Experimental report

12/10/2022

Proposal:	**5-41-1035**	**Council:**	4/2019

Title: Study of an incommensurate field-induced magnetic phase in hidden-order system U(Ru0.98Rh0.02)2Si2

Research area: Physics

This proposal is a continuation of 5-41-954

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Samples: U(Ru0.98Rh0.02)2Si2

Instrument	Requested days	Allocated days	From	To
IN22	8	8	20/01/2020	28/01/2020

Abstract:

Recently we have completed experiment 5-41-954: the high-field neutron diffraction in pulsed fields up to 40 T on a 2% Rh-doped URu2Si2. This study revealed that the field-induced phases have propagation vector Q = (0.63 0 ±δ) with δ very small. This result is in contrast to both the pure system and higher Rh-doping levels, where propagation vector q1 = (0.6 0 0) and q3 = (0.667 0 0) are found and suggests that a multi-k structure may be realized in high fields. The change in the propagation vector may be linked to modifications of the Fermi surface. The decrease of the intensity above 35.3 T (from the phase II to phase III (see Fig. 4 of the proposal) suggests a change in the δ value. Due to a short wavelength necessary to reach other Bragg reflections we were limited by the resolution of the instrument. In this proposal we wish to determine the value of δ for both phases II and III. We also suggest to study the field induced phase(s) at higher temperature, namely around 10 K, where the hidden order is dominant in this system. We ask for 8 days of beamtime at IN22.

The pristine system, URu_2Si_2, has been examined intensively over last years. The rich phase diagram includes superconductivity, non-Fermi liquid behavior, unknown Hidden Order (HO) and multiple high magnetic field phases appearing at high magnetic fields [1-3]. Thanks to a dedicated cryomagnet (developed by the LNCMI-Toulouse, the CEA-Grenoble, and the ILL-Grenoble) allowing neutron diffraction in pulsed fields up to 40 T, the magnetic structure of URu_2Si_2 in fields between 35 and 39 T has been determined [4]. In the pristine system the field-induced phase has propagation vector k_1 = (0.6 0 0) in contrast to Rh-doped systems with 4 and 8 % Rh, where propagation vector k_2 = (2/3 0 0) is found [5,6]. Immediate question arises whether the change in k is connected with the disappearance of the so-called hidden order (HO) in the pure systems. The main subject of this follow-up experiment was to disclose details of field-induced magnetic phases of the 2%Rh-doped URu_2Si_2 that exhibits still a presence of the HO state.

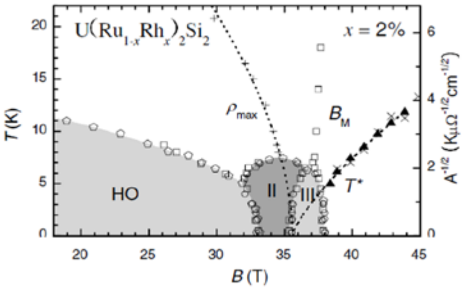

Fig. 1: Detail of the high-magnetic-field phase diagram for the 2% Rh-doped URu_2Si_2.

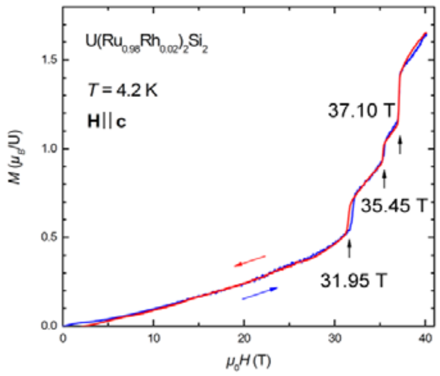

Fig. 2: Field dependence of the magnetization of the 2% Rh-doped URu_2Si_2 measured with field applied along the c axis.

In the previous experiment 5-41-954, the 0.7g heavy 2% Rh-doped URu_2Si_2 single crystal was studied with the incident neutrons of wavelength λ = 1.10 Å. The complicated H-T phase diagram [1] of the pristine compound has been found to be slightly modified (Fig. 1), in particular the critical fields of metamagnetic transitions are found at μ_0H_1 = 31.95/31.55 T, μ_0H_2 = 35.45 / 35.30 T (rising / falling fields), and μ_0H_3 = 37.1 T, respectively (Fig. 2). The state above 37.1 T is field-polarized state. The main result of this study was that the propagation vector Q = (0.63 0 0) of the first field-induced phase between μ_0H_1 and μ_0H_2 lie exactly between propagation vector found for the pure and 4% Rh doped systems. In the case of the second field-induced phase we have encountered history-dependent phenomena and could not conclude whether the propagation vector develops a c-axis component. Therefore we have proposed an experiment with an improved resolution.

