

Effect of pressure on magnetic structure in heavy fermion CeRhIn₅

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Abstract The effect of hydrostatic pressure on the incommensurate antiferromagnetic structure of CeRhIn₅ is investigated with neutron diffraction using a He pressure cell. At 3.8 kbar, the staggered magnetic moment is 0.37(4) μ_B per Ce at 1.6 K, which is the same as the ambient-pressure value. The Néel temperature $T_N = 3.8(1)$ K is also the same as the ambient-pressure one, although the curve of order parameter has changed by pressure. The incommensurability δ of the magnetic wave vector $\mathbf{q}_M = (1/2, 1/2, \delta)$ has reduced from $\delta = 0.297$ at ambient pressure to $\delta = 0.294(1)$ at 3.8 kbar.

1 Introduction

Superconductivity and antiferromagnetism exist in close proximity in the heavy fermion materials with chemical formula CeMIn₅, which have Sommerfeld constants $\gamma = 0.4, 0.7,$ and 0.3 J/mole K² for $M = \text{Rh}, \text{Ir},$ and Co , respectively[1,2]. These tetragonal materials (HoCoGa₅ structure with space group No. 123, P4/mmm) consist of alternating layers of the cubic heavy fermion antiferromagnet CeIn₃ and intervening MIn₂[3]. At ambient pressure, CeRhIn₅ is an antiferromagnet below $T_N = 3.8$ K, with magnetic moments on the Ce ions, $0.374(5)\mu_B$ at 1.4 K, lying in the basal plane and forming an incommensurate transverse spiral with a magnetic wave vector $\mathbf{q}_M = (1/2, 1/2, 0.297)$ [4,5]. Under a pressure of 17 kbar, CeRhIn₅ becomes a superconductor below $T_C = 2.1$ K[1]. Both CeIrIn₅ and CeCoIn₅ are superconductors at ambient pressure with $T_C = 0.4$ and 2.3 K, respectively[2]. Lines of nodes in the superconducting gap have been indicated from thermodynamic, transport, and NQR measurements[6,7,8,9]. 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 de Haas-van Alphen measurements[10], anisotropic 3D antiferromagnetic correlations are observed in direct measurements using neutron scattering[11] and inferred from a theoretical fit to NQR measurements[7,8].

Anisotropic magnetic correlation lengths of CeRhIn₅ indicate that the antiferromagnetic nearest-neighbor interaction in the CeIn₃ layer is stronger than the magnetic interaction between Ce neighbors that are separated by the RhIn₂ layer[11]. This may play a role in stabilizing the commensurate antiferromagnetic structure of Ce₂RhIn₈[12], which can be viewed as a periodic stacking of 2 layers of CeIn₃ on a layer of RhIn₂. The incommensurate magnetic structure of CeRhIn₅ is robust. While T_N is reduced linearly to zero with La doping on the Ce site at a critical dopant concentration around 0.4[13], the magnetic structure of Ce_{0.9}La_{0.1}RhIn₅ ($T_N = 2.7$ K) is still characterized by $\mathbf{q}_M = (1/2, 1/2, 0.297)$ and a staggered moment of $0.36(2)\mu_B$ at 1.4 K[14]. Applying pressure to CeRhIn₅ or doping it with Ir on the Rh site has only a small effect on T_N until the material becomes a superconductor[1,8,15]. We have found with neutron diffraction measurements that the suppression of the antiferromagnetic phase by Ir doping is through progressive reduction of the staggered moment of the incommensurate magnetic spiral[16]. Here we report the effect of pressure on magnetic structure of CeRhIn₅.

2 Experiments and Results

High pressure neutron diffraction experiments were performed at NIST using the thermal triple-axis spectrometer BT2 in a two-axis mode. To reduce neutron absorption by In and Rh, neutrons of incident energy $E = 35$ meV were selected using the (002) reflection of a pyrolytic graphite (PG) monochromator. A PG filter of 5 cm thickness was inserted in the incident neutron beam to remove higher order neutrons. The horizontal collimations were 60-40-40.

