Experimental report

17/10/2019

Proposal: **4-01-1624** **Council:** 4/2019

Title: Probing g-factor anisotropy in CeB6 by neutron scattering

Research area: Physics

This proposal is a continuation of 4-01-1583

Main proposer: **Pavlo PORTNICHENKO**

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Local contacts: Alexandre IVANOV

Samples: CeB6

Instrument	Requested days	Allocated days	From	To
IN12	4	0		
THALES	4	7	09/09/2019	13/09/2019
			20/09/2019	23/09/2019
IN3	1	1	23/09/2019	24/09/2019

Abstract:

CeB6 is a HF metal characterized by the rich magnetic-field-temperature phase diagram. Sharp resonant mode was revealed below TN at the propagation wave vector of the AFQ phase, and a strong FM mode at the zone center was discovered later. We measured magnetic field dependence of the FM resonance with the field applied parallel to [1 1 0], [1 1 1], [1 1 2] and [001]. Branches have a very clear anisotropy with respect to the field direction. We observed the onset of the second branch for fields parallel to [110] above 12T. For the magnetic field along [001] the second resonance can be clearly resolved already above 4T. In order to measure full field dependence of the lower energy resonance, which we were unable to resolve with the 15T magnet at FLEXX, we did a separate experiment at 4F2. Surprisingly, results from different instruments show some discrepancy, especially evident for the second mode. By now we have accumulated a large amount of data that we are preparing to publish. In this proposal we would like to complement already available dataset for the magnetic field along [001] with the field dependence of the resonances using the 10T magnet at IN12 or Thales.

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Introduction

CeB_6 is a heavy-fermion metal characterized by the rich magnetic-field–temperature phase diagram. In zero field, it exhibits a high-temperature paramagnetic phase I; an AFQ phase II at intermediate temperatures between T_N=2.3 K and T_Q=3.2 K [1]; and an AFM ground-state phase III below T_N. The AFQ state in CeB_6 has been extensively studied as it represents an example of a magnetically hidden order [1–3]. Sharp resonant mode was initially revealed below T_N at the propagation wave vector of the AFQ phase [4], and a strong FM mode in the magnetic excitation spectrum of CeB_6 at the zone center Γ was discovered later [5]. We have measured magnetic field dependence of the FM resonance at different instruments with the field applied parallel to $[1\bar{1}0]$,$[1\bar{1}1]$, $[1\bar{1}2]$ and [001]. Our neutron results show significant difference of the resonance energy upon change of the field direction. We managed to observe the onset of the second branch for fields parallel to $[1\bar{1}0]$ above ~ 12 T, as shown in fig. 1, as well as for the magnetic field along [001], where the second resonance can be clearly resolved already above 4 T. In order to measure the field dependence of both excitations over a full range of available fields we had to repeat measurement with different magnets, as our assumption was that the lower energy excitation can not be resolved due to enormously broad elastic line in 15 T magnet. We did a separate experiment at 4f2, which allowed us to identify the strongest lower energy excitation, however showed some discrepancy evident for the second mode. In order to clarify observed mismatch we decided to repeat the measurement with the different type of magnet at Thales.

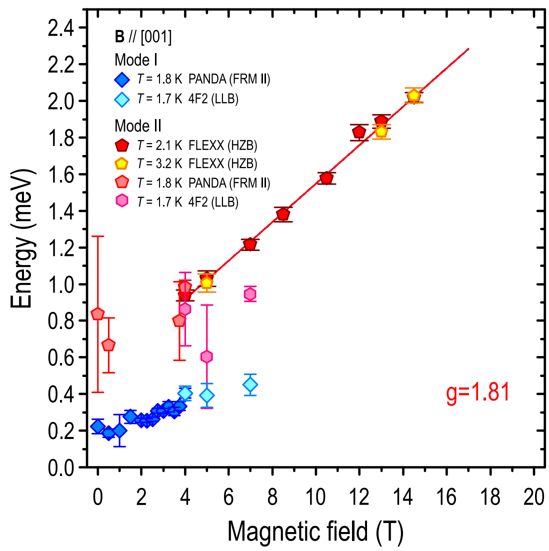

Fig. 1: Summary of the magnetic field dependence measured with neutrons for the magnetic field aligned parallel to [001].

