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Pressure-Induced Phase Transition and Scaling Behavior of Resistivity in the Low-Carrier System CeP

–Interplay of Magnetic Instability, Semimetal-Metal Transition and Isostructural Valence Transition–

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The series of semimetallic cerium monopnictides CeX (X =N, P, As, Sb, Bi) with the simple NaCl structure have received much attention focusing on the highly unusual physical properties in connection with their low carrier concentration, especially in CeP with its low carrier density of ≈ 0.01/Ce. This is because CeP is situated at an intermediate condition connecting the mixed-valence state in CeN to the complicated magnetic-states in CeSb. The most intriguing feature of CeP under pressure P is that this compound exhibits two kinds of different phase transitions at lower and higher pressure region, respectively. One is the P-induced magnetic phase transition observed on high quality single crystals above ≈ 0.3 GPa, from a simple type-I antiferromagnetic order to other magnetic phases with the complicated structures. The long-range magnetic order in CeP become unstable above 2.5 GPa and vanishes at ~ 5.5 GPa. The other interesting feature is the isostructural transition at ≈ 300 K under pressure ~ 9 GPa as the only Ce-based compounds, observed on the x-ray powder diffraction, which shows a discontinuous volume collapse of $\approx 3\%$ with an increase in valence of 0.2. The main purpose of this work is to establish the phase boundary of the isostructural valence transition more precisely, on the basis of the viewpoint from the resistivity as a function of P under fixed-temperatures, $\rho(P)$ isotherm, constructed by the measurements of the precise temperature (T) dependent electrical resistivity under fixed-pressures, $\rho(T)$ isobar, up to 8 GPa over the wide T-range from 4.2 to 300 K.

We revealed the following facts.

- $\rho(P)$ isotherm gives direct evidence for the P-induced semimetal to metal transition just above 5.5 GPa at $T = 35$ K in CeP.
- The transition pressure $P_{S-M}(T)$ is almost linear in T and connects continuously to the $P_{S-M}(T \approx 300\ \mathrm{K}) \sim 9$ GPa where the isostructural valence transition occurs.
- The $\rho(P)$ isotherms for 2.5 GPa $\leq P < P_{S-M}(T)$ are found to be scaled by the $P_{S-M}(T)$.
- The isostructural valence transition was observed as the semimetal to metal transition by electrical resistivity measurements under high pressure.
- The precise phase boundary of the isostructural valence transition in CeP over wide T-region below ≈ 300 K was determined as the first example of Ce-based compounds.
- From the Clausius-Clapeyron equation, the entropy change across the isomorphic transition in CeP is $\Delta S_{CeP} = \Delta V \frac{dP}{dT}$. Knowing the volume change ΔV at ≈ 300 K and the slope of the phase-boundary, ΔS_{CeP} is estimated to be $\approx (1.24 \pm 0.04) k_B$, where k_B is the Bolztmann constant. This value is very close to that of the isostructural $\gamma \rightarrow \alpha$ transition in elemental Ce, that is, $\Delta S_{\gamma \rightarrow \alpha} \approx 1.54 k_B$.