Title
Occurrence of magnetism in CeMIn5 - x Hgx (M = Rh, Ir)

Permalink
https://escholarship.org/uc/item/9wb8j2wm

Journal
Physica B: Condensed Matter, 403(5-9)

ISSN
0921-4526

Authors
Bauer, ED
Ronning, F
Maquilon, S
et al.

Publication Date
2008-04-01

DOI
10.1016/j.physb.2007.10.101

License
CC BY 4.0

Peer reviewed
Occurrence of magnetism in CeMIn$_{5-x}$Hg$_x$ (M = Rh, Ir)

E.D. Bauer$^{a,*}$, F. Ronning$^a$, S. Maquilon$^b$, L.D. Phamb, J.D. Thompson$^a$, Z. Fisk$^c$

$^a$Los Alamos National Laboratory, Los Alamos, NM 87545, USA
$^b$University of California, Davis, Davis, CA 95616, USA
$^c$University of California, Irvine, Irvine, CA 92697, USA

Abstract

The physical properties of CeM(In$_{1-x}$Hg$_x$)$_5$ (M = Rh, Ir) including specific heat and magnetic susceptibility are reported. Two magnetic phases exist in CeRhIn(In$_{1-x}$Hg$_x$)$_5$ with some evidence of a change from incommensurate magnetic order to a commensurate structure near 10\% nominal Hg substitution. In CeIr(In$_{1-x}$Hg$_x$)$_5$, an antiferromagnetic quantum critical point near $x = 3\%$ (followed by robust long-range antiferromagnetism for $x > 5\%$) appears to be separated from superconductivity in CeIrIn$_5$. The multitude of magnetic ground states observed in the CeM(In$_{1-x}$Hg$_x$)$_5$ materials is quite sensitive to doping and magnetic fields.

© 2007 Published by Elsevier B.V.

PACS: 74.70.Tx; 65.40.+a; 75.30.Mb

Keywords: Heavy fermion; Magnetic order; Superconductivity; Quantum critical point

The tetragonal CeMIn$_5$ (M = Co, Rh, Ir) heavy-fermion superconductors have attracted interest in recent years due to their high superconducting transition temperatures (e.g., $T_c = 2.3$ K in CeCoIn$_5$), unconventional superconductivity, and magnetic-field-induced exotic ground states [1]. In particular, field-induced quantum criticality at the upper critical field $H_{c2} = 5$ T in CeCoIn$_5$ and a possible field-induced magnetic state within the superconducting phase suggests close proximity to antiferromagnetism [2]. Isoelectronic substitution of Co or Ir in antiferromagnetic CeRhIn$_5$ yields coexistence of antiferromagnetism (AFM) and superconductivity over large regions as a function of substituent element [3,4], a result that is difficult to understand within the framework of a single band picture. The exciting discovery [5] of slight changes in the electronic structure of CeMIn$_5$ with Cd substitution at the percent level in CeCoIn$_5$ appears to have “uncovered” the hidden magnetism in this material, which is very different than electron doping with Sn [6], where there is no sign of long-range magnetic order. The substitution of Hg in CeMIn$_5$ offers yet another way to probe the proximity to magnetism in CeCoIn$_5$, the field-induced magnetic state under pressure in CeRhIn$_5$ [7], and the coexistence of magnetism and superconductivity.

Single crystals of CeM(In$_{1-x}$Hg$_x$)$_5$ (M = Rh, Ir) were grown in Hg/In flux. The nominal concentration of the Hg/In ratio is reported; microprobe analysis reveals an actual Hg concentration about 20\% of the nominal concentration.

The specific heat, plotted as $C/T$, of CeRhIn(In$_{1-x}$Hg$_x$)$_5$ is shown in Fig. 1a. The cusp-like anomaly at $T_N = 3.8$ K in pure CeRhIn$_5$ is initially suppressed with Hg substitution to $T_N \sim 2.6$ K and remains sharp until 20\% Hg, whereupon the transition broadens and increases to $T_N = 4.5$ K. The $T-x$ phase diagram of CeRhIn(In$_{1-x}$Hg$_x$)$_5$ is shown in the inset of Fig. 1a. A broad minimum of the $T_N(x)$ curve occurs between 5\% and 15\% Hg, after which the Néel transition increases rapidly. The shape of the $C(T)$ curves and the evolution of $T_N(x)$ in CeRhIn(In$_{1-x}$Hg$_x$)$_5$ is similar to the CeRh(In$_{1-x}$Cd$_x$)$_5$ system [5]. A qualitative change in the shape of the anomaly at the Néel transition in the magnetic susceptibility (not shown) from a broad maximum followed by a change in slope of $\chi(T)$ for $x < 10\%$, to a cusp-like feature (with no maximum at higher temperatures) for $x > 10\%$, [8-10].
suggests a change in magnetic structure near \( x = 10\% \). The mean-field-like anomaly for \( x > 10\% \) may reflect an evolution from an incommensurate magnetic structure [8] observed in CeRhIn_{5} to a simple structure, such as the one found in CeCoIn_{5} to a simple structure, which is similar to the transitions for 5% CeCo-In [8].

