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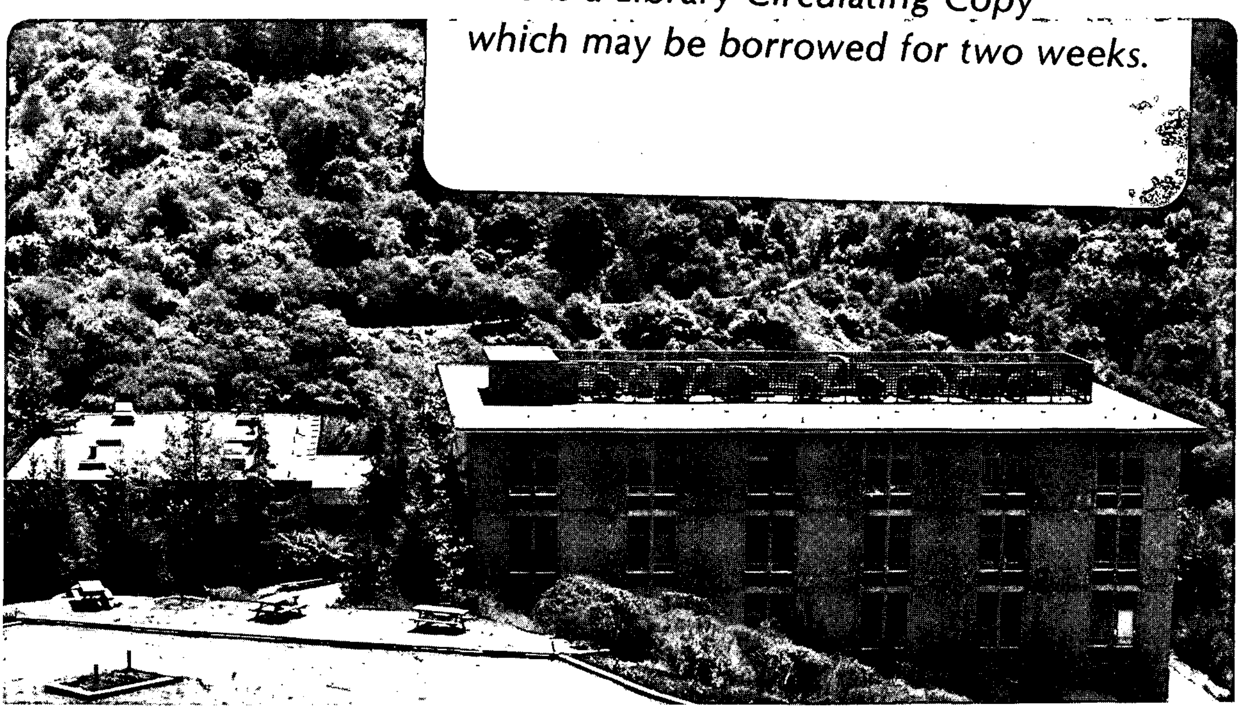

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DISCLAIMER

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PRESSURE DEPENDENCES OF THE SPECIFIC HEATS OF UPt_3, UBe_{13}, AND $CeAl_3$

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The specific heats of UPt_3, UBe_{13} and $CeAl_3$ have been measured under pressures to 9 kbar. The densities of electronic states decrease sharply with increasing pressure. For UPt_3 the spin fluctuation terms decrease with increasing pressure, suggesting a positive correlation with superconductivity.[1] For $CeAl_3$ there is a qualitative change in the temperature dependence of the specific heat.

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Abbreviated running title: Specific Heat of HFC's under Pressure

Key Words: heavy-fermion, specific heat, pressure-dependence

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Measurements of the properties of materials as a function of pressure (P) provide an additional dimension in which to make comparisons with model calculations or theory. They also provide a relatively straightforward basis for establishing correlations between different properties, e.g., one can look for correlations between superconductivity and magnetism without the complications of interpretation associated with measurements on a series of structurally and chemically different compounds. Measurement of the P dependence of properties is a particularly fruitful approach for heavy-fermion compounds (HFC's) because the extreme sensitivity to pressure of the 4f and 5f electrons involved in the phenomenon produces large effects at readily attainable pressures. Although the resistivity (ρ) and susceptibility (χ) of a number of HFC's have been measured at $P \neq 0$, it is only relatively recently that data on the specific heat (C) at $P \neq 0$ have become available. We describe here measurements of C(P) to P~9 kbar for UPt_3[1], UBe_{13}[2], and $CeAl_3$.[3] In addition, C(P) to P ~ 6 kbar has also been reported for $CeCu_2Si_2$.[4] In this brief note the emphasis is on a comparison of the available experimental data for C(P) for HFC's.

