MAGNETIC AND TRANSPORT PROPERTIES OF R_2MIn_8 (R=La,Ce Pr; M=Rh, Ir)* **

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We have grown single crystals of R_2MIn_8 compounds (R=La, Ce, Pr; M = Rh, Ir) and measured magnetic and transport properties of these crystals in the temperature range 1.8–300 K. We have found that Ce_2RhIn_8 is an antiferromagnet with a Néel temperature T_N=2.8 K and Ce_2IrIn_8 is in a paramagnetic state down to 1.8 K. The Ce-based compounds are dense Kondo materials with the Kondo temperatures of several tens of Kelvins and nearly a hundred Kelvin for Ce_2RhIn_8 and Ce_2IrIn_8, respectively. The Pr ions in the Pr-based compounds are in the singlet ground states.

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1. Introduction

The compounds Ce_mMIn_{3m+2} ($m = 1,2$; M=Co, Rh, Ir) have attracted much interest since the discovery of a new heavy fermion superconductors for the $CeMIn_5$ compounds [1–3]. These materials crystallize in the quasi-two-dimensional tetragonal Ho_mCoGa_{3m+2} structure, where m layers of $HoGa_3$ units stack sequentially along the c-axis with intervening layer of $CoGa_2$. The superconductivity observed in the $CeMIn_5$ compounds can be considered to be mediated by spin fluctuations that are present at a boundary of magnetic ordered phases, as in the case for other heavy Fermion superconductors [4]. For magnetically mediated superconductivity, quasi-two-dimensional crystal structure is favorable to stabilize the Cooper pairing [2]. Thus a family of Ce_2MIn_8 compounds is expected to be in the superconducting state under ambient or high pressures [5–7]. To investigate a quasi-two-dimensionality of the electrical band structure for R_2MIn_8 compounds, we have measured the de Haas–van Alphen effect on La_2RhIn_8 and reported in [8].

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In this work we have grown the single crystals of the R_2MIn_8 compounds (R=La, Ce , Pr; M=Rh, Ir) and reported magnetic susceptibility, electrical resistivity and Hall effect measurements on these single crystals to clarify the ground state properties at ambient pressure.

2. Experimental

Single crystals of R_2MIn_8 were grown from an In flux starting from the initial compositions of R:M:In=2:1:10 by a similar method described in [8]. The purities were $3N$ for R and M elements and $5N$ for In. The crystal structure and phase purity were confirmed by an X-ray powder diffraction method. The lattice parameters a (c) of R_2RhIn_8 are obtained as 4.691 (12.30) Å for R=La; 4.664(12.25) Å for R=Ce; 4.658(12.19) Å for R=Pr and those of R_2IrIn_8 4.703(12.36) Å for R=La; 4.701(12.20) Å for R=Ce; 4.652(12.17) Å for R=Pr. The lattice parameters for the La- and Ce-based compounds agree with [6,7,9]; those for Pr-based compounds are first reported and are consistent with the extrapolated values from the La- and Ce based compounds. The electrical resistivity and the Hall coefficient were measured by a usual four probes DC method. The magnetic susceptibility was measured by a SQUID magnetometer.

3. Result and discussion

We plot the temperature T dependence of the magnetic susceptibility (χ_c) for an applied field H along the c-axis and (χ_a) for the a-axis of the Ce_2MIn_8 and Pr_2MIn_8 compounds (M=Rh, Ir) in figures 1(a) and (b), respectively. The La_2MIn_8 compounds showed only a temperature independent diamagnetism between 1.8 K and 300 K.

The susceptibility for the Ce-based compounds was found to be described well by the Curie–Weiss law for both field directions at $T \geq 150K$. The effective Bohr magneton values P_{eff} are 2.6 for Ce_2RhIn_8 and 2.3 for Ce_2IrIn_8 in two different magnetic field directions. The latter values is reduced somewhat from the Hunt's rule value of 2.54 for Ce^{3+} ion. The paramagnetic Curie–Weiss temperatures Θ are -15 K and -85 K for $H\|c$ and $H\|a$, respectively. The Θ values of Ce_2IrIn_8 are nearly the same as those for Ce_2RhIn_8, indicating that crystal field effects act to the same extent on the magnetic properties for both Ce compounds.

At low temperatures, χ_a for Ce_2RhIn_8 increases with decreasing temperature, take a maximum at about 5K and then decrease, while χ_c continues to increase down to about 3 K and takes a kink. The inset presents variations of χ_c and χ_a for the lowest temperature part, in which both the kink in χ_c and a rapid decrease in χ_a appear at 2.8 K. The inset also contains the temperature dependence of the electrical resistivity, which shows a sharp change at 2.8 K. The behavior for χ and ρ shows that the Ce_2RhIn_8 compounds order antiferromagnetically at 2.8 K and take the magnetic moment in the c-plane. On the other hand, the χ curves for Ce_2IrIn_8 indicate that this compound is in a paramagnetic state down to 1.8 K. The behavior of χ for Ce_2RhIn_8 and Ce_2IrIn_8 is very similar to that for $CeRhIn_5$[1] and $CeIrIn_5$[3], respectively, except that $CeRhIn_5$ has a Néel temperature of 3.8K.

