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ESRF	**Experiment title: Magnetic Octupole Order in $Ce_{0.7}La_{0.3}B_6$? Convergence of experiment with Theory.**	**Experiment number**: HE-1944
Beamline: XMaS	**Date of experiment**: from: 22/9/04 to: 28/9/04	**Date of report**: 1/3/05
Shifts: 18	**Local contact(s)**: Dr D. Mannix	*Received at ESRF:*

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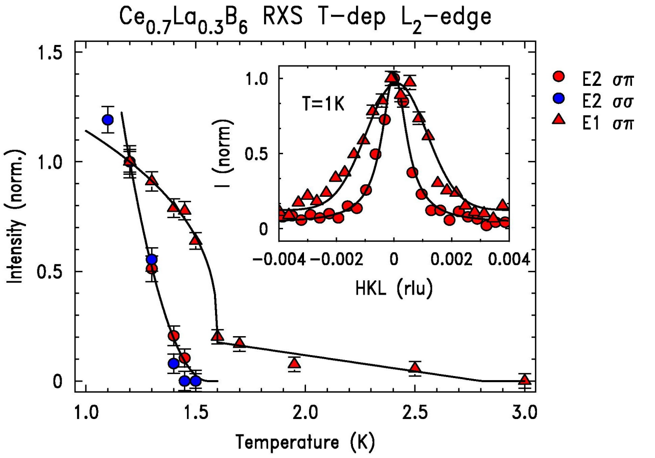
Report:

The aim of this experiment was to search for the proposed antiferro-octupole order (AFO) in Phase IV of $Ce_{0.7}La_{0.3}B_6$ [1], using Resonant X-ray Scattering (RXS). Although no direct evidence of magnetic octupole order has ever been reported, in theory, it maybe probed by RXS via E2 transitions. The RXS sensitivity arises from higher order terms in the E2 RXS described by rank-3 and rank-4 order tensors that couple to octupole and hexadecapole moments, respectively. The E1 RXS transitions contain only rank-1 and rank-2 order tensors which couple to dipole and quadrupole moments, respectively and so are insensitive to these higher order multipole degrees of freedom.

During our last experiment at XMaS, using the new ^{3}He displex with base temperature of 1K, we were successful in observing RXS at q=(½ ½ ½) positions below T_{IV}=1.4K. Unfortunately, with polarisation analysis, the measured RXS intensity was very weak, with only 0.8cts on a background of 0.02cts. Nethertheless, we succeeded in obtaining high quality data by counting 10min/data-point. It is important to emphasise that, since this is a low temperature experiment (1 K), making measurements at a higher flux insertion device beamline would not improve the situation due to the beam-heating effects. Unfortunately, the inevitable low scattering rate has severely limited the amount of data we were able to collect in the allocated time of 18 shifts.

Nevertheless, we have determined the temperature and azimuthal dependence of the intensity in both the σσ and σπ polarisations for both of the E1 and E2 RXS energy regimes. The temperature dependence is shown in figure 1. The E2 σσ (blue circles) and σπ (red circles) disappear above T_{IV}=1.5K as expected. In contrast, the E1 σπ intensity (red triangles) continues in temperature up to about 3K. Moreover, the q-width of this latter scattering is much broader the that of the E2 response suggesting short range order (as shown in the inset of fig 1). These results suggest that the E1 and E2 RXS originate from physically different ordering phenomena.

The azimuth dependence of E1 and E2 scattering is compared in figure 2. The E1 intensity occurs only in $\sigma\pi$ polarisation. This is consistent with antiferromagnetic dipole order of the 5*d* states. The broad q-width of the E1 which suggests short range ordered magnetic domains is consistent with the approximately flat E1 $\sigma\pi$ azimuth dependence (see figure 2), however this may also arise from a moment aligned along <111>. The E2 azimuth dependence is dramatically different. The E2 $\sigma\sigma$ has six-fold symmetry and the $\sigma\pi$ has 3-fold azimuthal symmetry. An analysis has been able to connect the 6-fold σ-σ azimuth with a rank-3 order tensor in the E2 RXS cross-section, giving direct confirmation of octupole order in phase IV of $Ce_{0.7}La_{0.3}B_6$. However, and this is a crucial point, the phase of the concomitant 3-fold σ-π scattering is 30 degrees away from the measured curve, i.e. with a point of inflection at $\Phi = 0$. *This enigma remains to be understood*. We note that hexadecapole order yields 6-fold symmetry in both channels. Concerning the E1 and E2 temperature dependencies, the fits in figure 1 are to the order parameters $I=|t|^{2\beta}$ with $\beta(E2)=3*\beta(E1)$, which may be expected for E1 dipole magnetic and E2 octupole magnetic order. Thus a satisfactory understanding of the physical state in $Ce_{0.7}La_{0.3}B_6$ still eludes us. In the models considered, a key feature is that the σ-π azimuth dependence is not symmetric about phi=0. Thus it is critical to obtain more data in our studies of this important prototype of strongly correlated electronic phases.



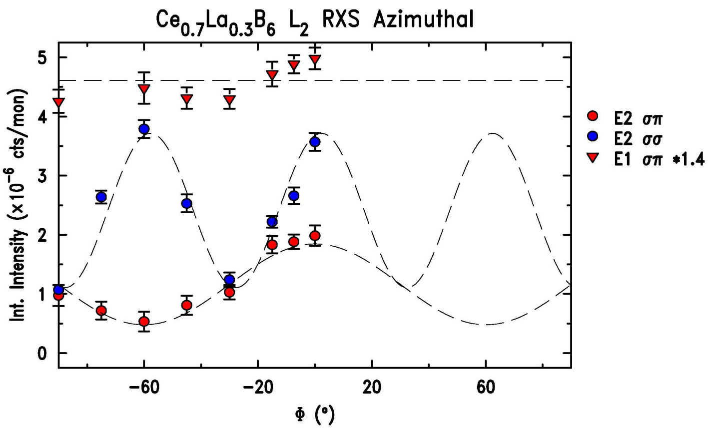


Figure 1. Left. The temperature dependence of the (3/2 3/2 3/2) reflection. The blue (red) circles represent the E2 $\sigma\sigma$ ($\sigma\pi$) intensities and the red triangles represent the E1 $\sigma\pi$ intensities. The E2 RXS disappear at T_{IV}=1.5K as expected. However, the E1 $\sigma\pi$ intensities continue up to 3K. Moreover, there is a considerable difference in q-width between E2 and E1 $\sigma\pi$ intensities as shown in the inset. This suggests that the E1 RXS arises from short range order. Figure 1 exhibits that E1 and E2 are spatially and thermally different, i.e. of different physical origin.

Figure 2 Right. The azimuth dependence. The E1 $\sigma\pi$ azimuth is essentially featureless. This is consistent with short range ordered domains on 5*d* antiferromagnetic order and/or a moment along <111>. The E2 $\sigma\pi$ has 3-fold azimuthal symmetry and the E2 $\sigma\sigma$ has 6-fold symmetry as indicated by the dashed eye-line guides. Whilst our analysis connects the 6-fold σ-σ azimuth with octupole order in phase IV of $Ce_{0.7}La_{0.3}B_6$, the calculated phase of the concomitant 3-fold σ-π scattering is 30 degrees away from the measured curve, i.e. with a point of inflection at $\Phi = 0$. *This enigma remains to be understood.*

References

[1] K. Kubo and Y. Kuromoto. J. Phys. Soc. Japan **73** 216 (2004).