Josephson effect in heavy-fermion superconductor $CeTIn_5$ (T=Co, Ir)

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Abstract

The Josephson effect between a single crystal $CeTIn_5$ (T=Co, Ir) and an *s*-wave superconductor has been investigated for $CeTIn_5$-Cu-Nb junctions. Josephson critical current I_c is observed just below superconducting transition temperature T_c for $CeCoIn_5$, while the temperature below which I_c appears varies from junction to junction and I_c rises gradually at first for $CeIrIn_5$, probably reflecting a distribution of the local transition temperature in $CeIrIn_5$.

Key words: heavy-fermion superconductor; Josephson effect; $CeIrIn_5$; $CeCoIn_5$

Recently, a new family of heavy-fermion superconductors: $CeIrIn_5$ (T_c=0.4 K)[1] and $CeCoIn_5$ (T_c=2.3 K)[2] have been discovered. In addition to the difference in a thermodynamic transition temperature T_c, an unusual superconducting property has been reported for $CeIrIn_5$; the electrical resistivity vanishes at a much higher temperature, T_0=1.2 K[1]. In our previous paper, we have reported that the Josephson effect between $CeIrIn_5$ and Nb is observed well above T_c[3]. In this paper, the Josephson effect of $CeCoIn_5$ has been measured and compared with the result for $CeIrIn_5$.

The single crystals of $CeCoIn_5$ and $CeIrIn_5$ were cut to the appropriate shape to use as a substrate. The sample surface was rf sputter etched by Ar ion and then Cu (normal metal) and Nb (*s*-wave superconductor) were deposited by rf sputtering technique. The junctions are denoted in such a way as $I \parallel [001]$, on the assumption that the preferred current direction is perpendicular to the crystal surface on which the junction is fabricated. The thickness d_N of Cu and the junction area S are listed in Table 1. The details of the sample preparation and the measuring technique have been described in our previous paper[3].

We show in Fig. 1 the typical properties of the Josephson effect between $CeCoIn_5$ and Nb. The current-voltage characteristics in the inset is the typical one of SNS′ junctions; the voltage appears at the critical value I_c, and no hysteresis is observed. The quality of the junction is demonstrated in the magnetic field dependence of I_c. A Fraunhofer diffraction pattern, which is expected in a uniform junction, is not observed in Fig. 1; I_c oscillates with no definite period, although the falling envelope is seen with an increase in magnetic field. This pattern suggests that the junction is not uniform, that is, the local critical current density fluctuates spatially.

Table 1
Properties of $CeTIn_5$-Cu-Nb junctions, where d_N and S are the thickness of Cu and the junction area, respectively.

Substrate	Current direction	d_N (μm)	S (mm^2)
$CeCoIn_5$	[001]	0.8	0.24
$CeIrIn_5$	[110]	0.8	0.097
$CeIrIn_5$	[001]	0.8	0.11

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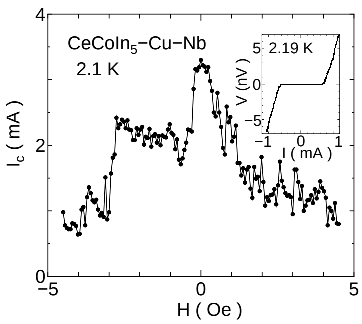

Fig. 1. Typical properties of $CeCoIn_5$-Cu-Nb junction. Magnetic field dependence of Josephson critical current I_c suggests that the junction is not uniform. The solid line through the data points is guide to the eye. Inset: $I - V$ characteristic showing Josephson critical current.

Figure 2 shows the temperature dependence of the junction resistance R and the Josephson critical current I_c for the $CeCoIn_5$-Cu-Nb junction. Below the critical temperature of Nb, R consists of the resistance of Nb-Cu boundary, Cu, Cu-$CeCoIn_5$ boundary, and $CeCoIn_5$. When the temperature is lowered, a decrease in R due to the superconducting transition is observed at about 2.2 K, followed subsequently by the vanishment of R due to the Josephson effect. A small dip at about 3 K may be ascribed to the superconducting transition of a trace of In metal in $CeCoIn_5$. As the temperature is lowered, the Josephson critical current increases.

The temperature dependence of Ic differs markedly from that of $CeIrIn_5$[3], as seen in Fig. 3. Although the linear variation of Ic, which is expected near Tc in the SNS$'$ junction[4], is not clearly seen, Ic appears just below Tc, and increases rapidly for $CeCoIn_5$. In the case of $CeIrIn_5$, the temperature at which Ic appears is near the transition temperature to the zero-resistivity state, T_0=0.8 K. In addition, Ic increases rather slowly at first with a decrease in temperature.

In our previous paper, we have pointed out the possibility of a distribution of the local transition temperature above T_c in $CeIrIn_5$[3]. The inhomogeneity of superconductivity is reported in ref. [5] also. In that case, the temperature dependence of Ic for $CeIrIn_5$ may be explained as follows; near T_0, only a small part of the junction area is superconducting, and small Ic is observed. As the temperature is lowered, more and more part becomes superconductive, and the increasing rate of Ic rises.

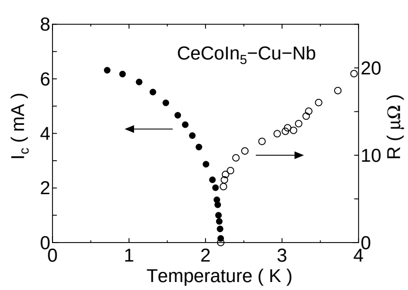

Fig. 2. Temperature dependence of junction resistance R and Josephson critical current I_c for $CeCoIn_5$-Cu-Nb junction.

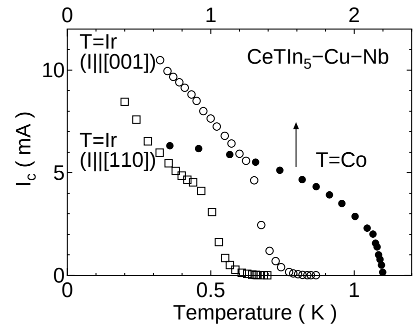

Fig. 3. Temperature dependence of Josephson critical current I_c for three junctions. The top abscissa corresponds to the data for $CeCoIn_5$.

In conclusion, the comparison of the Josephson effect has shown that $CeCoIn_5$ is an ordinary superconductor in that the Josephson critical current Ic appears just below Tc, whereas the inhomogeneous superconducting state in $CeIrIn_5$ may be reflected on the temperature dependence of Ic.

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