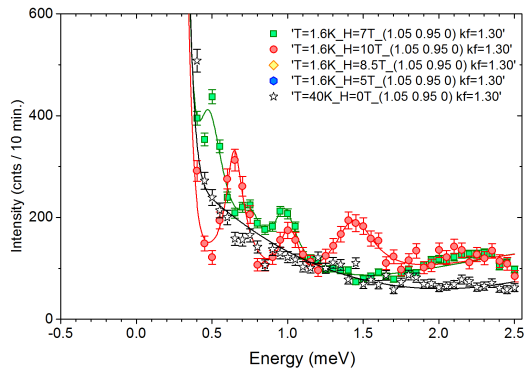

Fig. 2: INS spectra measured near the zone center at a slightly incommensurate wave vector using 10 T magnet.

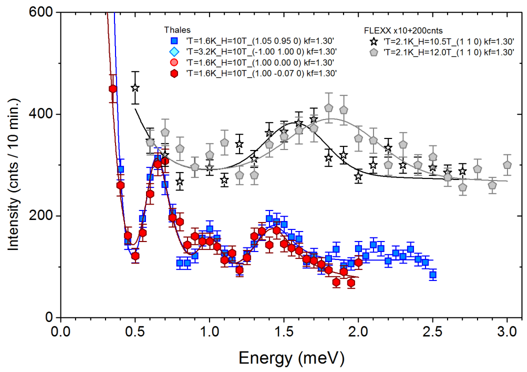

Fig. 3: Comparison of INS spectra measured at FLEXX and Thales.

Experimental configuration

Measurements were performed on single-crystalline sample of CeB_6 with a mass of 4 gram, prepared from 99.6 % isotopically enriched ^{11}B to minimize neutron absorption. The sample was mounted in the cryomagnet with a maximal field of $B = 10$ T with its crystallographic [001] axis aligned vertically. Using the published lattice parameters $a = b = c = 4.14$ Å, $\alpha = \beta = \gamma = 90°$ and measured in-plane reflections we aligned on the most intense (110) reflections. The resulting scattering plane was ($HK0$). The measurements were performed with a Be-filter. Both monochromator and analyzer were in the focusing mode. The wave vector of the scattered neutrons k_f was fixed to $k_f = 1.3$ Å^{-1}.

Results

As the first step we tried to repeat the 7 T scan, in order to check the resonance energy, obtained from our previous experiments at FLEXX and 4f2. Measured value was significantly different from the one from FLEXX. In addition we observed additional excitation. To confirm the magnetic nature of all three excitations we measured 40 K scan at 0 T and used it as a background. As shown in fig. 2, background at a chosen wave vector is smooth, thus all three excitations have a magnetic origin.

Surprisingly the excitation with the lowest energy was strongest, unlike in our previous experiment at FLEXX. Direct comparison of the results measured at FLEXX and Thales and shown in fig. 3 suggests that the low energy excitation can be easily resolved at high field, even when measurements are done in 15 T magnet, which known to have broader elastic line when compared with other magnets. We asked for additional time, to measure the same sample at Thales with 15 T magnet. We were generously given 3 additional days with the 15 T magnet.

Discrepancy between different instruments

In addition to the obvious difference, that we used different magnets, we realized that during FLEXX experiment we increased magnetic field to 8.5 T and 14.5 T immediately. Although to the best of our knowledge there are no phase transitions above 10 T, except predicted ordering of O_2^0 quadrupole, unlike O_2^2 or O_{xy} which is responsible for the low field AFQ phase [2]. To check this we programmed same scans at 13.5 T and 7 T (unfortunately lambda stage did not work properly and we decided to switch it off).

After repeating scans at high field we got exactly same result as previously at FLEXX. As shown in fig. 4 there is no evidence of the lower energy excitation, and the energy of the only observable resonance is significantly different from the one measured with 10 T magnet but matches perfectly one obtained at FLEXX. It is known that after cycling the magnetic field to maximum value and back to zero, a finite residual field will be present at a sample area. After ramping the magnetic field back to zero I realized that I can not find that AFM Bragg reflection. I could easily feel the residual field of the magnet, but its strength was too week to suppress the AFM phase. I also failed in my attempts to find structural (110) Bragg reflection, but I immediately found (100). Since the crystal was mounted in a way that it could rotate along one of (100) or (010) crystallographic directions, it became clear that the sample simply turned. There is no doubt that after I removed the sample I realized that the sample was ca. 30° off from its original orientation. Unfortunately, it remains unclear at which point the sample rotated and why this did not happen when we used 10 T magnet.