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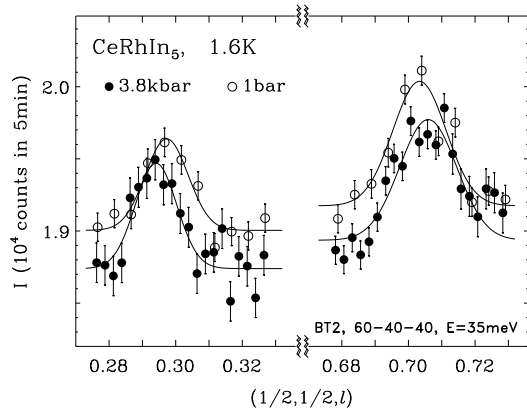


Fig. 1 Elastic scan through a pair of magnetic Bragg points at 1.6 K and under pressure of 3.8 kbar (solid circles) and 1 bar (open circles).

The pressure cell[17] was made of a BeCu alloy, Berylco 25. The cell body is a cylinder with outer diameter 1/2 inch and inner diameter 1/8 inch. Helium was used as the pressure transmitting medium and was compressed into the pressure cell through a stainless steel capillary. The pressure in the cell was monitored by a manganin resistance gauge and by measuring the lattice constant of graphite in the cell. During the experiment at 3.8 kbar, pressure decreased 0.04 kbar due to small He leaks.

The single crystal sample of CeRhIn₅ was grown from an In flux. It was cut to a rectangular bar to fit inside the pressure cell so that the axis of the cell was parallel to the (1, -1, 0) crystal orientation. The neutron scattering plane was the (*hhl*) plane. The pressure cell was mounted on the cold finger of a top loading, pumped He cryostat.

Solid circles in Fig. 1 show a pair of magnetic Bragg peaks in a Brillouin zone, measured at 3.8 kbar. No other peaks were found along the (1/2, 1/2, *l*) line in a search from (1/2, 1/2, 0) to (1/2, 1/2, 1). Compared to data measured at 1 bar (see open circles), it is clear that the period of the incommensurate spiral increases with pressure. The magnetic wave vector, (1/2, 1/2, δ), changes from $\delta = 0.297(1)$ [4] at ambient pressure to 0.294(1) at 3.8 kbar. Intensities of the magnetic Bragg peaks at the two pressures, however, remain the same within the error bars. The staggered moment is determined to be 0.37(4) μ_B per Ce ion by comparing magnetic Bragg intensities of the 3.8 kbar and 1 bar measurements.

The intensity of the (1/2, 1/2, 0.706) magnetic Bragg peak is shown in Fig. 2 as the square of the order parameter of the magnetic phase transition at 3.8 kbar. The Néel temperature changes little, which is consistent with bulk and NQR measurements[1, 8]. However, the intensity increases more rapidly below T_N under pressure as compared to the ambient pressure result.

Mito and co-workers recently reported a linear reduction with pressure of the internal field at the In(1) site

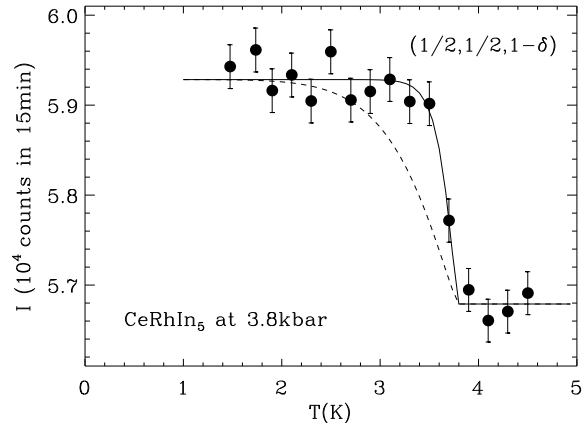


Fig. 2 Temperature dependence of the (1/2, 1/2, 0.706) magnetic Bragg peak of CeRhIn₅ under 3.8 kbar pressure. The solid line is a guide to the eyes, and the dashed line represents the square of the order-parameter curve at 1 bar[4].

in an NQR study on CeRhIn₅[8]. They suggested that either the staggered moment decreased with pressure or the moment tilted progressively towards the *c*-axis when pressure was raised to the critical pressure of 16.3 kbar. The former explanation would imply a $\sim 25\%$ reduction of the staggered moment at 3.8 kbar and is not consistent with our data. The latter explanation may lead to extra magnetic Bragg peaks characterized by a wave vector (1/2, 1/2, 0) or (1/2, 1/2, 1/2), which we do not observe in our work. One possibility is that the hyperfine interaction at the In(1) site may be sensitive to pressure.

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