EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office using the **Electronic Report Submission Application:**

http://193.49.43.2:8080/smis/servlet/UserUtils?start

Reports supporting requests for additional beam time

Reports can now be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** **Double-q charge density wave in $CeAl_2$**	**Experiment number**: HE1825
Beamline: ID20	**Date of experiment**: from: 10/02/2005 to: 15/02/2005	**Date of report**: 13/02/2006
Shifts: 18	**Local contact(s)**: Carsten DETLEFS	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Anne STUNAULT

Jacques SCHWEIZER

Françoise GIVORD

Report:

The Kondo compound $CeAl_2$ crystallizes in the cubic Laves phase $MgCu_2$, in which the Ce site has two atomic positions in the asymetric unit cell (Ce_I and Ce_{II}), as the carbon atoms in the diamond structure. Its magnetic structure, below T_N = 3.8K, is caracterized by a propagation vector **k**=(1/2+δ, 1/2-δ, 1/2), a propagation vector in two parts: an antiferromagnetic part (1/2, 1/2, 1/2) and a modulation part (δ, -δ, 0). This structure was first described by a single **k** propagation vector, an antiferromagnetic modulated structure. It has then been shown that the structure is double **k**, with 2 propagation vectors, $\mathbf{k_1}$=(1/2+δ, 1/2-δ, 1/2) and $\mathbf{k_2}$=(1/2+δ, 1/2-δ, -1/2), which share the modulation part (δ, -δ, 0), but with different directions for the antiferromagnetic propagation: (1/2, 1/2, 1/2) and (1/2, 1/2, -1/2). Such a double **k** structure corresponds for the two Ce sites of the asymmetric unit cell to two helices with opposite chiralities. These helices are elliptic, which means that some magnetic moments are reduced compared to the others (the Kondo effect).

We have used the synchrotron radiation to search displacement waves resulting from the onset of the magnetic structure. To do that, we were guided by group theory which tells us which kind of Fourier coefficient $\mathbf{u}^\mathbf{k}$ can be expected from magneto-elastic energy terms which are quadratic in $\mathbf{m}^\mathbf{k}$ and linear in $\mathbf{u}^\mathbf{k}$. As the magnetic structure of $CeAl_2$ is double **k**, there are 3 possibilities for the displacement waves:

- the classical displacement with a propagation vector which is the double of the magnetic propagation vector: $\mathbf{k} = \pm 2\,\mathbf{k_1}$ or $\mathbf{k} = \pm 2\,\mathbf{k_2}$.

- two propagation vectors which couple the two different propagation vectors of the magnetic structure: $\mathbf{k} = \pm(\mathbf{k}_1 + \mathbf{k}_2)$ and $\mathbf{k} = \pm(\mathbf{k}_1 - \mathbf{k}_2)$.
We have found the satellites of the usual propagation vector **2k** (table I). We have also found, though one order of magnitude less intense, the satellites due to the propagation vectors $\mathbf{k}_1+\mathbf{k}_2$ (table II). But, concerning contributions corresponding to the propagation $\mathbf{k}_1-\mathbf{k}_2$, we have looked for 8 reflections (table III) which were all measured zero, except for one of them, reflection (5 0 1). Going back to the group $G_{\mathbf{k}_1-\mathbf{k}_2} = G_{(001}$, with the operators of the space group which leave the vector $\mathbf{k}_1-\mathbf{k}_2 = (0, 0, 1)$ invariant, it appears that it has no trivial representation, and therefore that no monomial of type $\mathbf{m}^{-k_1}\mathbf{m}^{k_2}\mathbf{u}^{k_1-k_2}$ can remain invariant in the operations of this group.

Here are the reflections that we have found :

Table I : $\mathbf{k} = \pm 2\mathbf{k}_1$ or $\mathbf{k} = \pm 2\mathbf{k}_2$

5+2δ	1-2δ	1	8300 c/mn
5-2δ	1+2δ	1	5016
5+2δ	1	1−2δ	750
5−2δ	1−2δ	1	75
5	1+2δ	1−2δ	540
5	1−2δ	1+2δ	50
6+2δ	2δ	-2	40
6	2δ	−2−2δ	20
6+2δ	0	−2−2δ	16
6−2δ	0	−2−2δ	0
6+2δ	2−2δ	−2	7900
6−2δ	2−2δ	−2	500
6+2δ	2	−2−2δ	1080
6	2+2δ	−2+2δ	1300

Table II : $\mathbf{k} = \pm(\mathbf{k}_1+\mathbf{k}_2)$

4	1+2δ	1+2δ	200 c/min
4	1+2δ	1-2δ	10
4+2δ	2δ	1	10
4+2δ	1	2δ	20
4+2δ	1	−2δ	60
5+2δ	1+2δ	0	0
5+2δ	1−2δ	0	150
5+2δ	0	1−2δ	10
5−2δ	1+2δ	0	55
5	2δ	−2+2δ	75
5	2δ	−2−2δ	150
5	2δ	−2δ	530
5	−2δ	2δ	620
5	2δ	2δ	300
5	−2δ	−2δ	235
6	1+2δ	−1+2δ	770

Table III : $\mathbf{k} = \pm(\mathbf{k}_1-\mathbf{k}_2)$

4	1	0	0 c/min
4	1	1	0
5	0	0	0
5	1	0	0
5	0	1	245 ± 10
5	0	-2	0
6	1	-1	0
6	2	-1	0