [28] and $CeCu_2Ge_2$. For the former compound fits were done in between 40 mK $< T <$ 1.5 K, that is $T_A^{(n)}$ is fixed while for the latter $T_A^{(n)}$ is a free parameter and the T-interval is naturally limited at low temperature by the superconducting transition for $P_c < P < \sim 20$ GPa. In the magnetic region of both compounds, n is greater than the Fermi liquid value $n = 2$ due to electron–magnon scattering. The structure in $n(P)$ below P_c reflects the complexity of the magnetic phase diagram. Near and above P_c the two compounds seem to behave differently.

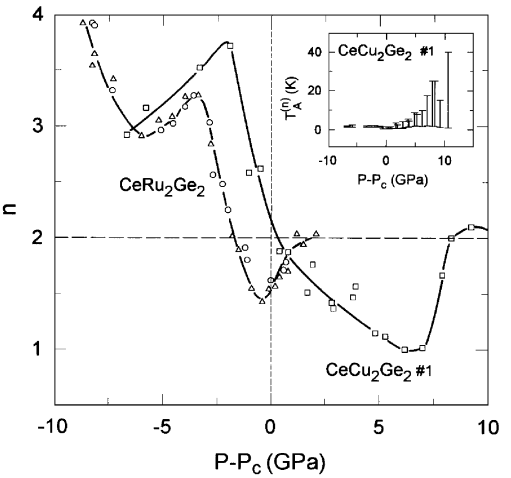

Fig. 5. The exponent n of the power law $\rho = \rho_0 + AT^n$ for $CeRu_2Ge_2$ and $CeCu_2Ge_2$. The inset shows the temperature $T_A^{(n)}$ up to which the law is valid for $CeCu_2Ge_2$.

In $CeRu_2Ge_2$, n attains values between $\frac{3}{2} < n < \frac{5}{3}$ in the P-interval $P_c \pm 0.8$ GPa. The two extreme values for n are predicted for antiferromagnetic [29] and ferromagnetic [30] spin fluctuations, respectively. Moreover, for this two kinds of fluctuations theory predicts exponents for the vanishing of the magnetic ordering temperature at P_c which are close to the experimental value [20]. Let us note however, that in the pressure range $P_c \pm 0.8$ GPa and above 1.5 K the curvature of $\rho(T)$ changes its sign as a function of P and so a linear T-dependence of ρ occurs up to ~ 35 K.

In the case of $CeCu_2Ge_2$ the exponent n decreases rapidly with P in the magnetic instability region and crosses almost exactly the value $n = 2$ at P_c. In fact, the P-interval where n is smaller than two corresponds approximately to that of superconductivity. In particular, n decreases down to $n \sim 1$ at the pressure where $T_c(P)$ is maximum. As for $CeRu_2Ge_2$, the linearity of $\rho(T)$ coincides with the sign change of the curvature. This linearity extends up to ~ 25 K and seems characteristic of a marginal Fermi liquid behaviour of a system for which the energies of two electronic (valence) configurations are degenerate [31,32]. Thus, a further sign is obtained that charge fluctuations play an essential role in the $T_c(P)$ enhancement and the situation of $CeCu_2Ge_2$ or $CeCu_2Si_2$ could be reminiscent of that of high T_c cuprates like $YBa_2Cu_3O_7$ [31].

In order to suppress superconductivity, measurements performed in magnetic field for $CeCu_2Ge_2$ [19,33] and $CeCu_2Si_2$ [15] show that above P_c a crossover towards a Fermi liquid regime occurs at a temperature of the

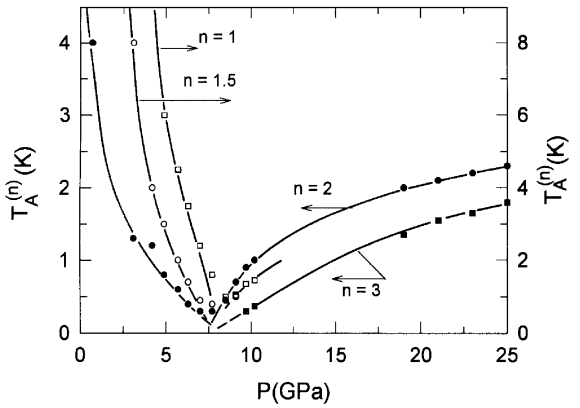

Fig. 6. P-dependence of temperature limit $T_A^{(n)}$ up to which the relationship $\rho = \rho_0 + AT^n$ is valid in $YbCu_2Si_2$.

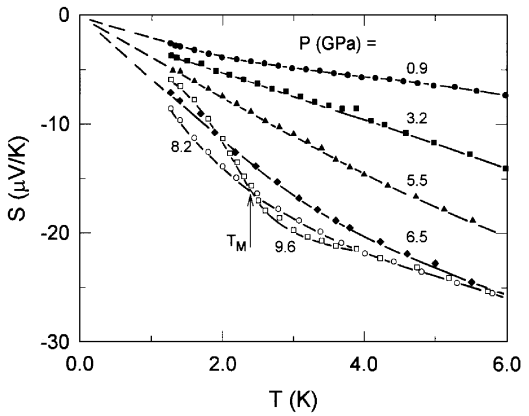

Fig. 7. Low T-part of the thermopower of $YbCu_2Si_2$ at selected pressure. The magnetic ordering is seen at $P = 9.6$ GPa at T_M.

order of T_c. The A coefficients determined down to very low T in magnetic field are somewhat larger than those evaluated at zero field in a narrow T-interval just above T_c but their P-dependences are similar. More generally, it is noteworthy that a quasi-linear $\rho(T)$ dependence in an intermediate temperature interval is very often observed in Ce and Yb based HF compounds at pressures different to P_c as for various Yb-compounds [27] and $CeCu_2Ge_2$, or at pressures indistinguishable from P_c as in $CeRu_2Ge_2$ [28].