Although HFC's have in common high values of C/T for T<10K, the T dependence of C/T varies considerably. Some P=0 data are shown in Fig. 1. The decrease in C/T for $CeAl_3$ at T<0.4K is generally associated with the development of coherence in a Kondo lattice.[5,6] On that basis, the continued increase in C/T for $CeCu_6$ would indicate a different energy scale for the interactions between the heavy fermions and the development of coherence. UBe_{13} shows the beginning of a levelling off of C/T near 1K, but an increase rather than a decrease at lower T. UPt_3 is unusual among metals in general and unique among superconductors in showing the T dependence expected for spin fluctuations: $C/T = \gamma + \delta T^2 \ln T + T^2$. For UPt_3, C is qualitatively different from that of the other HFC's. However, the difference may be a manifestation only of differences in the energy scales associated with the formation of the Kondo lattice and interaction between the heavy fermions and not of a more fundamental difference.

The P dependence of C/T for UPt_3, shown in Fig. 2, is remarkably strong. It is conveniently characterized by the Gruneisen parameters (defined as $\Gamma_X \equiv -\partial \ln X / \partial \ln V$, where V is the volume) $\Gamma_\gamma = -57$; Γ_δ, $\Gamma \sim -250$. From the P dependence of the coefficients in the expression for C one can derive the P dependence of microscopic parameters associated with spin-fluctuations: between 0 and 8.9 kbar, the spin-fluctuation temperature (T_{sf}) increases from 60 to 88K, the Fermi temperature (T_F) increases from 154 to 196K, and γ_0, which corresponds to the bare density of electronic states, decreases from 260 to 204 mJ/mole K^2. The suppression of spin-fluctuation effects and the relatively strong decrease in the transition temperature for superconductivity (T_c) with increasing pressure suggest a positive correlation between the two that would not be expected for a BCS superconductor.[1] An independent analysis of the same data on the basis of Fermi-liquid theory has led to the conclusion that UPt_3 is a p-wave superconductor of purely electronic origin.[7]

In one important respect, the pressure dependence of the density of electronic states, the results for UBe_{13}, shown in Fig. 3, are similar to those for UPt_3. For UBe_{13}, $\Gamma_\gamma \sim -60$ at the lowest P and ~ -44 at the highest. Furthermore, the volume dependences of T_c are also similar: for UPt_3, $\Gamma_{T_c} \sim -76$ from C data and ~ -52 for χ data[8], while for UBe_{13} from the data reported here, $\Gamma_{T_c} \sim -62$. Thus, in spite of the marked difference in the temperature dependences of C, and the more conspicuous role of spin-fluctuations in determining C for UPt_3, the volume dependences of both T_c and the density of electronic states for the two uranium-based HFC superconductors are very similar. For $CeCu_2Si_2$, $\Gamma_\gamma \sim -70$, also similar to the values for the uranium compounds, but $\Gamma_{T_c} \sim 7$.

The pressure dependence of C for $CeAl_3$ is even stronger than that for the HFC superconductors, and, as shown in Fig. 4, it is highly non-linear and leads to a qualitative change in the shape of C/T vs T. The maximum in C/T that occurs near 0.4K at P=0 is dramatically suppressed at a pressure of only 0.4 kbar. In the vicinity of that temperature, Γ_C varies from -132 at 0.4 kbar to -19.4 at 8.2 kbar. The maximum in C/T at P=0 has been taken as defining the temperature (T*) at which interactions between the heavy fermions become important.[5] Since the data do not extend below T* (P=0) for P≠0, they do not give an unequivocal measure of the P-dependence of T*, but the rapid decrease of C/T itself suggests a correspondingly rapid decrease in the strength of the interactions. Finally, at the highest pressures, the properties of $CeAl_3$ may be approaching those of an intermediate valence compound (IVC): extrapolation of Γ_γ

to 20 kbar gives $\Gamma_\gamma \sim -14$, which is of the order of magnitude of values typically found[9] for IVC's.

