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Effect of La doping on magnetic structure in heavy fermion CeRhIn₅

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Abstract

The magnetic structure of Ce_{0.9}La_{0.1}RhIn₅ is measured using neutron diffraction. It is identical to the incommensurate transverse spiral for CeRhIn₅, with a magnetic wave vector $\mathbf{q}_M = (1/2, 1/2, 0.297)$, a staggered moment of $0.38(2)\mu_B$ at 1.4K and a reduced Néel temperature of 2.7 K.

Key words:

magnetic structure, heavy fermion superconductor, neutron diffraction

Superconductivity has been recently discovered in heavy fermion materials CeMIn₅ with transition temperature $T_C = 2.1$ K for $M=\text{Rh}$ at 17 kbar, $T_C = 0.4$ K for $M=\text{Ir}$, and $T_C = 2.3$ K for $M=\text{Co}$ [1]. Lines of nodes in the superconducting gap have been indicated from thermodynamic, transport and NQR measurements[2–4]. This type of anisotropic superconductivity in heavy fermion materials is widely believed to be mediated by antiferromagnetic fluctuations. While a two-dimensional (2D) Fermi surface of undulating cylinders is detected in the de Haas-van Alphen measurements[5], antiferromagnetic correlations are 3D from direct measurements using neutron scattering[6] and from a theoretic fit to the NQR measurements[3].

CeRhIn₅ is an antiferromagnet below $T_N = 3.8$ K at ambient pressure. A spiral magnetic structure was first detected with the NQR measurements[7]. Neutron diffraction measurements reveal a magnetic moment of $0.374(5)\mu_B$ residing on the Ce ion and forming an incommensurate spiral with a magnetic wave vector $\mathbf{q}_M = (1/2, 1/2, 0.297)$ [8]. This may be contrasted with commensurate

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antiferromagnetic structures of structurally related heavy fermion Ce_2RhIn_8 and CeIn_3 [9]. Applying pressure to CeRhIn_5 or doping it with Ir on the Rh site has only a small effect on T_N until the material becomes a superconductor[1,10], while doping with La on the Ce site reduces T_N linearly[11]. We have found with neutron diffraction measurements that the incommensurate magnetic structure is robust against these external perturbations. Results on $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$ are reported here.

A plate-like single crystal sample of $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$, weighing 0.4 g, was grown from an In flux. It has the tetragonal HoCoGa_5 structure (space group No. 123, P4/mmm) with lattice parameters $a = 4.643\text{\AA}$ and $b = 7.530\text{\AA}$ below 20 K. Neutron diffraction experiments were performed at NIST using the thermal triple-axis spectrometer BT9 in a two-axis mode. Neutrons with incident energy $E = 35$ meV were selected using the (002) reflection of a pyrolytic graphite (PG) monochromator. PG filters of total thickness 8cm were used to remove higher-order neutrons. The horizontal collimations were 40-48-48. The sample temperature was regulated by a top loading pumped He cryostat.

Temperature dependent Bragg peaks were found in $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$ along the $(1/2, 1/2, l)$ line only at incommensurate positions characterized by $\mathbf{q}_M = (1/2, 1/2, 0.297)$, which is identical to that for pure CeRhIn_5 . Fig. 1(a) shows a pair of magnetic satellite peaks in a Brillouin zone at 1.4 K and above the Néel temperature. The intensity of the $(1/2, 1/2, 1.297)$ Bragg peak is shown in Fig 1(b) as the square of the order parameter of the antiferromagnetic phase transition. A Néel temperature of 2.7 K is determined. As shown by the scans at various temperatures in the inset to Fig. 1(b), there is no detectable temperature dependence in the incommensurate magnetic wave vector. This is identical to what is observed for pure CeRhIn_5 [8].

To determine the magnetic structure for $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$, 20 independent magnetic Bragg peaks were measured with rocking scans at 1.4 K. Integrated intensities of these peaks are normalized to the structural Bragg peak (220) to yield magnetic cross sections, $\sigma_{obs}(\mathbf{q}) = I(\mathbf{q}) \sin(\theta_4)$, in absolute units (see Table 1). The same magnetic model for CeRhIn_5 [8],

$$\sigma(\mathbf{q}) = \left(\frac{\gamma r_0}{2}\right)^2 \langle M \rangle^2 |f(q)|^2 (1 + |\hat{\mathbf{q}} \cdot \hat{\mathbf{c}}|^2),$$

offers a reasonable description for $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$. The staggered magnetic moment, M , at 1.4K is $0.38(2)\mu_B$ per $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$. Within the error bar, this is the same as the moment for pure CeRhIn_5 . Calculated cross sections, σ_{cal} , are listed in Table 1.

In summary, magnetic structure of $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$ is identical to that for pure CeRhIn_5 . While the Néel temperature is reduced from 3.8 K to 2.7 K upon

10% substitution of Ce by La, the staggered moment remains the same within the error bar.

