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Geometrical frustration of quadrupolar moments in DyB_4

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Introduction

A tetragonal rare-earth compound DyB_4 has been attracting growing interest as a system where the quadrupolar moment of Dy might be fluctuating because of the geometrical frustration. The lattice of Dy is illustrated in Fig. 1; note that this is equivalent to the Shastry-Sutherland lattice. The Dy lattice here can be regarded as a combination of square and triangular connections because the nearest neighbor (orange) and the next nearest neighbor (pink) connections have almost the same distance.

DyB_4 interestingly exhibits two phase transitons at T_{N1}=20.3 K and at T_{N2}=12.7 K. It is established by neutron powder diffraction that an antiferromagnetic order occurs at T_{N1} with magnetic moments align along the c-axis and propagate along the [100] direction. Also shown in Fig. 1 is this c-axis magnetic moment. What is intriguing is that the entropy of Rln2 still remain and that the elastic softening and absorption are enhanced for $T_{N2} < T < T_{N1}$. These results indicate that the quadrupolar degeneracy is somehow not lifted even below T_{N1}.

Results, Analysis, and Discussion

Resonant x-ray scattering experiment has been performed at BL16A2 and the (1 0 0) forbidden reflection has been investigated in detail. Only the σ-π' scattering was observed at any azimuthal angle. Azimuthal angle is defined to be zero when the c-axis is parallel to the scattering plane. Figure 2 shows the temperature dependence of the integrated intensity of the rocking scan at the E1 resonance and its half width at half maximum.

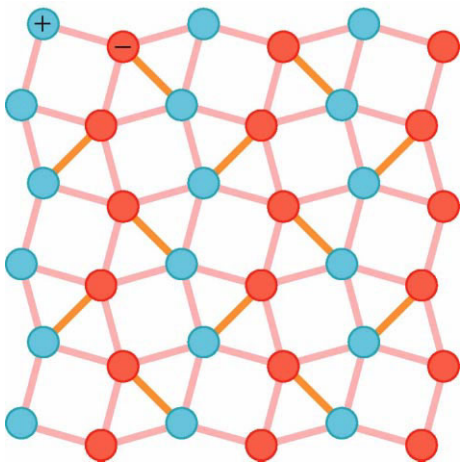

Figure 1: Lattice of Dy within the ab-plane of DyB4. Blue and red circle represent Dy with up and down spins along the c-axis, respectively.

At Ψ=0°, the intensity rises up steeply below T_{N1} and HWHM is very small though it slightly decreases with decreasing temperature. Contrastingly, at Ψ=90°, the intensity exhibits a sudden increase below TN2 and HWHM is clealy broader than the resolution limit; it also exhibits a sudden drop below T_{N2}.

A simple magnetic structure assuming only the c-axis component as shown in Fig. 1 cannot explain the nonzero intensity at Ψ=90°. It is necessary to introduce in-plane magnetic and quadrupolar components. A detailed analysis shows that the structure factor at Ψ=0° is proportional to <Jz>, whereas at Ψ=90° it is proportional to <Jx> and <Ozx>. In view of the results of ultrasonic measurements, it is likely that the quadrupolar degree of freedom plays an important role. Broad peak width at Ψ=90° indicate that the <Ozx> quadrupolar moment has short range correlation because of the geometrical frustration, whereas the <Jz> magnetic moment observed at Ψ=0° has a long range order. Elastic softening indicate that there is no static order of <Ozx>; but, it is possible to observe the short range correlation by RXS because the time scale of observation is very short. These results suggest that the <Ozx> moment is fluctuating.

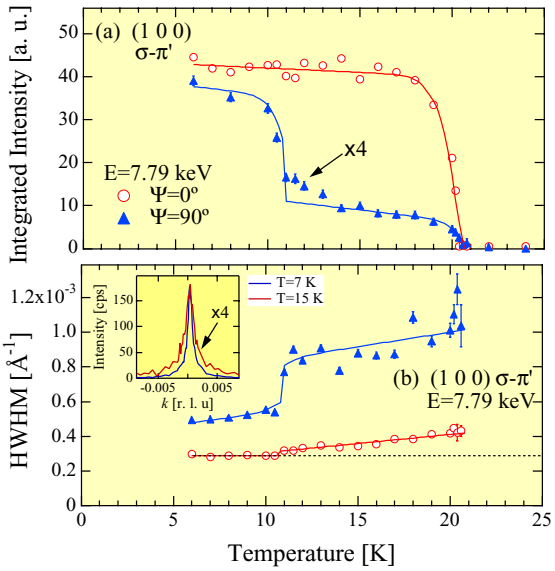

Figure 2: (top) Temperature dependence of the integrated intensity at Ψ=0° and 90°. (bottom) Half width at half maximum of the rocking scan. Inset shows the peak profile at Ψ=90°. Dotted line is the resolution limit.

References

[1] D. Okuyama et al., to be submitted.

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