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FIGURE CAPTIONS

Fig. 1 Normal-state data for C/T for selected HFC's. The dashed extension of the curve for UBe_{13} represents a simple polynomial extrapolation of the data that is consistent with the superconducting state entropy. The curve for -Ce, which exhibits a "high" value of C/T at 0K, is included for comparison.

Fig. 2 The P dependence of C/T for UPt_3. The increase in C/T at the lowest temperatures reflects the onset of superconductivity. The dashed and solid curves represent fits to spin-fluctuation theory as indicated.

Fig. 3 The pressure dependence of C/T for UBe_{13}. The anomaly below 0.9K is associated with the superconducting transition.

Fig. 4 The pressure dependence of C/T for $CeAl_3$. The inset shows an empirical $P^{1/6}$ behavior for C/T at 0.4K, the temperature of the P=0 peak in C/T.

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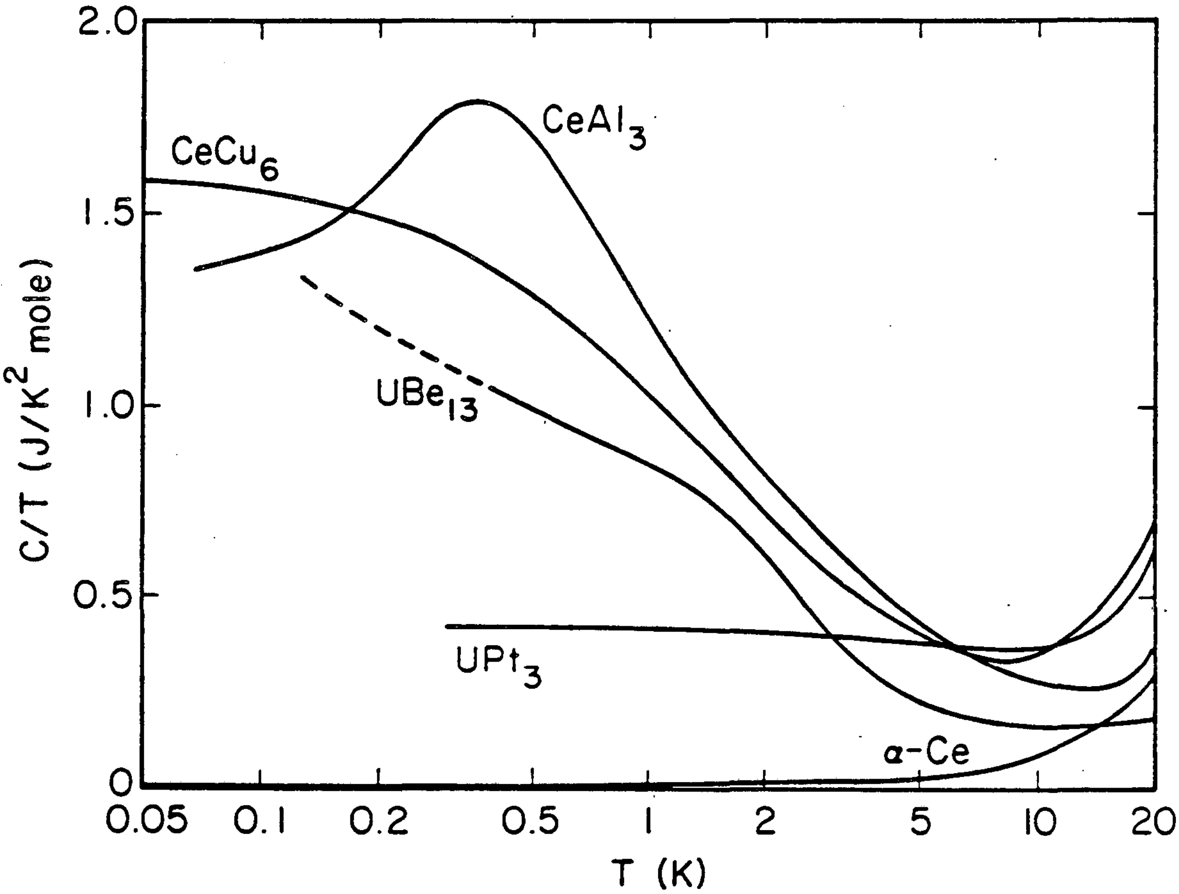

