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High-field re-entrance of the magnetoelectric effect in $LiNiPO_4$ investigated in pulsed fields

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Introduction

Material $LiNiPO_4$ belongs to the family of the magnetoelectric *lithium-ortho-phosphates*. The material exhibits an *XY-like behavior* and the strong *antiferromagnetic interactions* are mainly in the (b,c)-plane.

Magnetism The *magnetic phase diagram* of $LiNiPO_4$ as function of temperature and applied magnetic field along c has been thoroughly investigated up to 17.3 T in DC fields. Several different antiferromagnetic phases have been characterized [2,3].

Goal *More transitions* have been reported at *fields up to 22 T* [4] and our goal is to investigate and characterize these.

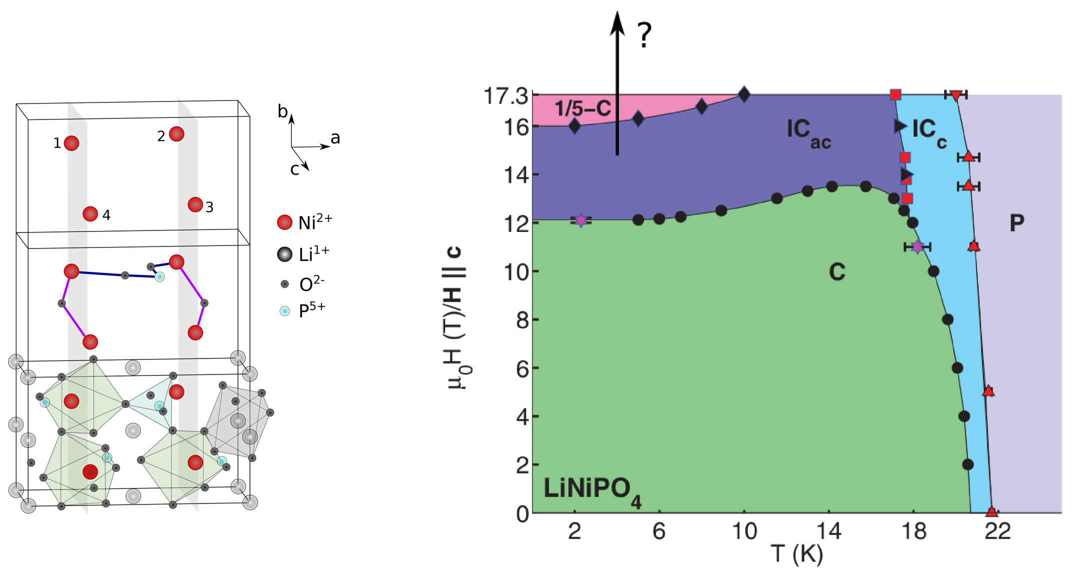

Figure 1: ***(Left)*** *Three unit cells of $LiNiPO_4$. After [1].* ***(Right)*** *The phase diagram of $LiNiPO_4$ up to 17.3 T [2]. The arrow shows where we investigated.*

Neutron Diffraction in Pulsed Fields

Pulsed magnetic fields are to date the only way to achieve magnetic fields above 17.3 T while performing a neutron experiment.

Magnet Current from a *capacitor bank* is dumped into a coil creating a magnet pulse with *maximum strength* **30 T**. The pulse duration is ∼ 5 ms and a pulse can be released every ∼ 5 min to allow the coil to *cool down* in between pulses. The magnet setup requires a special sample holder which restricts the *scattering angle* to maximum **14°**.

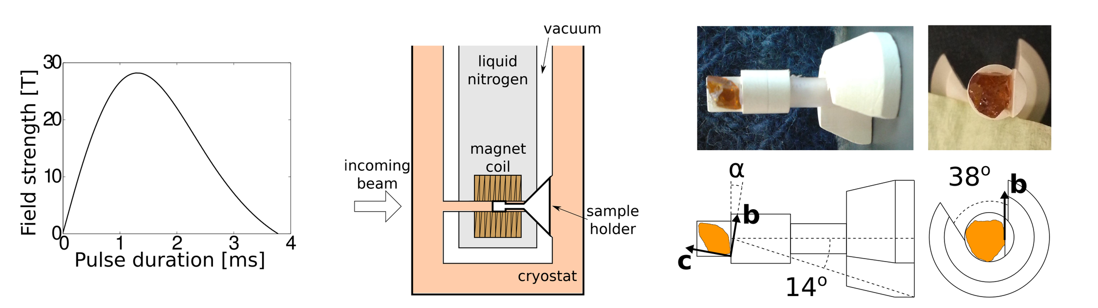

Figure 2: ***(Left)*** *Magnet pulse shape.* ***(Middle)*** *Magnet setup inside cryostat.* ***(Right)*** *Sample holder.*

Neutrons We performed at *Laue neutron diffraction* experiment with wavelengths λ = [0.2,0.7] Å. The instrument used was *SEQUOIA* at the Spallation Neutron Source at Oak Ridge National Laboratory.

