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Low-temperature specific heat study of antiferromagnetic transition in ternary rare-earth metal silicide $R_5Ir_4Si_{10}$ (R= Tb, Dy, Ho, Er)

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Abstract

We investigated antiferromagnetic transitions of $R_5Ir_4Si_{10}$ (R= Tb, Dy, Ho, Er) by measuring the low-temperature specific heat. The antiferromagnetic transition temperature T_N is precisely determined. T_N is l0.7 K for R = Tb, T_N is 5.8 K for R = Dy, T_N is 5.1 K for R = Ho and T_N is 3.5 K for R = Er, respectively. These results suggest that the antiferromagnetic transition of the ternary rare-earth metal silicide $R_5Ir_4Si_{10}$ is dominated by the exchange interaction between R^{3+} ions like as the antiferromagnetic transitions in the ternary rare-earth metal compounds RCu_2Ge_2 (R = rare-earth metal). In addition, we report the upturn of the specific heat below 1.5 K observed for R = Tb and Ho.

Keywords: antiferromagnetic transition, ternary rare-earth metal silicide, low-temperature specific heat
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l. Introduction

The ternary rare-earth metal silicide $R_5Ir_4Si_{10}$ (R= Tb, Dy, Ho, Er) compounds exhibit antiferromagnetic transitions at low-temperatures. These materials crystallize in the tetragonal $Sc_5Co_4Si_{10}$-type structure

and the space group is P4/mbm [1]. The features of the crystal structure are the absence of the clusters of transition-metal atoms and the direct bonds between transition-metal atoms. These features are in contrast to those of Chevrel-phase chalcognides RMo_6S_8 (R= rare-earth metal) and rhodium boride compounds RRh_4B_4 (R = rare-earth metal) [2]. The projection along the c-axis of the crystal structure of $Sc_5Co_4Si_{10}$ is shown in Fig.1. In the $R_5Ir_4Si_{10}$ (R= rare-earth metal) groups, Ir and Si atoms form planar nets of pentagons, hexagons and octagons which are stacked parallel to the plane which is perpendicular to the c-axis and connected along c-axis via lr-Si-lr zigzag chain. The pentagon. hexagon and octagon layers are separated by layers of rare-earth atoms. All lr-Si and Si-Si distances are short and indicative of strong covalent interactions. In many other ternary rare-earth metal silicides such as $ThCr_2Si_2$. $CeNiSi_2$ and $LaRe_2Si_2$, the network of Si and transition-metal atoms exhists. The previous investigations of $R_5Ir_4Si_{10}$ polycrystalline specimens showed that these compounds undergo antiferromagnetic transitions at low-temperatures [3-5]. In this paper, we report the precise behaviors of antiferromagnetic transitions of the $R_5Ir_4Si_{10}$ groups by using both single crystals and high-resolution measurements of the low-temperature specific heat.

2. Experiments

The single crystals used in the present studies were grown by Czochoralski pulling method with a tetra-arc furnace under high purity argon atmosphere. The purity of starting materials as follows; the purity of Si is 99.9999% whereas that of both R and lr is 99.9%. During the crystal growth a clear facetting has been observed sometimes. We confirmed as-grown crystals to be a single crystal by the transmission Laue X-ray photograph method. The single crystals were elongated along the c-axis. The quality of the single crystals was improved by a solid-state electro-transport method (SSE). The behavior of antiferromagnetic transitions were investigated by measuring the low-temperature specific heat.

3. Results

In Figs.2-4 we show the temperature dependence of the low-temperature specific heat. The anomalies associated with the antiferromagnetic transitions in $R_5Ir_4Si_{10}$ (R= Tb, Dy, Ho, Er) compounds have been clearly observed. In Fig.2 are shown the data of $Tb_5Ir_4Si_{10}$, in Fig.3 are shown the data of $Dy_5Ir_4Si_{10}$, in Fig. 4 are shown the data of $Ho_5Ir_4Si_{10}$ and in Fig.5 are shown the data of $Er_5Ir_4Si_{10}$, respectively. We show T_N for the de Gennes factor of each rare-earth metal of the $R_5Ir_4Si_{10}$ groups in Fig. 6. Furthermore, we observed the upturn of the specific heat below 1.5 K in $Tb_5Ir_4Si_{10}$ and $Ho_5Ir_4Si_{10}$.