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Fig. 1

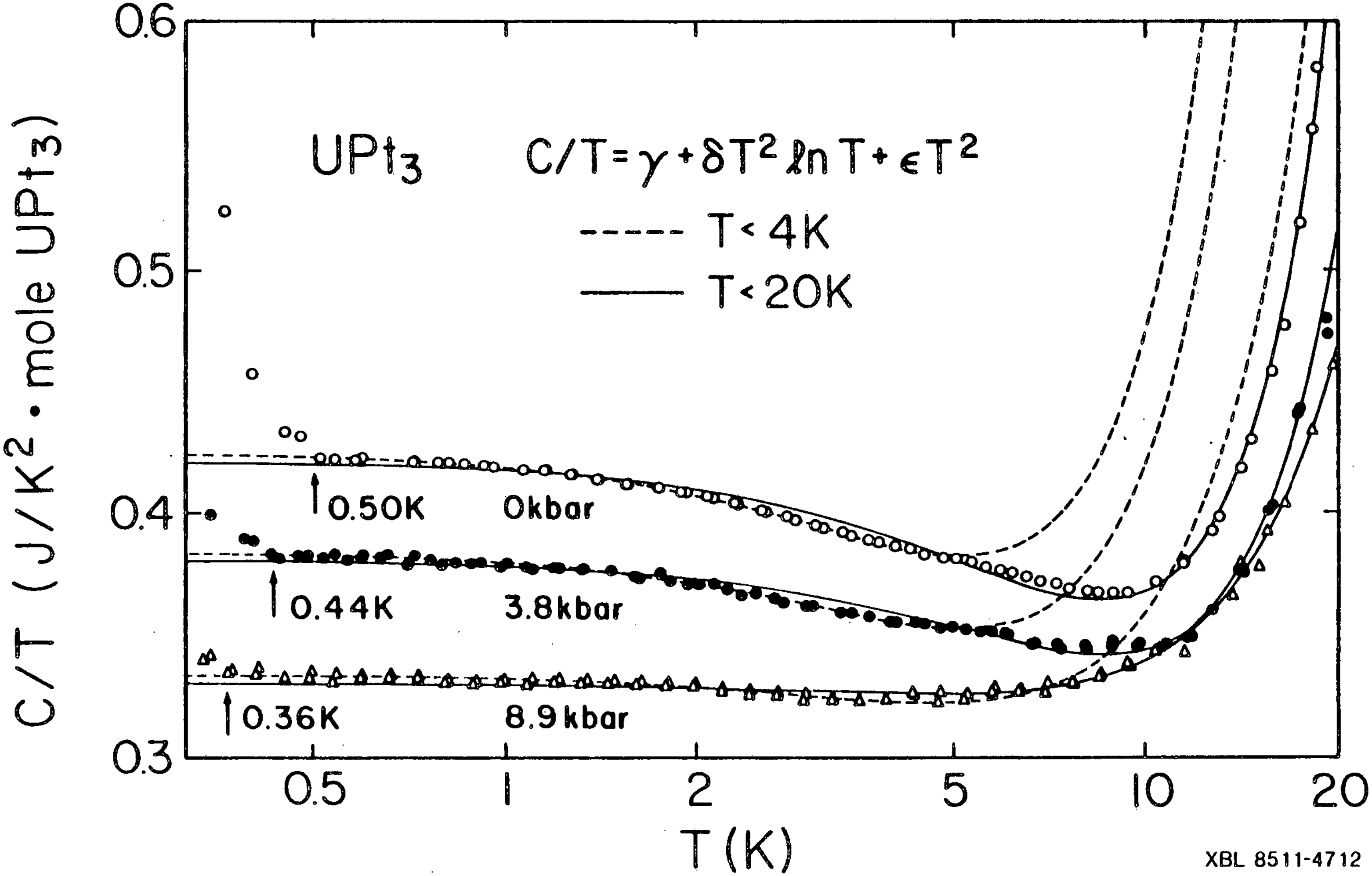
UPt3
C/T=γ+δT2 ℓn T+εT2
T< 4K
T< 20K
0.50K
0kbar
0.44K
3.8kbar
0.36K
8.9kbar
C/T (J/K2 • mole UPt3)
T(K)
0.6
0.5
0.4
0.3
0.5
1
2
5
10
20
XBL 8511-4712