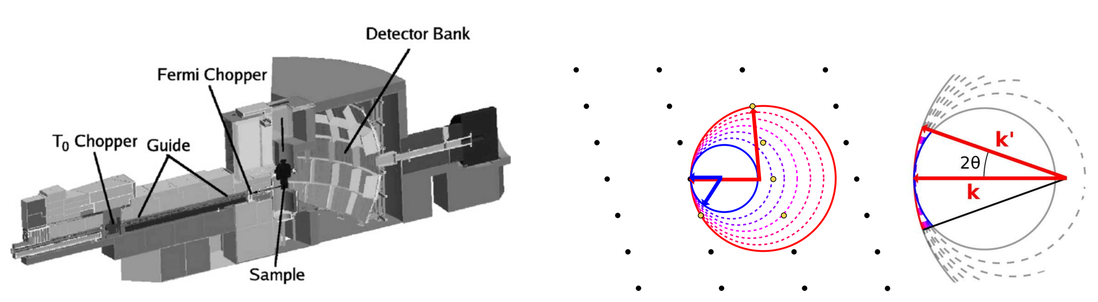

Figure 3: ***(Left)*** *The SEQUOIA instrument* ***(Right)*** *Laue diffraction, text book example and what we are actually able to see due to the 14° limit on the scattering angle.*

Re-entrance of the Linear Magnetoelectric Effect

The *magnetization* and *electric polarization* were measured in pulsed fields by T. Kihara. The results of both bulk and neutron experiments are presented below. Note that the phases C, IC_{ac} and 1/5-C correspond to the phases I, II and III respectively.

Magnetization *Five phases* were observed up to 30 T and the material is only magnetized ∼ 1/3 M_S at 30 T, where M_S = 2.2 μ_B.

Polarization A *re-entrance of the linear magnetoelectric effect* was discovered in phase IV. The field was applied along c and the polarization measured along a. The effect is *abscent* in phase V.

Neutrons *1274* neutrons were detected with a *field on*! Despite the low statistics we are still able to follow the position of the propagation vector as the field is increased.