In the case of $YbCu_2Si_2$ the P-dependences of the temperatures $T_A^{(n)}$, up to which a power law $\rho \propto T^n$ is valid, are shown in Fig. 6 for different exponents n. The temperatures $T_A^{(n)}$ vanish as the critical pressure $P_c \approx 8$ GPa is reached. Although a certain data dispersion is evident, the ratio $T_A^{(n)}/T_A^{(n=2)}$, with $n = \frac{3}{2}$ or $n = \frac{5}{3}$, does not diverge approaching P_c from the non-magnetic side as it is predicted in the case of antiferromagnetic or ferromagnetic spin fluctuations, respectively [30]. Apparently, no particular crossover regime develops approaching P_c.

The Fermi liquid behaviour is supported by thermopower results shown in Fig. 7 [34]. Indeed for $P < P_c$ the thermopower S varies linearly with temperature and extrapolates to $S = 0$ at $T = 0$. Substantial deviation from linearity occurs at temperature much higher than $T_A^{(n=2)}$. Approaching P_c the slope $|\partial S/\partial T|$ which should vary as T_K^{-1} [35,36] increases with P and is maximum at P_c. At $P = 9.6$ GPa, i.e. above P_c a kink marks the magnetic ordering temperature in agreement with resistivity. Thus, considering $S \propto T$ as the hallmark of Fermi liquid behaviour [36] and even so data are limited down to 1.2 K, it appears that the thermopower does not exhibit a different behaviour close to P_c. A similar conclusion can be drawn from high pressure investigations of $S(T)$ of $CeCu_2Ge_2$ and $CePd_2Si_2$ [5].

6. Concluding remarks

Pressure has opened up a large field for investigations especially of HF systems and should play an increasing role in the future although only a few experiments are feasible. With regard to the transport measurements presented here, the pressure gradient in the cell and the sample inhomogeneity limit several conclusions about, e.g. the coexistence of magnetism and superconductivity or deviation from Fermi liquid behaviour. At the magnetic ordering temperature, anomalies in the electrical resistivity or thermopower are less pronounced and the superconducting transition is enlarged with further possible strain effects.

The variability from sample to sample of properties of several HF compounds emphasises the difficulty of their metallurgy. Moreover, it is possible to investigate different parts of one sample on a length scale of 100 μm by resistivity. The discrepancies in the properties of one sample measured at these different parts corresponds to a constant P-shift often larger than that ascribed to the pressure gradient. This leads to the conclusion that the samples are often not homogeneous. It might be even possible that inhomogeneity occurs at a microscopic scale leading to a distribution of Kondo temperatures and under certain conditions to a deviation of Fermi liquid behaviour [37]. Thus, considering the various experimental limitations, no clear sign of a quantum critical point at P_c is found for the compounds investigated in this paper. If evidence exist they are restricted to very narrow pressure and temperature intervals. On the other hand, the large dependence upon pressure and magnetic field of the residual resistivity ρ_0 raises the question of the separation of the temperature dependent part of the resistivity. A challenging experiment would be to measure $\rho_0(P)$ for the best lattice for which the lowest

ρ_0 value has been obtained. For such experiments a new generation of high pressure cells using solid helium as transmitting pressure medium which guaranties the best hydrostatic conditions could be useful. The feasibility of these experiments has already been demonstrated [38].

The superconducting transition temperature T_c of $CeCu_2Si_2$ and $CeCu_2Ge_2$ is enhanced in pressure regions where the Ce-valence is changing. This was already pointed out from previous resistivity, thermopower and X-ray measurements. In the P-intervals of the T_c enhancement it is shown in this paper that: (i) the temperatures of the resistivity maxima T_1^{max} and T_2^{max} merge, (ii) the residual resistivity has a marked peak and (iii) the Fermi liquid term $A \propto (m^*)^2$ drops. Furthermore, at the pressure of the $T_c(P)$ maximum, $\rho(T)$ is quasi-linear up to a temperature of about $10T_c$. All these features of the normal phase strongly suggest that charges fluctuations are involved in superconductivity.

Experimentally several points still remain mysterious. The sudden increase of T_c (at ~ 13 GPa for $CeCu_2Ge_2$) as well as the increase of the width of T_c might indicate the occurrence of a first-order valence transition and that the two phases exist in a certain P-interval. It is also not quite clear whether or not the $T_c(P)$ maximum coincides exactly with the drop of A. Apparently T_c is maximum when A starts to drop, emphasising the role of charge fluctuations, and T_c vanishes when A has recovered the scaling $A \propto (T_1^{max})^{-2}$, that is the system has achieved its transition to the intermediate valence regime. Such challenging questions could be clarified by high-pressure investigations in better hydrostatic conditions.

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