Fig. 2

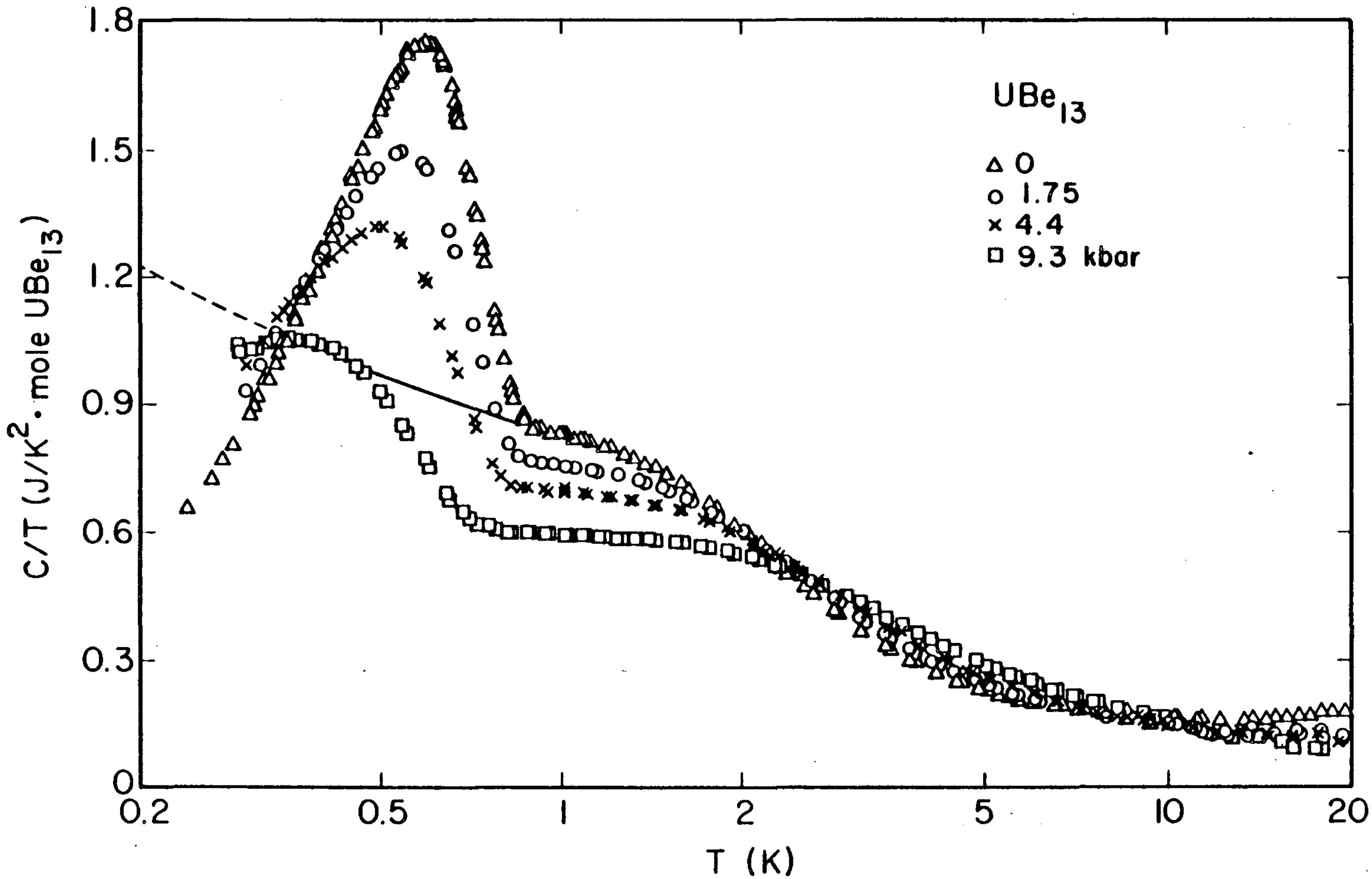

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Fig. 3