To answer this question we realigned the sample once again and measured (110) Bragg reflection as a function of field and temperature. At a first stage we cooled down the sample to 1.7 K and started to increase field strength. Intensity disappeared abruptly around 8 T, as shown in fig. 5. We also did field cooling, in order to check if the sample rotates upon entering AFQ phase. As shown in fig. 6, upon crossover from the paramagnetic to AFQ phase around 8 K peak intensity shows gradual increase, but just as with the case of field dependence disappeared abruptly around 4 K.

These results show that the data, measured at FLEXX experiment was actually obtained in a wrong orientation. Single excitation, which was assumed to be the higher energy mode II, actually was the strongest excitation measured for the field applied along [110] significantly further from the commensurate Bragg reflection. As a last step to prove this we measured inelastic scan at 7 T, slightly below the field value at which sample changes its orientation, with different field history. In the first case, shown with red square markers in fig. 7, we increased the field from 0 T to 7 T immediately after appropriate sample alinement and cooling. We can clearly resolve three excitations, similar to results obtained with 10 T magnet. On the other hand, after we increased field strength to its maximum value, and afterwards going back to 7 T as expected we observe only one excitation. The fact that in 10 T magnet sample does not rotate even at highest field requires further clarification.

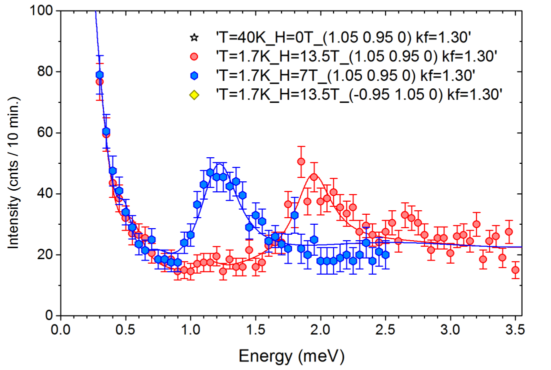

Fig. 4: INS spectra measured near the zone center at a slightly incommensurate wave vector using 15 T magnet.

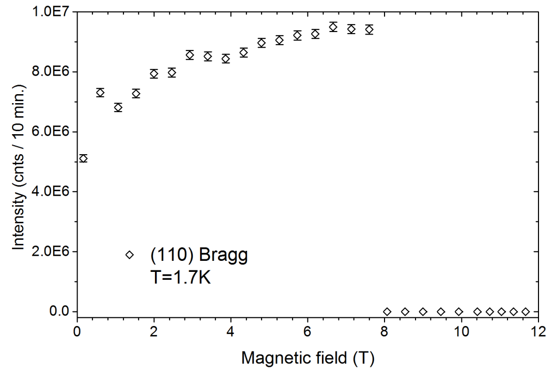

Fig. 5: Magnetic field dependence of the structural (110) Bragg reflection measured at a base temperature.

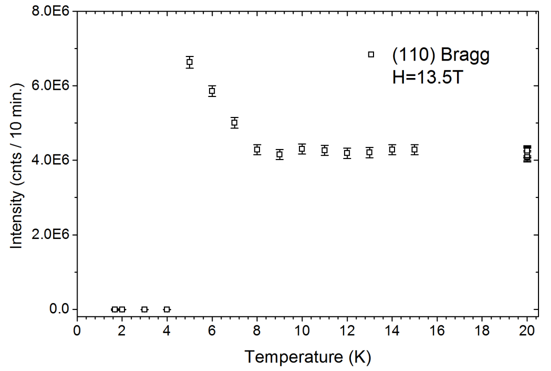

Fig. 6: Temperature dependence of the structural (110) Bragg reflection measured at 13.5 T.

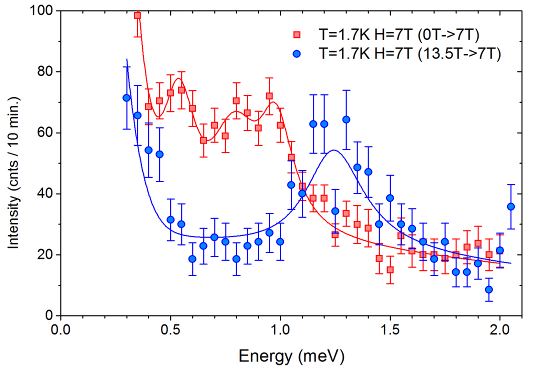

Fig. 7: INS spectra measured near the zone center at 7 T with different field history, as indicated at the legend.

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[3] H. Kusunose and Y. Kuramoto, JPSJ **70**, 1751 (2001).
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[5] H. Jang *et al.*, Nature Mater. **13**, 682 (2014).
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