Experimental report

23/02/2018

Proposal: **4-01-1538** **Council:** 10/2016

Title: Anomalous spin susceptibility due to spin-orbit coupling

Research area: Physics

This proposal is a new proposal

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Samples: $CePt_3Si$

Instrument	Requested days	Allocated days	From	To
THALES	7	0		
IN12	7	7	01/03/2017	08/03/2017

Abstract:

We propose to test the theoretical prediction that the c-axis spin susceptibility in a tetragonal metal depends on the relative orientation between an applied magnetic field in the a-b plane and a wave vector also in the a-b plane. The effect arises due to peculiarities of the spin-orbit coupling in a two-band metal, and can be measured using field-projected polarization analysis on a cold triple axis spectrometer equipped with a horizontal magnet.

The spin-orbit interaction may give rise to unexpected "symmetry-breaking" effects in metals. This is in particular true for metals without inversion symmetry [1–3], where the spin-orbit coupling becomes antisymmetric of so-called Rashba type, $\boldsymbol{\gamma}(\mathbf{k}) = -\boldsymbol{\gamma}(-\mathbf{k})$ [4]. This splits the Fermi surface and removes the spin degeneracy of the electronic states. A surprising theoretical prediction was that in a noncentrosymmetric tetragonal metal, the spin susceptibility $\chi_{aa}(\mathbf{q})$ would be different from $\chi_{bb}(\mathbf{q})$ for a wave vector $\mathbf{q}$ along the crystallographic a axis [5]. In other words, a finite wave vector $\mathbf{q}$ "breaks" the tetragonal symmetry of the crystal. This effect was recently demonstrated in the noncentrosymmetric heavy-fermion superconductor $CePt_3Si$ by polarized inelastic neutron scattering on a single crystal [6].

However, even centrosymmetric metals may show unusual effects due to the spin-orbit coupling. It was recently predicted that the ordinary spin-orbit coupling in a two-band model also "breaks" the tetragonal symmetry in the presence of a magnetic field in the basal plane $\mathbf{H}_{ab}$ [7,8]. Specifically, it was shown that for a wave vector $\mathbf{q}_{ab}$ in the tetragonal base plane, the spin susceptibility along the tetragonal axis, $\chi_{cc}(\mathbf{q}_{ab})$, would depend on the relative direction of $\mathbf{H}_{ab}$ and $\mathbf{q}_{ab}$, i.e. $\chi_{cc}(\mathbf{q}_{ab} \parallel \mathbf{H}_{ab}) \neq \chi_{cc}(\mathbf{q}_{ab} \perp \mathbf{H}_{ab})$. The derivation in [7,8] was made for a system with inversion symmetry, but the extra term arising in the free energy for noncentrosymmetric systems does not change the final expression for the magnetic susceptibility using the same assumptions [9].

To test this prediction, we have chosen the noncentrosymmetric tetragonal heavy-fermion superconductor $CePt_3Si$ [10,11], for which large single crystals can be grown. The crystal-field ground state doublet is well separated from the first excited doublet, as shown by a combination of polarization-dependent soft x-ray absorption spectroscopy and polarized inelastic neutron scattering on single crystals [12]. The exchange interactions are dominantly antiferromagnetic as shown by the Curie-Weiss temperature, $\theta_{\rm CW} = -45$ K [10,11]. Long-range antiferromagnetic order is observed below $T_N \approx 2.2$ K with a propagation vector $\mathbf{k} = (0, 0, ^1\!/_2)$ [10,13–15], and mixed singlet-triplet superconductivity below $T_c \approx 0.7$ K. The magnetic excitations have been extensively studied by inelastic neutron scattering on single crystals in all three phases: in the superconducting antiferromagnetically ordered phase, in the normal conducting antiferromagnetically ordered phase, and in the paramagnetic phase up to temperatures of $10\,T_N$ [14]. The large value of the linear term in the specific heat, $\gamma = 390$ mJK^{-2}mole^{-1}, shows that heavy quasiparticles are formed due to the hybridization of the near-local $4f^1$-band electrons with the conduction electrons, resulting in a Kondo temperature of $T_K \approx 10$ K. This hybridization implies that there are two bands in $CePt_3Si$, a requisite for the observation of the predicted effect.