4. Discussion

As is shown in fig. 6, in the ternary rare-earth metal silicides $R_5Ir_4Si_{10}$ (R=Tb, Dy, Ho, Er) the antiferromagnetic transition temperature T_N increases when the de Gennes factor of the rare-earth metal increases like as the binary compound RIn_3 (R =Gd, Tb, Dy, Ho, Er) [6] and the ternary compound RCu_2Ge_2 (R= Gd, Tb, Dy, Ho, Er) [7]. This result means that we need not take the crystalline electric field effects into consideration in the $R_5Ir_4Si_{10}$ compounds. Therefore, the antiferromagnetic transition in the $R_5Ir_4Si_{10}$ compounds is dominated by the exchange interaction between R^{3+} ions. So that T_N decreases with increasing the de Gennes factor of the rare-earth metal. However, we could not get the good crystal of $Gd_5Ir_4Si_{10}$ in this study.

As mentioned in the results section, the upturn of the specific heat is clearly observed in R = Tb and Ho. We consider that these upturns are due to the nuclear magnetism contribution of the rare earth metals. This nuclear magnetism contribution for the low-temperature specific heat is very excellent in $Ho_5Ir_4Si_{10}$. In the measurement of $Er_5Ir_4Si_{10}$ we observed a shoulder in the vicinity of 2K. However, we cannot explain the origin of this shoulder. This shoulder in the SSE processed sample is smaller than that of the as-grown crystal. This result suggests that the shoulder is due to the impurity. We need further studies.

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Figure Captions

Fig.1. Projection of $Sc_5Co_4Si_{10}$ along the c-axis. Filled circles correspond to z = 0, 1; open circles to z = 1/2 where z is the fractional coordinate along the c-axis.

Fig.2. Temperature dependence of the low-temperature specific heat in $Tb_5Ir_4Si_{10}$.

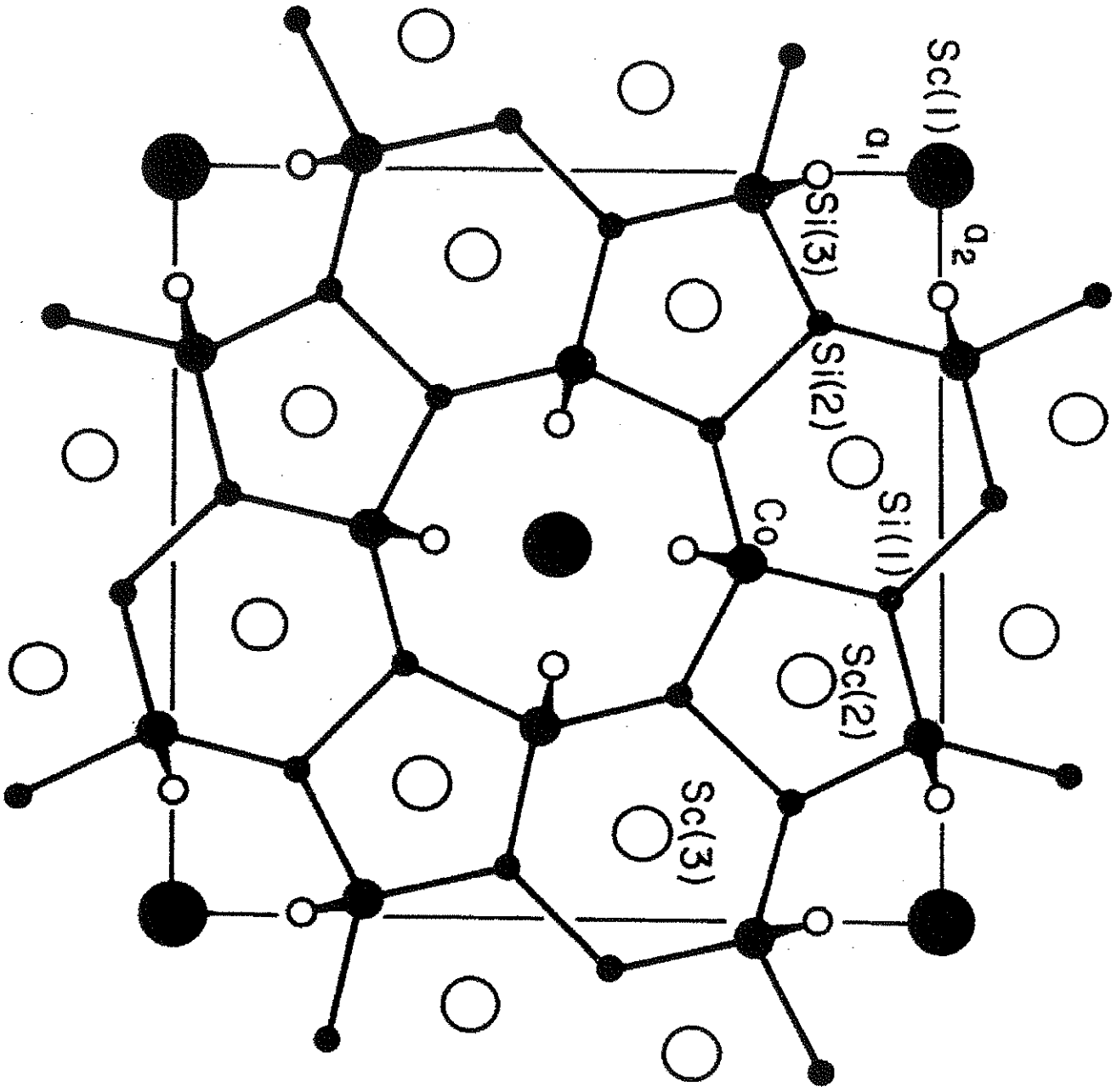
Fig.3. Temperature dependence of the low-temperature specific heat in $Dy_5Ir_4Si_{10}$.