The CeRh(In_{0.8}Hg_{0.2})_{5} sample shows a remarkable sensitivity to magnetic field as displayed in Fig. 1b. The specific heat anomaly at the Neél temperature is reminiscent of a broad second-order transition. With increasing magnetic field up to \( H = 5\,\text{T} \), the anomaly is suppressed in temperature and the magnitude of \( C/T \) decreases slightly. For \( H \approx 6\,\text{T} \), the transition is roughly constant in temperature at \( T_{N} = 2.7\,\text{K} \) and sharpens considerably suggesting a change to a new magnetic structure with field as shown in the inset of Fig. 1b. It is interesting to note that the shape of the anomaly and the value \( T_{N} \) of the 20% \( \text{Hg} \) sample in field is similar to the transitions for 5% \( \leq x \leq 15\% \) in zero field where \( T_{N}(x) \) is a minimum.

The magnetic contribution to the specific heat \( \Delta C/T \) of CeIr(In_{1-x}Hg_{x})_{5} for 0 \( \leq x \leq 25\% \) is shown in Fig. 2 on a semi-log scale, after subtraction of the nonmagnetic contribution of LaIrIn_{5}. Superconductivity is observed at \( T_{c} = 0.4\,\text{K} \) for CeIrIn_{5}. Peaks in \( \Delta C/T \) reveal AFM order for \( x > 5\% \), reaching \( T_{N} = 8\,\text{K} \) at 25% \( \text{Hg} \). Of all the CeM(In_{1-x}Hg_{x})_{5} (M = Co, Rh, Ir) systems, the CeIr(In_{1-x}Hg_{x})_{5} materials show the largest values of the Neél temperature. The absence of superconductivity or long-range order is found in a narrow concentration range near 3% \( \text{Hg} \) (above 0.4 K). At this concentration, \( \Delta C/T \) follows a non-Fermi liquid logarithmic divergence over nearly a decade in temperature from 0.6 to 5.5 K, indicating proximity to an AFM quantum critical point. Similar behavior is found in the CeIr(In_{1-x}Cd_{x})_{5} compounds, with the non-Fermi liquid behavior extending down to 50 mK for the \( \text{Cd} = 3\% \) material [5,10]. A gap between the superconducting and magnetic regions of the phase diagram has not been observed in heavy-fermion superconductors before. Such a gap may have its origin in the unusual superconductivity in CeIrIn_{5}, since there evidence that this superconducting phase appears to be distinct from another superconducting phase present on the other side of the minimum in \( T_{c} \) near \( y=0.9 \) in CeRh_{1-x}Ir_{x}In_{5} [11].

Multiple magnetic instabilities occur in CeMIn_{5-x}Hg_{x} judging from the phase diagrams presented in Figs. 1 and 2, which can be accessed easily with chemical substitution at the percent level or modest magnetic fields. This sensitivity to doping and magnetic field suggests a delicate tuning of the quasi two-dimensional Fermi surface sheets on a global scale and is supported by a rigid band-shift picture implied from the reversibility of \( \text{Cd} \) and \( \text{Hg} \) doping and pressure in these “115” systems. However, recent Co and In nuclear quadrupole resonance experiments on CeCo(In_{1-x}Cd_{x})_{5} infer that the Cd ions (and, by analogy, the Hg ions) nucleate magnetic order on a local scale [12]. Resolving this apparent conundrum of Fermi surface effects vs. local tuning of the chemical environment in CeM(In_{1-x}Hg_{x})_{5} and considering its implications for unconventional superconductivity, quantum criticality,
and the coexistence of superconductivity and magnetism must await further experiments.

Work at Los Alamos was performed under the auspices of the U.S. DOE. We thank the Sarah Roeske Electron Microprobe Laboratory at the UC-Davis Geology Department for assistance with the microprobe measurements.

References