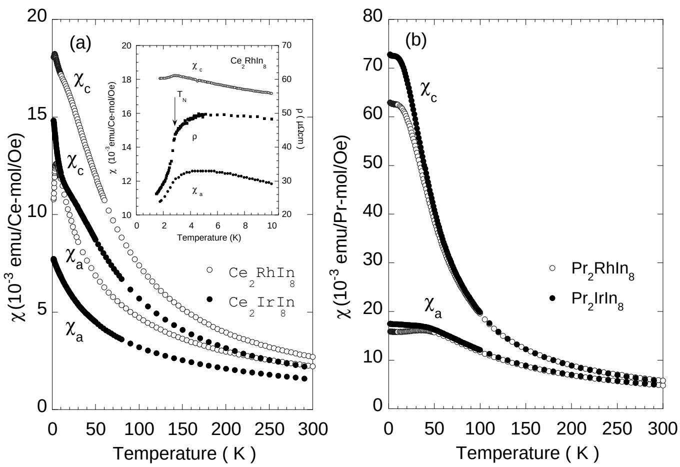

Fig. 1. Magnetic susceptibility for Ce_2MIn_8 (a) and Pr_2MIn_8 (b), where M= Rh and Ir. The inset in (a) presents temperature dependence of susceptibility and electrical resistivity at low temperatures.

Figure 1(b) shows that the temperature dependence of χ for Pr_2RhIn_8 and Pr_2IrIn_8 are similar for each field direction of $H\|a$ and c. The values of P_{eff} obtained from the Curie–Weiss law agree with the Hunt's rule value of 3.58 to within an experimental error. The Θ values are 15K for $H\|c$ and -36K for $H\|c$ for both compounds. As T decreases, each χ curve deviates downward from the Curie–Weiss law and tends to constant value nearly independent of the M elements for both field directions. This low temperature dependence of χ indicates that the ground state of Pr ion in Pr_2MIn_8 is in a singlet state and observed temperature independent χ is due to a Van Vleck contribution.

Figure 2 shows the temperature dependence of the electrical resistivity ρ with the current parallel to the a direction for the R_2MIn_8 compounds (R =La, Ce, Pr; M=Rh, Ir). The resistivity of Ce_2RhIn_8 decreases slowly with decreasing temperature down to 150 K, increases logarithmically, takes a maximum at 5 K and then decreases sharply. This feature clearly indicates that the $CeRhIn_8$ compound is a dense Kondo material of which Kondo temperature is several tens of Kelvins and a coherent state develops at about 5K.

As already shown in figure 1, this compound becomes an antiferromagnet at 2.8 K. The ρ curve for Ce_2IrIn_8 shows the similar temperature dependence. But it takes a maximum at about 50 K, indicating that the Kondo temperature is an order of 100 K. This explains the reason why the effective Bohr magneton for Ce_2IrIn_8 is somewhat smaller than the Ce^{3+} Hunt's value, because the magnetic moment should be reduced at high temperatures by the Kondo effect.

The resistivity for the Pr-based compounds shows rapid increase at $T \leq 100\,K$, and varies linearly for $T \geq 100\,K$. The low temperature variation of ρ should be due to spin disorder scattering because Pr ion in the tetragonal symmetry can take a singlet ground states in which magnetic moment is noticeably reduced in comparison with that of a free Pr^3+ ion.

A very peculiar behavior in ρ is observed in La_2RhIn_8; ρ increases rapidly up to 50 K and varies linearly for $T \geq 100\,K$. For $T \leq 15K$, ρ is proportional to T^3. A similar temperature dependence of ρ is observed in $La_2Rh_3S_5$[10]. Qualitatively, this dependence agrees with the Wilson's s–d interband scattering model. But the problem remains unsolved from a quantitative view. No anomaly is observed in the resistivity of La_2IrIn_8.

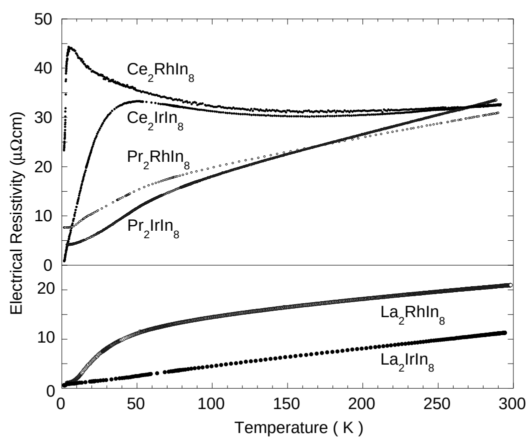

Fig. 2. Temperature dependence of resistivity for R_2MIn_8(R=La,Ce,Pr; M=Rh,Ir).