Using polarized neutrons and polarization analysis on IN12, we measured the spin susceptibility along the tetragonal axis of a large 6-g single crystal of $CePt_3Si$ with a magnetic field $\mathbf{H}$ applied in the tetragonal basal plane, using the HM3 horizontal cryomagnet. The measurements were performed in the non-superconducting "paramagnetic" phase at $T = 5$ K. The spin flipper in the incident beam was sufficiently far from the magnet that measurements could be performed up to $H = 4.5$ T. The spin flipper mounted in the scattered beam was too close to the magnet and stopped working already at $H = 0.5$ T. Fortunately, only one flipper was required for the measurements. The quite restrictive geometry of the HM3 magnet with its four 45°-wide accessible sectors lead to that a final wave vector of $k_f = 2.25$ Å^{-1} was used. Unfortunately, no difference between the magnetic response for the wave vector $\mathbf{q}$ parallel or perpendicular to the field $\mathbf{H}$ was observed, see figure 1. One reason may be that the signal is too weak in the used geometry, as the magnetic susceptibility is probed at $q_l = 0$, whereas the magnetic correlations are antiferromagnetic and hence largest for half-integer q_l.

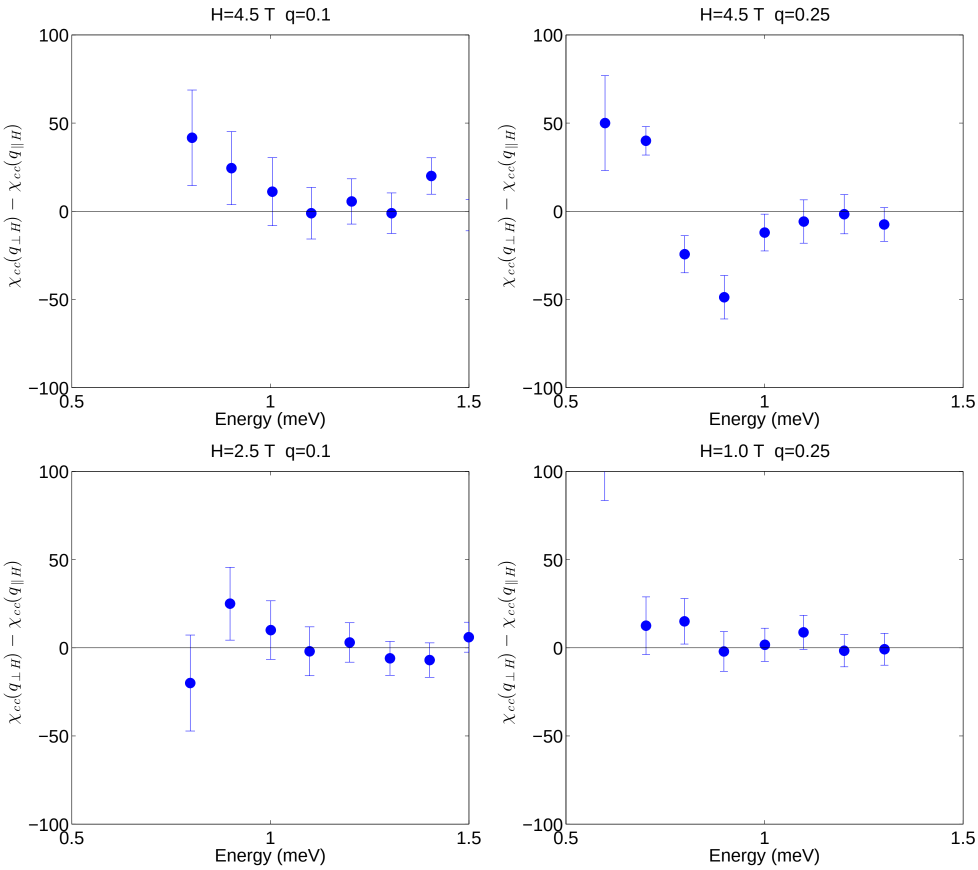

Fig. 1: Wave-vector anisotropy of the dynamic magnetic c-axis susceptibility of $CePt_3Si$ at $T = 5$ K for different magnetic fields H and wave vectors q.

References

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