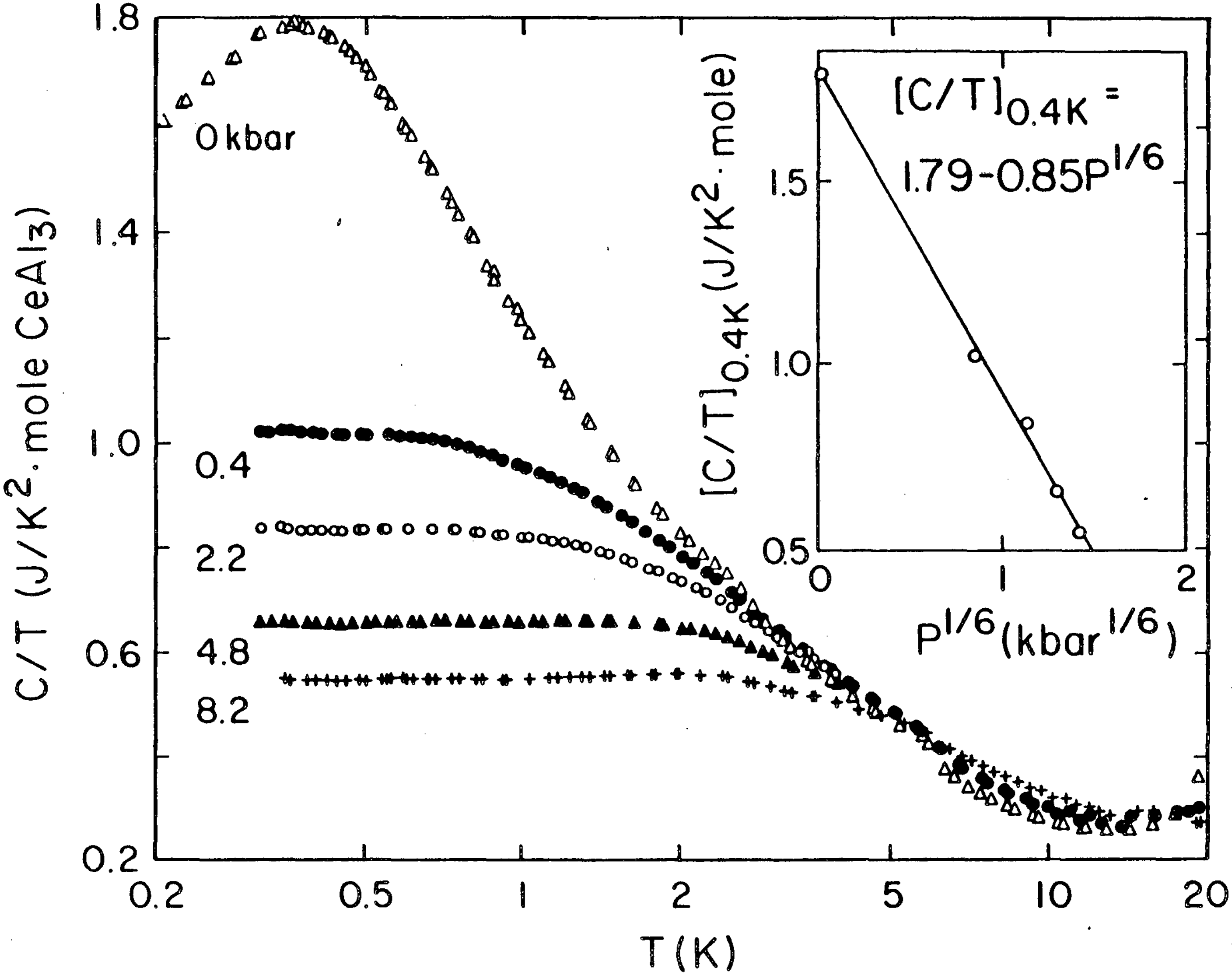

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Fig. 4