Figure 3 shows the temperature dependence of the Hall coefficient measured with $H \| c$ for the La- and Pr-based compounds (a) and the Ce-based compounds (b). R_H of the La-based compounds show a very weak temperature dependence down to about 50 K and upturn at low temperatures. For the Pr-based compounds R_H is also temperature independent for 50 K$\leq T \leq$ 300 K. The low temperature decrease in R_H for the Pr-based compounds should be an anomalous Hall effect owing to the large paramagnetism as shown in figure 1(b). R_H of both Ce-based compounds show weak temperature dependencies with decreasing temperature down to 100 K, increase gradually below 100 K, take a maximum at the temperature where the resistivity takes a maximum, and then decrease remarkably. These behavior agree with an universal temperature dependence of $R_{\rm H}$ for heavy electron materials [11].

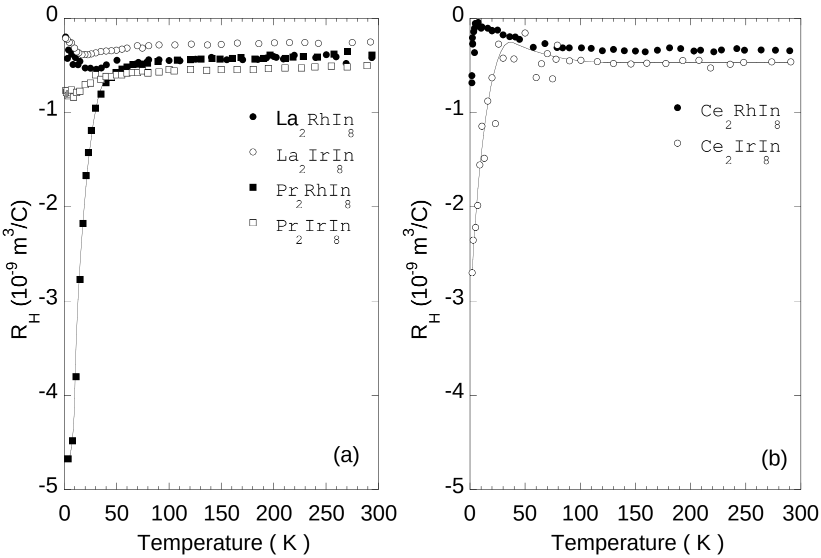

Fig. 3. Temperature dependence of the Hall coefficient for La_2MIn_8 and Pr_2MIn_8 (a) and Ce_2MIn_8 (b) for M=Rh, Ir.

In summary, we have studied magnetic and transport properties of the compounds R_2MIn_8 (R=La, Ce, Pr; and M=Rh, Ir) in the temperature range 1.8–300 K. The Ce_2RhIn_8 and Ce_2IrIn_8 compounds are dense Kondo materials with the Kondo temperature of several tens of Kelvins and a hundred Kelvin, respectively. The former orders antiferromagnetically at 2.8 K. The Pr ions in the Pr-based compounds are in the singlet ground state. A peculiar temperature dependence appears in the resistivity of La_2RhIn_8, which remains unsolved.

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REFERENCES

[1] H. Hegger, C. Petrovic, E.G. Moshopoulou, M.F. Hundley, J.L. Sarrao, Z. Fisk, J.D. Thompson, *Phys. Rev. Lett.* **84**, 4986 (2000).

[2] C. Petrovic, P.G. Pagliuso, M.F. Hundley, R. Movshovich, J.L. Sarrao, J.D. Thompson, Z. Fisk, P. Monthoux, *J. Phys.: Condens. Matter* **13**, L337 (2001).

[3] C. Petrovic, R. Movshovich, M. Jaime, P.G. Pagliuso, M.F. Hundley, J.L. Sarrao, Z. Fisk, J.D. Thompson, *Europhys. Lett.* **53**, 354 (2001).

[4] F. Steglich, *J. Magn. Magn. Mater.* **226–230**, 1 (2001).

[5] N.O. Moreno, M.F. Hundley, P.G. Pagliuso, R. Movshovich, M. Nicklas, J.D. Thompson, J.L. Sarrao, Z. Fisk, *Physica B* **312–313**, 241 (2002).

[6] A.L. Cornelius, P.G. Pagliuso, M.F. Hundley, J.L. Sarrao,*Phys. Rev.* **B64**, 144411 (2001).

[7] J.D. Thompson, R. Movshovich, Z. Fisk, F. Bouquet, N.J. Curro, R.A. Fisher, P.C. Hammel, H. Hegger, M.F. Hundley, M. Jaime, P.G. Pagliuso, C. Petrovic, N.E. Phillips, J.L. Sarrao, *J. Magn. Magn. Mater.* **226**–230, 5 (2001).

[8] S. Ohara, Y. Shomi, I. Sakamoto, *J. Phys. Soc. Jpn.* **71**, Suppl. 258 (2002).

[9] P.G. Pagliuso, J.D. Thompson, M.F. Hundley, J.L. Sarrao, Z. Fisk, *Phys. Rev.* **B63**, 54426 (2001).

[10] S. Ramakrishnan, N.G. Patil, A.D. Chinchure, V.R. Marathe, *Phys. Rev.* **B64**, 64514(2001).

[11] Y. Ōnuki, S.W. Yun, K. Satoh, H. Sugawara, H. Sato, *Transport and Thermal Properties of f-Electron Systems*, Plenum Press, New York and London 1993, p.103.