Superconductivity and magnetism of the R$_6$Ni$_2$Sn (R = Y and rare earth) compounds

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Abstract

We have performed AC electrical resistivity $\rho$, DC magnetic susceptibility $\chi_{DC}$ and heat capacity $C(T)$ measurements on the ternary compounds R$_6$Ni$_2$Sn (R = Y and rare earth). Our results show that La$_6$Ni$_2$Sn becomes superconducting with $T_c \sim 2.3$ K. Except for R = Y, Ce, and Pr, most of the R$_6$Ni$_2$Sn compounds undergo various magnetic transitions as revealed from the appearance of features in both $\chi(T)$ and $C(T)$ curves, and changes of the slopes in the $\rho(T)$ curves. Ce$_6$Ni$_2$Sn is a heavy fermion compound with its specific heat $C/T$ increases logarithmically for 1 K $<$ $T$ $<$ 7 K and reaches a value of $\sim$160 mJ/mol Ce–K$^2$ at 0.35 K.

PACS: 71.27+a; 74.25.Fy; 75.30.Cr

Keywords: Superconductivity; Magnetic transition; Heavy fermion

The R$_6$Ni$_2$Sn (R = rare earth) compounds belong to the Ho$_6$Ni$_2$Ga-type structure with space group Immm [1]. Among them, Er$_6$Ni$_2$Sn has been mostly studied because of its usage for the magnetic refrigeration [2,3]. Recent study reveals that La$_6$Ni$_2$Sn is a type-II superconductor with a transition temperature $T_c$ of 2.25 K [4]. To have further understanding about these compounds, we have studied the transport, magnetic, and specific heat properties of these systems.

Polycrystalline samples of R$_6$Ni$_2$Sn (R = Y and rare earth) were prepared by arc-melting stoichiometric amounts of the constituent elements (R: 99.99%, Ni: 99.99%, Sn: 99.9999%) together on a water-cooled copper hearth in a Zr-gettered argon atmosphere. The as-melted samples were subsequently wrapped in Ta foil, sealed in quartz tube in argon atmosphere, and annealed at 550°C for 3 days. AC electrical resistivity of bar-shaped samples has been measured in a $^4$He cryostat.
using a four-probe AC technique. DC magnetic susceptibility measurements were performed in a commercial superconducting quantum interference device (SQUID) magnetometer from 2 to 300 K in various applied magnetic fields. The specific heat of Ce$_6$Ni$_2$Sn was measured using in $^3$He microcalorimeter in the temperature range between 0.35 and 20 K with $H = 0$.

The normalized electrical resistance $R(T)/R(300 \text{ K})$ vs. $T$ curves for the R$_6$Ni$_2$Sn (R = Y, La, Ce, and Pr) compounds are plotted in Fig. 1(a) for $0 \leq T \leq 300 \text{ K}$. The $R(T)/R(300 \text{ K})$ curves for these samples exhibit typical characteristics of common metal and decrease monotonically with decreasing temperature $T$. The abrupt drop of $R(T)/R(300 \text{ K})$ to zero value, as shown in the inset, reveals that La$_6$Ni$_2$Sn becomes superconducting below 2.3 K [4]. Shown in Fig. 1(a) is the $R(T)/R(300 \text{ K})$ curve for Nd$_6$Ni$_2$Sn. A rapid drop at 30 K and a change of the slope at 6.5 K in the $R(T)/R(300 \text{ K})$ curve indicates the occurrence of two magnetic transitions in this compound. This is consistent with the result of the magnetic susceptibility study which reveals that Nd$_6$Ni$_2$Sn undergoes antiferromagnetic transition at 29 K followed by an order–order transition at 6.2 K. Various magnetic transitions at low temperatures were also observed in the R$_6$Ni$_2$Sn compounds with R = Sm, Gd, Tb, Dy, and Ho [5].

The low-temperature specific heat of Ce$_6$Ni$_2$Sn is depicted in Fig. 2(a), where $C/T$ vs. $T^2$ are plotted. The specific behaviour for this compound reveals characteristics of heavy fermion compounds. A characteristic logarithmic divergence of $C/T$ data over the temperature range of $1 K < T < 7 K$ indicates non-Fermi liquid behaviour in this compound. The obtained value of $C/T$ is $\sim 160 \text{ mJ/mol Ce–K}^2$ at 0.35 K. The $\chi(T)$
and $\chi^{-1}(T)$ vs. $T$ curves for Ce$_6$Ni$_2$Sn, as plotted in Fig. 2(b), reveal that this compound is non-magnetic for $T > 2$ K. Above $\sim 100$ K, the $\chi(T)$ curve follows a Curie–Weiss behaviour with a value of effective moment $\mu_{\text{eff}} = 2.68 \mu_B$.

In summary, we have studied the electrical, magnetic, and specific properties of the R$_6$Ni$_2$Sn compounds. We found that La$_6$Ni$_2$Sn becomes superconducting below 2.3 K. Two magnetic transitions were observed in Nd$_6$Ni$_2$Sn at 30 and 6.5 K, respectively.

We found that Ce$_6$Ni$_2$Sn is a non-magnetic heavy fermion system with an obtained value of $C/ T = 160$ mJ/mol Ce–K$^2$ at 0.35 K.

This work was supported by the ROC National Science Council under Grant no. NSC 92-2112-M002-031.

References