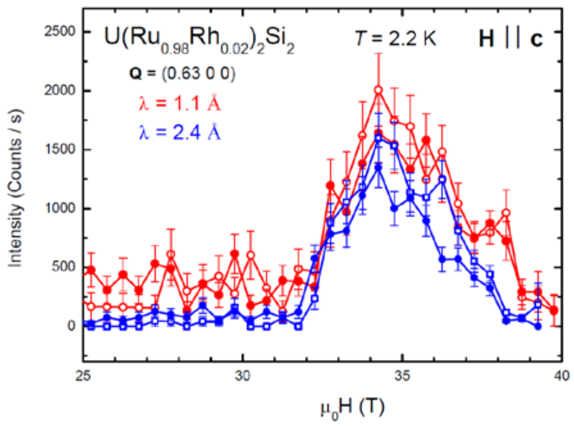

Fig. 3: Field dependences of the diffracted intensities at the Q = (0.63 0 0) position with increasing (open points) and deceasing fields as recorded with the incident wavelength of λ = 1.1 Å (red) and λ = 2.4 Å, respectively.

The neutron diffraction experiment was carried out on the very same sample using the triple-axis spectrometer IN22 (CRG-CEA at the ILL) operated in a double-axis mode. Incident neutrons of wavelength λ = 2.4 Å were selected using a pyrolytic graphite (PG) monochromator. The field pulses were produced every ~ 7-8 minutes by discharging ~ 1 MJ capacitor banks to a nitrogen cooled conical solenoid magnet. The crystal has been glued to a sapphire holder in the (h 0 l) plane, with field nearly along the tetragonal axis of the sample.

During the experiment we have concentrated mainly on measurements at base temperature of 2.2 K. In Fig. 3 we show a comparison between data obtained in the previous experiment with λ = 1.1 Å (with lower resolution) and current experiment with λ = 2.4 Å. As can be seen, both experimental data sets compare well but the latter experiment lead to lower background signal and hence better signal to noise ratio.

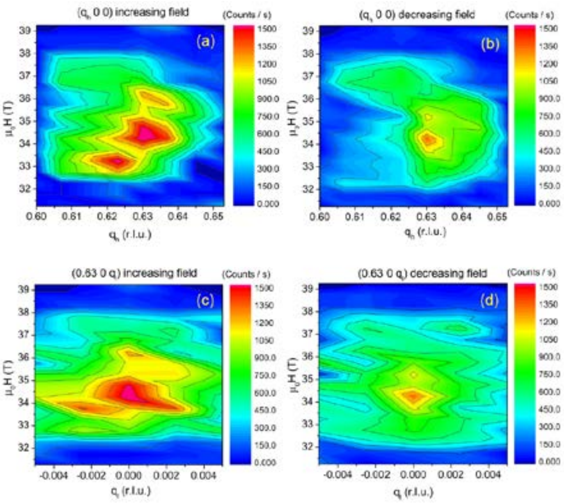

Fig. 4: Field dependencies of the diffracted intensities at various reciprocal positions in false colors obtained during experiment with λ = 2.4 Å. Panels (a) and (b) show data at (Qh 0 0) positions, panels (c) and (d) data obtained at Q= (0.63 0 Ql) positions with increasing and decreasing fields, respectively.

We have performed an excessive search for magnetic, field-induced diffracted signal around Q = (0.63 0 0) position. Results are summarized in Fig. 4. Note that the signal is not resolution limited and appears to be wider. As can be seen, the maximum is found at Q = (0.63 0 0). This holds for both field induced phases. However, a clear decrease of the diffracted intensity at Q = (0.63 0 0) for fields between μ_0H_2 and μ_0H_3 is observed. Based on the data obtained in the previous experiment we have speculated that this magnetic structure has a propagation vector with a small transverse component along the c-axis direction. Current data do not support this speculation.

The determination of actual field-induced magnetic structures is difficult due to low number of observed magnetic reflections, even if we combine both experiments. For fields above μ_0H_3, i.e. in the case of the field polarized phase, we observe additional intensity at the top of the (101) reflection. Assuming equal moments on the two magnetic sites, we arrive to a ferromagnetic alignment of U moments of 1.8 (0.2) μ_B directed along the c axis, in agreement with magnetization data.

In the case of the other two field induced phases, due to absence of diffracted signal at positions of the second and third higher harmonics it is clear that both field induced phases are of a sine-wave modulated type. Symmetry analysis suggests that the two U sites are decoupled and U moments can be oriented either along the c axis or perpendicular to it. The phase shift between the two sites plays, however, a decisive role in the determination of the moment magnitude. At this moment we cannot exclude neither a model involving two single-Q domains nor a double-Q magnetic structure. In both cases U moments would be directed along the c axis and modulated within the basal plane having a small ferromagnetic component along the tetragonal axis. The respective components would be different for different models and field-induced phases. The transition across μ_0H_2, could be either due to repopulation of the two single-Q domians, due to change in the phase shift between the two U sites or due to transition from a single-Q towards a double-Q magnetic structure.

References

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