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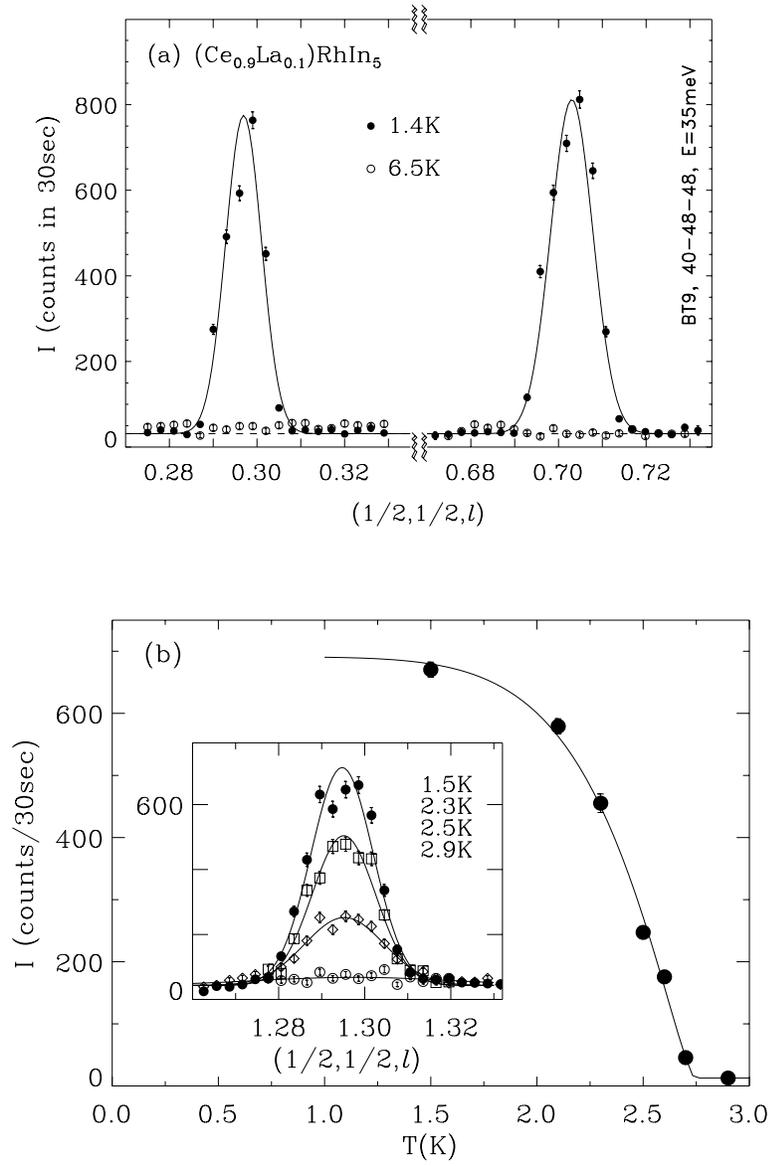


Fig. 1. (a) Elastic scan through a pair of magnetic Bragg points at 1.4 and 6.5 K. (b) Temperature dependence of the $(1/2, 1/2, 1.297)$ Bragg peak. Inset: Elastic scans, with decreasing intensity, at 1.5, 2.3, 2.5, and 2.9 K.

\mathbf{q}	σ_{obs}	σ_{cal}	\mathbf{q}	σ_{obs}	σ_{cal}
(0.5 0.5 -0.297)	9.9(2)	10.0	(0.5 0.5 0.297)	12.1(2)	10.0
(0.5 0.5 0.703)	14.8(3)	11.6	(0.5 0.5 1.297)	15.7(3)	13.0
(0.5 0.5 1.703)	14.2(3)	12.9	(0.5 0.5 2.297)	10.0(3)	11.6
(0.5 0.5 2.703)	6.8(3)	10.3	(0.5 0.5 3.297)	4.6(3)	8.3
(0.5 0.5 3.703)	3.7(3)	7.0	(0.5 0.5 4.297)	3.7(2)	5.2
(0.5 0.5 4.703)	4.3(2)	4.2	(0.5 0.5 5.297)	3.2(2)	2.9
(0.5 0.5 5.703)	2.9(2)	2.3	(0.5 0.5 6.297)	1.8(2)	1.5
(1.5 1.5 0.297)	4.8(2)	4.5	(1.5 1.5 0.703)	4.9(2)	4.5
(1.5 1.5 1.297)	5.2(3)	4.5	(1.5 1.5 1.703)	5.1(2)	4.5
(1.5 1.5 2.297)	4.1(2)	4.2	(1.5 1.5 2.703)	3.4(2)	3.9
(2.5 2.5 1.297)	0.9(1)	1.2	(2.5 2.5 1.703)	1.2(1)	1.1

Table 1

Magnetic Bragg intensity, σ_{obs} , observed at 1.4 K in unit of 10^{-3} b per $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$. The theoretic intensity, σ_{cal} , is calculated using $M = 0.38\mu_B$ per $\text{Ce}_{0.9}\text{La}_{0.1}\text{RhIn}_5$.