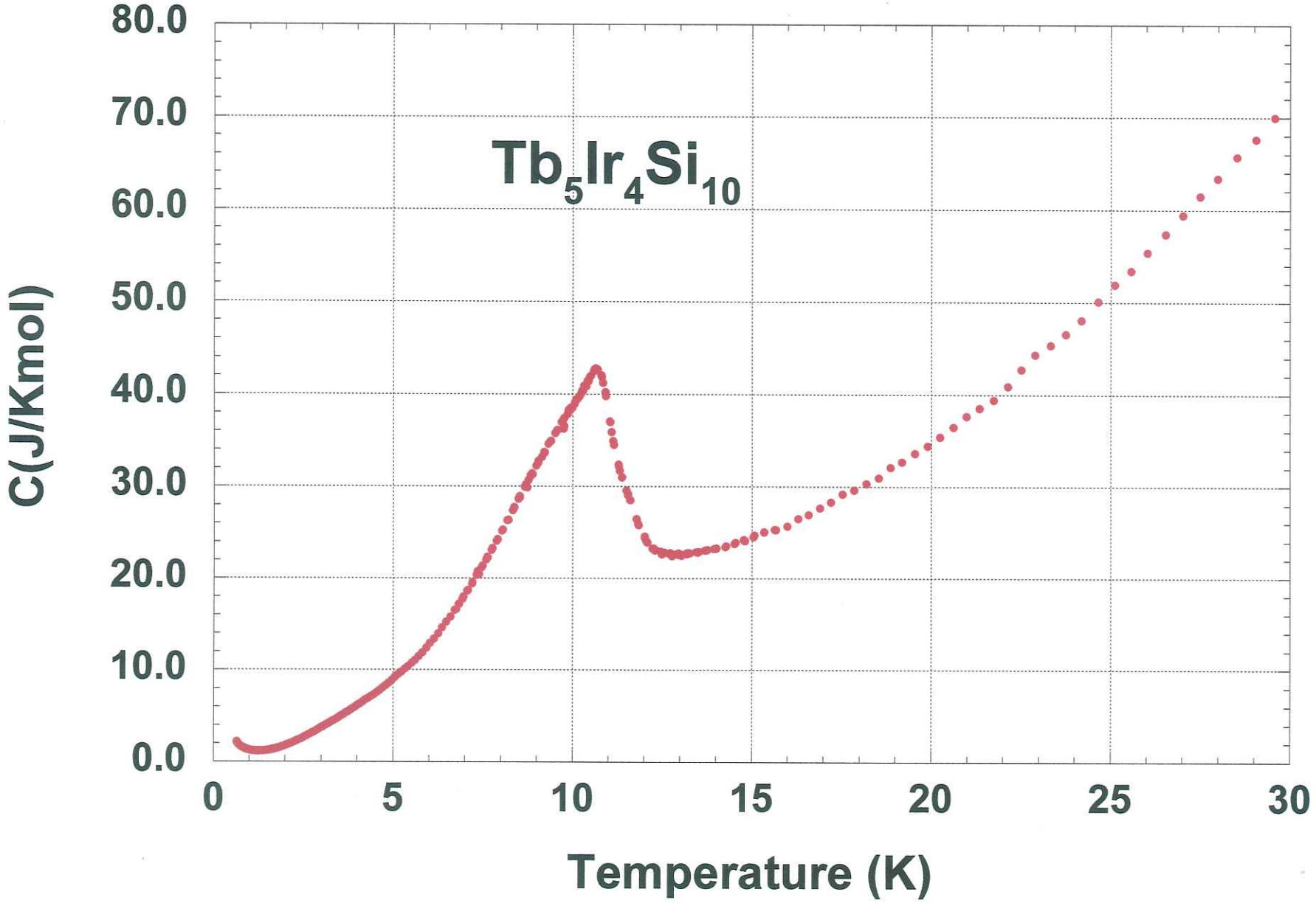
Fig.4. Temperature dependence of the low-temperature specific heat in $Ho_5Ir_4Si_{10}$.

