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Title	High-quality single crystal growth and unique electronic states in Eu-based intermetallic compounds( Abstract_論文要旨 )
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## 論文要旨

### 論文題目

High-quality single crystal growth and unique electronic states  
in Eu-based intermetallic compounds  
(ユウロピウム化合物の純良単結晶育成と特異な電子状態)

We succeeded in growing high-quality single crystals of Eu compounds, and measured the electrical resistivity, magnetic susceptibility, high-field magnetization, specific heat, thermoelectric power, and de Haas-van Alphen (dHvA) effect, together with the electrical resistivity and thermoelectric power under pressures.

A simple canting magnetization was observed in Eu-divalent antiferromagnets of  $\text{EuBi}_3$ ,  $\text{EuCd}_{11}$ , and  $\text{EuGa}_4$ , together with the previous result in  $\text{EuPb}_3$ . We propose a relation between  $H_c$  and  $T_N - \theta_p$ , namely  $H_c = (k_B/3\mu_B)(T_N - \theta_p)$ , based on an antiferromagnetic two-sublattice model, where  $H_c$  is a critical field reaching  $7\mu_B/\text{Eu}$ ,  $T_N$  is the Néel temperature, and  $\theta_p$  is the paramagnetic Curie temperature. This is one of the characteristic features in the Eu-divalent electronic state.

We carried out the dHvA experiments for Eu-divalent compounds of  $\text{EuBi}_3$ ,  $\text{EuSn}_3$ ,  $\text{EuPd}_2$ ,  $\text{EuCd}_{11}$ ,  $\text{EuGa}_4$ , and  $\text{EuRu}_2\text{P}_2$ . The angular dependences of the dHvA frequencies  $F (=c\hbar S_F/2\pi e)$ , where  $S_F$  is the maximum or minimum cross-sectional area of the Fermi surface, are well explained by the results of energy band calculations for the corresponding non-4*f* reference Sr compounds, for example  $\text{SrBi}_3$  for  $\text{EuBi}_3$ . We found a charge density wave (CDW) in  $\text{EuGa}_4$  at pressures higher than about 1 GPa, for example  $T_{\text{CDW}} = 160$  K at about 2 GPa. The similar CDW phenomenon was also observed at  $T_{\text{CDW}} = 140$  K in  $\text{EuAl}_4$  and  $T_{\text{CDW}} = 243$  K in  $\text{SrAl}_4$  at ambient pressure.

The Fermi surface properties of a typical Eu-trivalent compound  $\text{EuPd}_3$ , which was obtained from the dHvA experiments, are well explained from the results of energy band calculations in the LDA+*Ud* scheme. This means that the 4*f* orbitals are far separated from the Fermi level, and do not contribute to the conduction electrons.

We also clarified that the heavy fermion state in  $\text{EuNi}_2\text{P}_2$  with an electronic specific heat coefficient  $\gamma = 93$  mJ/(K<sup>2</sup>·mol) is based on the Kondo effect, revealing a characteristic shrinkage of the volume below about 100 K. The thermoelectric power also possesses a characteristic peak at 40 K. The Kondo temperature is thus determined as  $T_K = 80$  K. Furthermore, we found the valence transition in  $\text{EuGa}_4$ ,  $\text{EuNi}_2\text{Ge}_2$ ,  $\text{EuRu}_2\text{P}_2$ , and  $\text{EuRhSi}_3$  at  $P_c \approx 6, 2.3, 8,$  and  $4$  GPa, respectively, by measuring the electrical resistivity under pressure. After the valence transition, the electronic state of  $\text{EuNi}_2\text{Ge}_2$  is almost the same as the typical trivalent electronic state of  $\text{EuPd}_3$ , while the heavy fermion state is realized in  $\text{EuGa}_4$ ,  $\text{EuRu}_2\text{P}_2$ , and  $\text{EuRhSi}_3$ .

The divalent, trivalent, and heavy fermion states in Eu compounds are clarified in the present study.

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