

# Observation of Antiferroquadrupole ordering in CeB<sub>6</sub> by using resonant X-ray scattering technique

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## Introduction

Resonant X-ray scattering (RXS) technique to observe orbital ordered states has been developed in  $3d$ -electron system. The orbital ordering of  $3d$ -electron is accompanied with atomic displacement because the electron is spread in space. Therefore, the scattering mechanism of RXS becomes a complicated problem. In  $f$ -electron system, on the other hand, orbital ordering without atomic displacement owing to electron-electron interaction exists, which is called antiferroquadrupole (AFQ) ordering, so the RXS is able to become the only experimental technique to measure the quadrupole order parameter including  $Q$ -information. CeB<sub>6</sub> has been considered a typical compound for AFQ ordering. However, the AFQ order parameter  $q_Q = (\frac{1}{2}, \frac{1}{2}, \frac{1}{2})$  under zero magnetic field had not been observed.

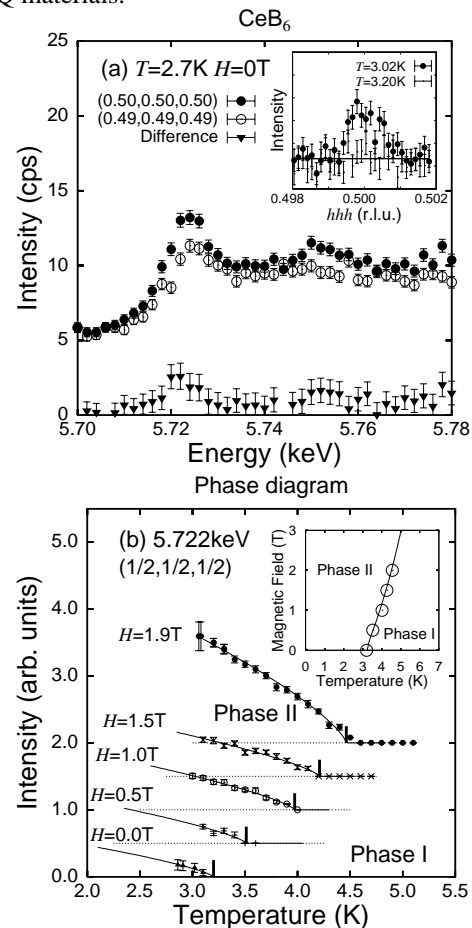
## Experiment

X-ray scattering experiments were carried out at the beamline 4C and 16A2. The incident x-ray energy is about 5.72 keV of Ce  $L_3$ -edge. A four-circle diffractometer equipped with a He-flow cryostat was used. The flow of He gas in the sample space prevent the sample surface from heating up due to the x-ray irradiation. The temperature could be decreased down to 2.5 K by He-pumping, and the magnetic field can be applied up to  $H = 2$  T with a superconduction magnet. The magnetic field was applied along the  $[11\bar{2}]$ .

## Results and Discussion

By using this RXS technique, we have succeeded to observe the order parameter at  $q_Q$  of the AFQ state for the first time [1]. Figure (a) shows the energy dependence of scattering intensities at  $q_Q$  with  $H = 0$  T and  $T = 2.7$  K. The intensity at  $(0.49, 0.49, 0.49)$  is mainly attributed to the fluorescence of the Ce ion so that we regard the intensity as the background. The difference between the two intensities is also shown in the figure. The weak signal of RXS is observed at the  $2p \rightarrow 5d$  dipole transition energy ( $\sim 5.722$  keV). The  $(hhh)$  scans of the reciprocal lattice

space at 5.722 keV are shown in the inset. The signal of RXS disappears above the transition temperature ( $T_Q$ ). The dependence of the integrated intensities on the temperature and field is summarized in fig. (b). The increase in  $T_Q$ , which is an unusual behavior of CeB<sub>6</sub>, is clearly shown in the phase diagram. This success will be crucial in the study of AFQ materials.



## References

[1] H. Nakao *et al.*, cond-mat/0106183, and references therein.

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