Fig.5. Temperature dependence of the low-temperature specific heat in $Er_5Ir_4Si_{10}$.

Fig.6. Antiferromagnetic transition temperature T_N for the de Gennes factor of each rare-earth metal in $R_5Ir_4Si_{10}$ compounds.

Figure(s)

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70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
C(J/Kmol)
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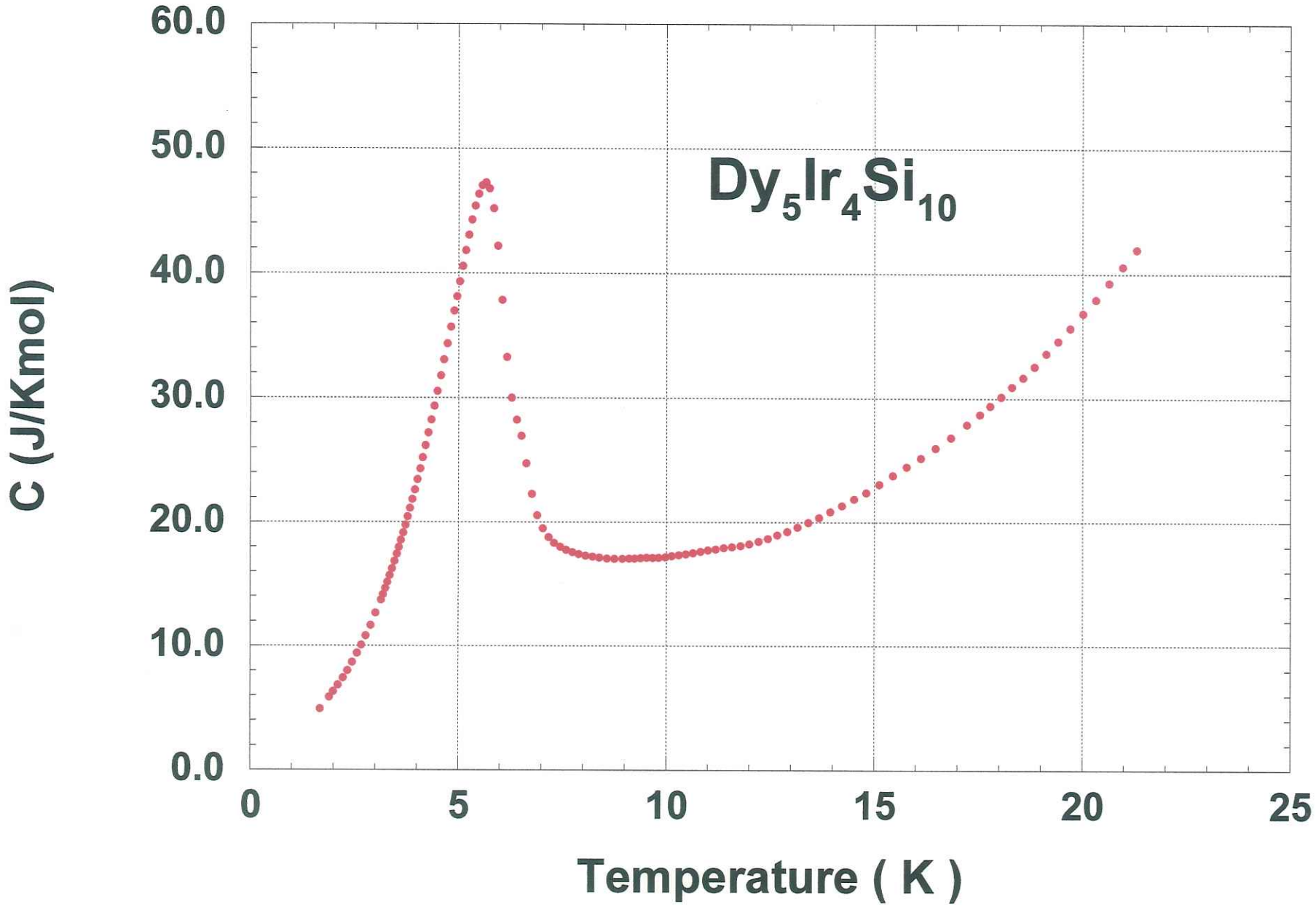
0
5
10
15
20
25
30
Temperature (K)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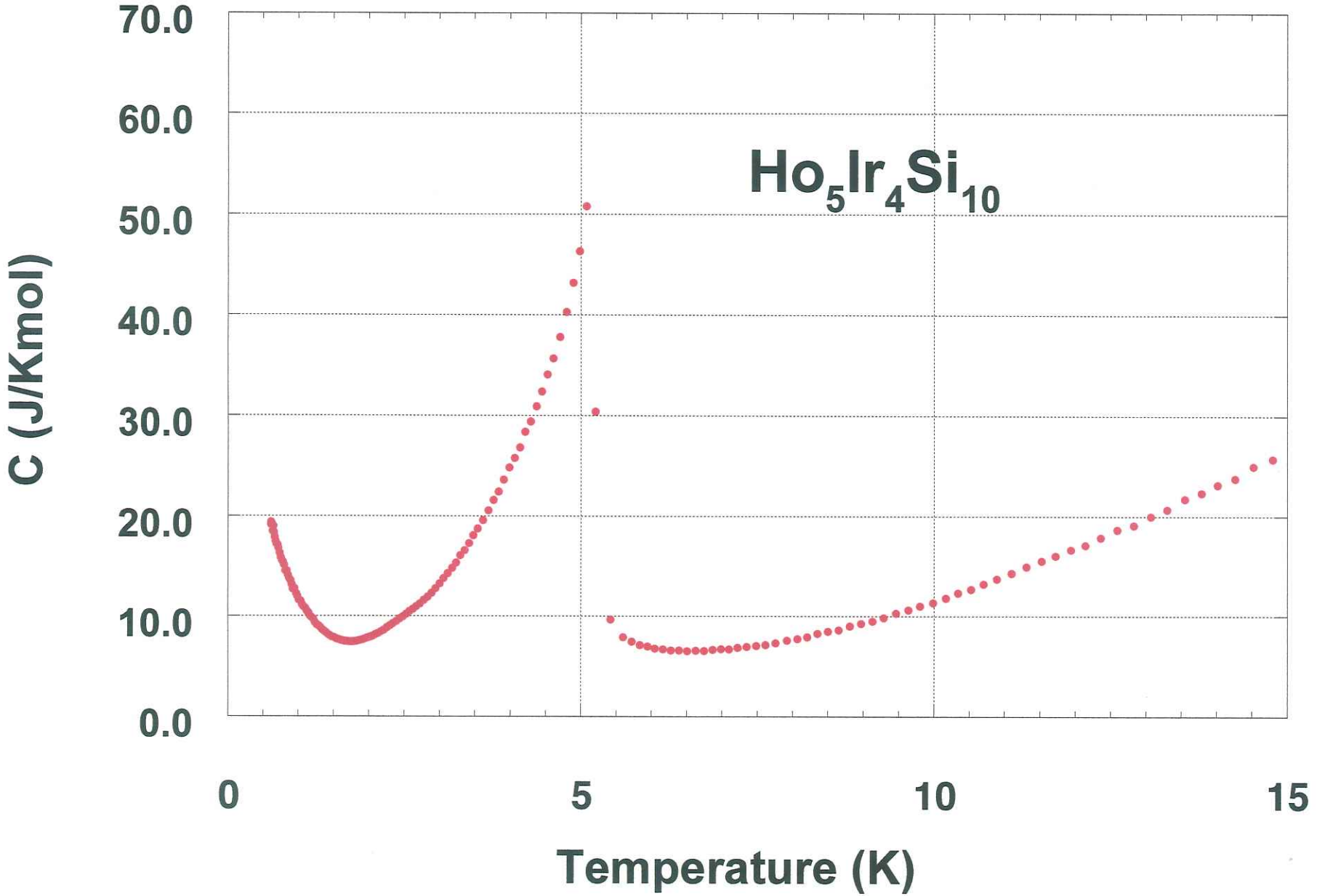
50.0
40.0
30.0
20.0
10.0
0.0
C (J/Kmol)
Dy5Ir4Si10
0
5
10
15
20
25
