ESRF	**Experiment title:** Resonant x-ray scattering study of the magneto-elastic coupling in rare earth ferroborates.	**Experiment number:** HE-3183
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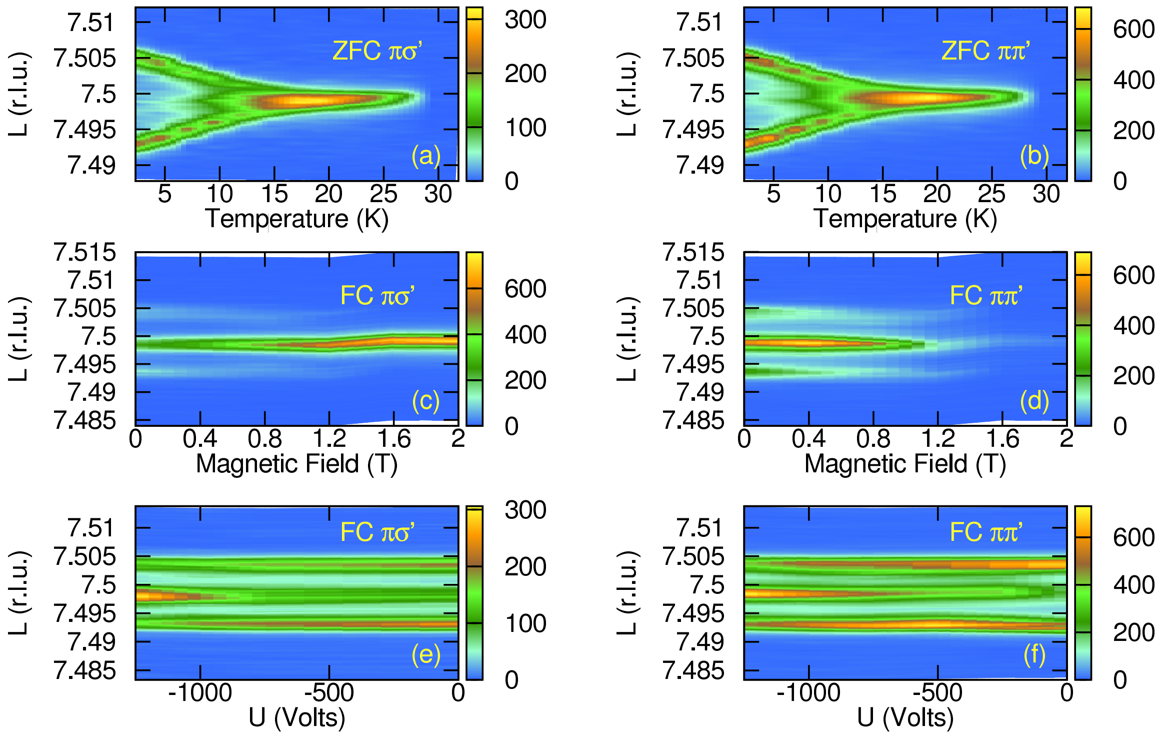
Report:

To study the magneto-electric properties of the multiferroic compound $NdFe_3(BO_3)_4$, resonant x-ray diffraction experiments at the Nd $L_{2,3}$ and Fe K edges were performed. Measurements as a function of temperature, polarization as well as applied electric and magnetic fields for several magnetic reflections with modulation vector $(0, 0, 3n/2)$.

Experiment: The experiments were performed at the Nd $L_{2,3}$ and Fe K edges using the cryomagnet available at beamline ID20. For this set-up, the scattering geometry is in the horizontal plane and the magnetic field (B) is applied in the vertical direction. Electric fields (E) with voltages up to 1500 V could be applied, by using the e-stick. The measurements were done at 2K<T<34K and both B and E fields where applied parallel to the crystallographic *a*-direction. In addition, polarization analysis of the scattered intensities was made using a Cu(220) analyzer crystal. By means of a diamond phase plate, the incoming polarization was controlled and switched between circularly right, circularly left as well as linear vertically and horizontally polarized.

Results: Some of the experimental results at the Fe K edge are summarized in the figure below. Figures (a) and (b) show the temperature dependence of the (0,0,15/2) magnetic reflection in the $\pi\sigma$' and $\pi\pi$' channels. The plots show the upraising of the magnetic peak below T_N=30K and the subsequent commensurate (CM) to incommensurate (ICM) transition at $T_{ICM} \sim$15K. Below T_{ICM} the position of the satellite peaks changes while cooling and their intensity increases. The commensurate reflection (0,0,15/2) is still present below T_{ICM}, but its intensity is rather low. Figures (c) and (d) show the intensity of the magnetic reflections at T=2K, after field cooling (CF) with B=2T, as a function of applied magnetic field. In the $\pi\sigma$' channel it can be seen that by increasing the field, the intensity of the CM peak is gradually enhanced while the satellite intensities decrease.



When a field of B=1.2T is reached, the ICM phase is totally suppressed. If we now look at the $\pi\pi$’ channel, all the intensities are gradually suppressed and at B=1.2T, no significant intensity is measured. These observations are in agreement with a spin-flop transition, where the magnetic moments flop in a direction perpendicular to the applied B, as reported in [1]. In this case, the spins are aligned in the scattering plane above B=1.2T and, therefore, the intensity in the $\pi\pi$’ channel disappears. Figures (e) and (f) show the effect of an electric field on the superlattice reflections. Similar to (c) and (d) the central peak intensity is enhanced by increasing the applied voltage, while the two satellites are suppressed. Thus, the effect of both fields on the magnetic structure seems to be similar in the sense, that both stabilize the CM phase. The position of the reflections, in neither affected by B nor by E field. Our measurements provided a good overview of the coupling between magnetism and ferroelectric order, thereby revealing an extremely rich magnetoelectric behavior, showing that resonant magnetic x-ray scattering is perfectly suited to study the magnetic structure and the magnetoelectric coupling in $NdFe_3(BO_3)_4$.

Outlook: In order to determine the CM and ICM magnetic structure of the Nd and Fe sublattices of $NdFe_3(BO_3)_4$ and to determine the spin directions and the exact periodicity in an element specic way, experiments at the Nd $L_{2,3}$ and Fe K-edge, where both the dipole and the quadrupole resonances were observed, are needed. In particular, we aim to exploit the different polarization dependence of the dipole and quadrupole resonances. This type of measurement will allow to distinguish magnetic from structural scattering; an important aspect if one is interested in the interplay of structural distortions related to the ferroelectric polarization and the spin ordering. Moreover, we further expect to obtain a complete picture of the changes in the magnetoelectric ordering induced by magnetic and electric fields. Such experiments should enable to clarify the magnetoelectric coupling in these compounds.

References:

[1] D. V. Volkov et al, JETP, **104**, (2007), 897.