High pressure electrical resistivity in La doped CeIn₃

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Abstract. Antiferromagnetic ordering temperature of heavy fermion material CeIn₃ is at 10K. In CeIn₃ when the magnetic ordering is suppressed by high pressure above 2.5GPa, magnetically mediated superconductivity emerges. Substituting La for Ce reduces the Néel temperature to facilitate reaching critical pressure at which the Néel order disappears. Pressure-Néel temperature phase diagram was mapped to determine critical pressure where the Néel temperature is suppressed to absolute zero.

1. Introduction
Superconductivity in magnetic material emerges near the quantum critical point (QCP) where magnetic ordering is well suppressed to arise quantum fluctuation. Near the QCP, quantum fluctuation survives long in time and distance to show superconductivity in some materials. Examples of external parameter to suppress magnetic ordering are alloying (x), magnetic field (H) and pressure (p).

High pressure is a powerful tool to tune electronic state of condensed matter. The high pressure technique is applied to induce superconductivity in magnetic material like heavy fermion system. Heavy fermion antiferromagnets CeIn₃ and CePd₂Si₂ are typical examples to show magnetically mediated superconductivity under pressure in heavy fermion system[1]. In such materials, the 4f electron of Ce is expected to owe quantum criticality or superconductivity. Because number of 4f electrons is controllable with controlling La concentration in a Ce compound, strength of magnetic interactions is weaken and the Néel temperature becomes lower with increasing La concentration [2, 3]. The lower Néel temperature indicates lower critical pressure near which superconductivity might emerge. In this paper we report high pressure electrical resistivity measurements to determine critical pressure in Ce₀.₈₅La₀.₁₅In₃.

2. Experiment
Single crystals of Ce₀.₈₅La₀.₁₅In₃ were grown with the self-flux method. X-ray diffraction measurement was performed to confirm the sample single-phase. Magnetization and magnetic susceptibility measurements at ambient pressure were done with MPMS-SQUID magnetometer. Electrical resistivity at ambient and high pressures with piston cylinder cell below 3GPa were performed with the standard four probe method in ⁴He cryostat or dilution refrigerator.
3. Results and Discussion

Figure 1 shows temperature dependences of electrical resistivities at 0, 0.5, 1.0 and 1.5GPa in Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3}. The anomaly from the Néel order is observed at 8.4K at ambient pressure. La doping to CeIn\textsubscript{3} reduces number of 4\textit{f} electrons and widen distance between Ce ions. Because those two effects cause weakening of RKKY interaction, the Néel temperature could be reduced in Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3}.

To Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3}, we applied pressure for observing pressure dependence of Néel temperature shift. The Néel temperature is decreased to 7.4K at 0.5GPa. Temperature dependences of electrical resistivity at 1.0 and 1.5GPa in Fig.1 show the anomaly was broadened to be hump and the anomaly decreases with applying pressure. Those anomalies, corresponding to Néel ordering, are indicated with black arrows in Fig.1.

![Figure 1](image1.png)

**Figure 1.** Temperature dependence of electrical resistivity in Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3} at ambient and high pressures. Anomalies that are relevant to Néel ordering are indicated black arrows.

![Figure 2](image2.png)

**Figure 2.** Pressure dependence of Néel ordering temperature in Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3}. Black open circles represent determined T\textsubscript{N} by us in Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3}. Blue symbols show read data from Ref.[1]. Black solid and blue dashed lines show a quadratic fitting curves.

Figure 2 shows p-T phase diagram. Black open circles represent measured Néel temperatures in Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3}. Blue symbols show read data from Ref. [1]. Black solid and blue dashed lines represent fitting curve as the function of T\textsubscript{N}=T\textsubscript{N}\textsuperscript{*} × [1-(p/p\textsubscript{c})\textsuperscript{2}] where T\textsubscript{N}\textsuperscript{*} is Néel temperature and p\textsubscript{c} means critical pressure. The T\textsubscript{N}\textsuperscript{*} is 8.3K for Ce\textsubscript{0.85}La\textsubscript{0.15}In\textsubscript{3} and T\textsubscript{N}\textsuperscript{*} is 10K for CeIn\textsubscript{3}.
The critical pressures for CeIn$_3$ and for Ce$_{0.85}$La$_{0.15}$In$_3$ are 3.1 and 2.2GPa, respectively. With applying pressure to Ce$_{0.85}$La$_{0.15}$In$_3$, the Néel temperature reduces to lower one following to the quadratic function.

Although we are not able to directly compare the behavior of Ce$_{0.85}$La$_{0.15}$In$_3$ with that of Kondo lattice compound of CeIn$_3$ because alloying introduces disorder or randomness, pressure suppresses Néel order both in Ce$_{0.85}$La$_{0.15}$In$_3$ and CeIn$_3$. Because reduction of number of 4f electrons and widening distance between spins weaken the RKKY interaction, 15 percent alloying reduces the Néel temperature from 10K for CeIn$_3$ to 8K for Ce$_{0.85}$La$_{0.15}$In$_3$. It is shown that the critical pressure also reduces from 3.1GPa for CeIn$_3$ to 2.2GPa for Ce$_{0.85}$La$_{0.15}$In$_3$ as seen in the p-T phase diagram of Ce$_{0.85}$La$_{0.15}$In$_3$. Lower critical pressure could be caused the Néel order is suppressed easier in Ce$_{0.85}$La$_{0.15}$In$_3$ than in CeIn$_3$.

### 4. Summary

The Néel temperature reduces by both alloying and applying pressure. Fifteen percent alloying lets $T_N$ reduced from 10K to 8K because of reduction of RKKY interaction. At Ce$_{0.85}$La$_{0.15}$In$_3$, pressure dependence of $T_N$ shows quadratic reduction as seen in CeIn$_3$. The p-T phase diagram of Ce$_{0.85}$La$_{0.15}$In$_3$ was drawn to determined the critical pressure to be at 2.2GPa.

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