Temperature (K)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40.0
30.0
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10.0
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C (J/Kmol)
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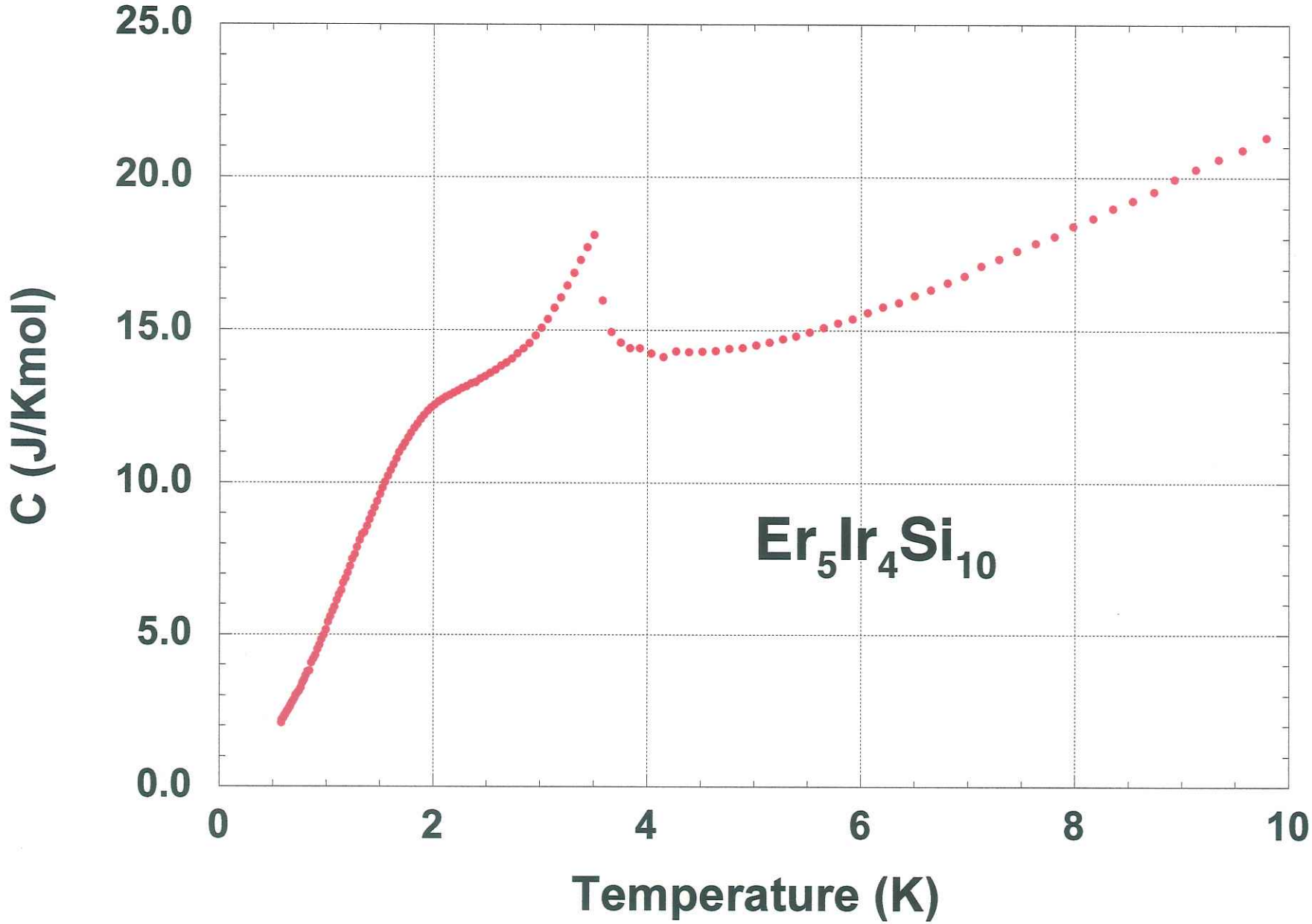
0
5
10
15
Temperature (K)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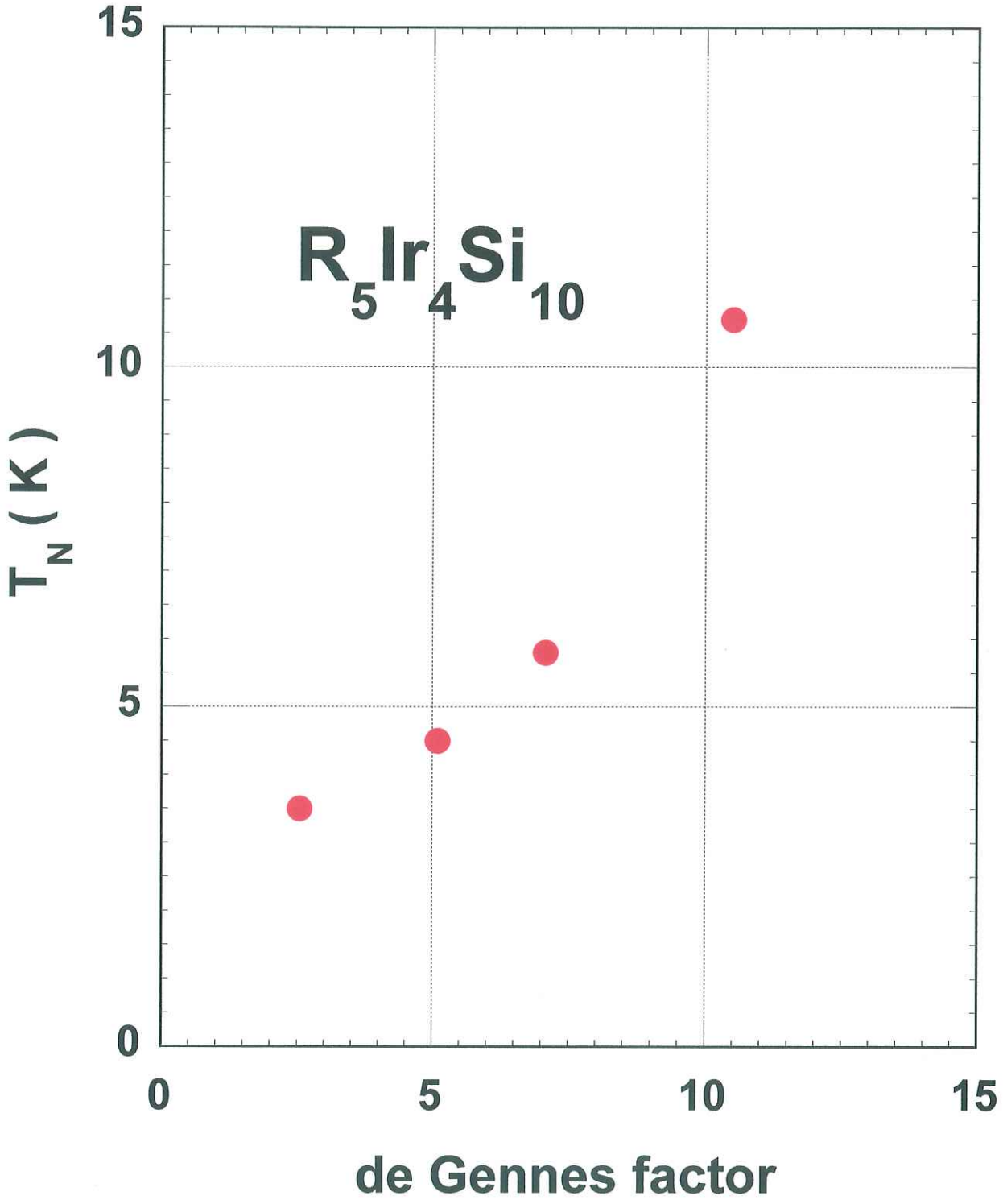
10.0
5.0
0.0
C (J/Kmol)
0
2
4
6
8
10
Temperature (K)
Er5Ir4Si10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10
5
0
0
5
10
15
T_N (K)
de Gennes factor

*** Response to Reviewers**

The submitted files type could not be determined.

FILE NAME: List of changes