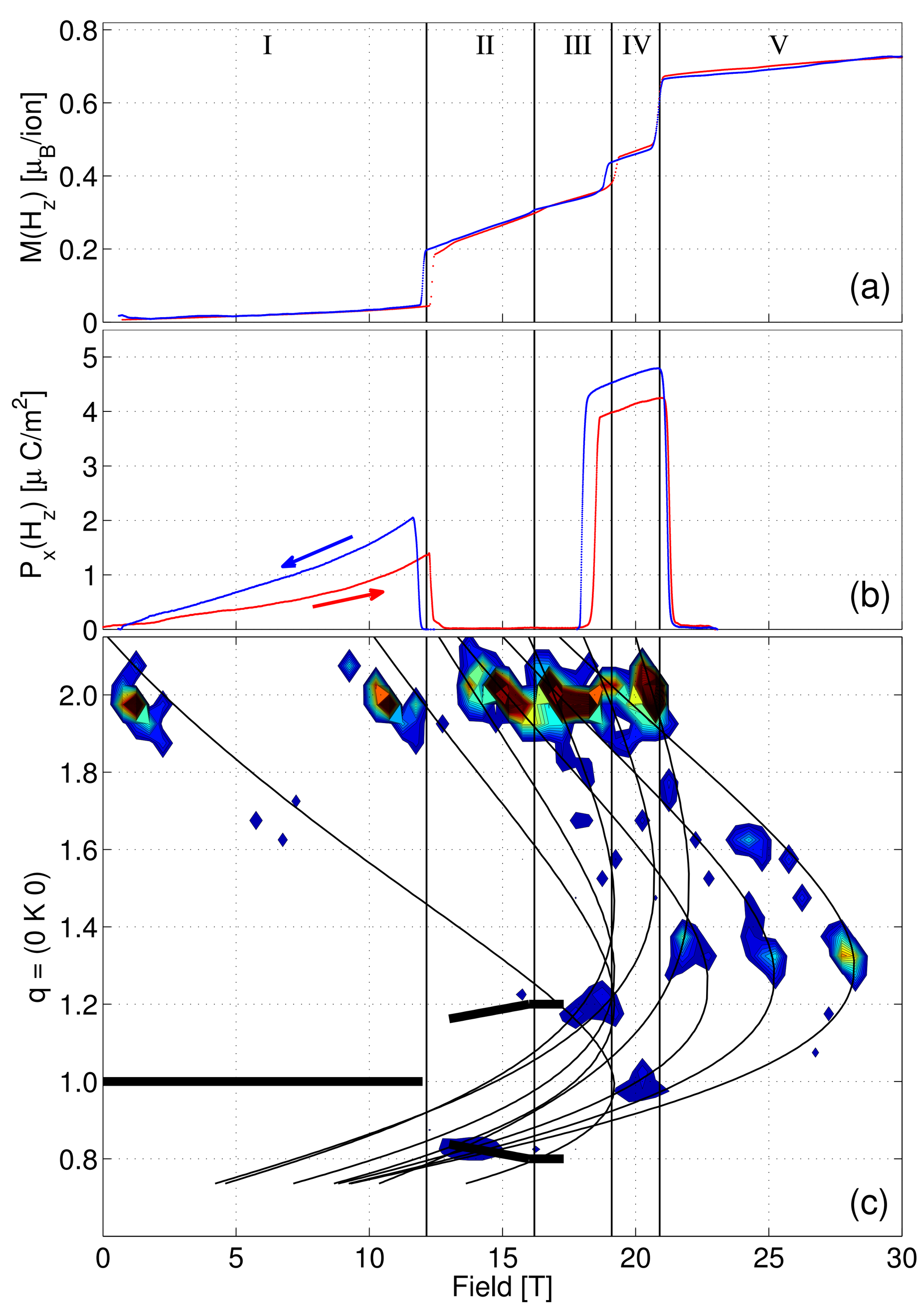

Figure 4: ***(a)*** *and* ***(b)*** *Magnetization and polarization respectively as function of field.* ***(c)*** *Colorplot of the normalized intensity of the propagation vector q = (0K0) as function of applied field. The solid curves are field sweeps for different magnet settings. The thick lines are known propagations vectors in the low-field phases.*

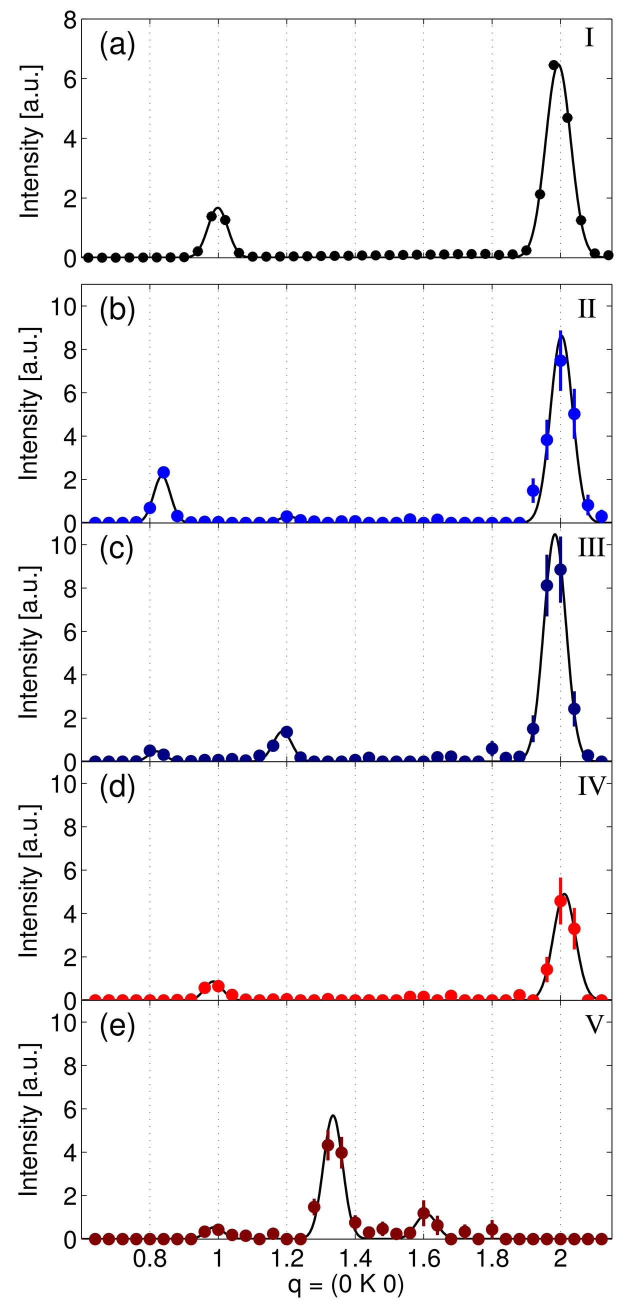

Figure 5: ***(a)-(e)*** *Intensity as function of q = (0K0) for phases I-V respectively. The positions of the Bragg peaks clearly change from phase to phase.*

Possible Magnetic Structures in the High-Field Phases

The neutron statistics are low and only one Bragg peak has been measured for each phase. However, together with the bulk measurement we can still suggest possible spin structures at high fields.

Phase IV The re-entrance of the magnetoelectric effect and the propagation vector q = (0,1,0) indicate that the magnetic structure is similar to the low-field commensurate structure in phase I.

Phase V Using M ≈ 1/3 M_S and the propagation vector q = (0,4/3,0) Jens Jensen was able to stabalize a meta-stable state which is a superposition of a commensurate and an incommensurate structure.

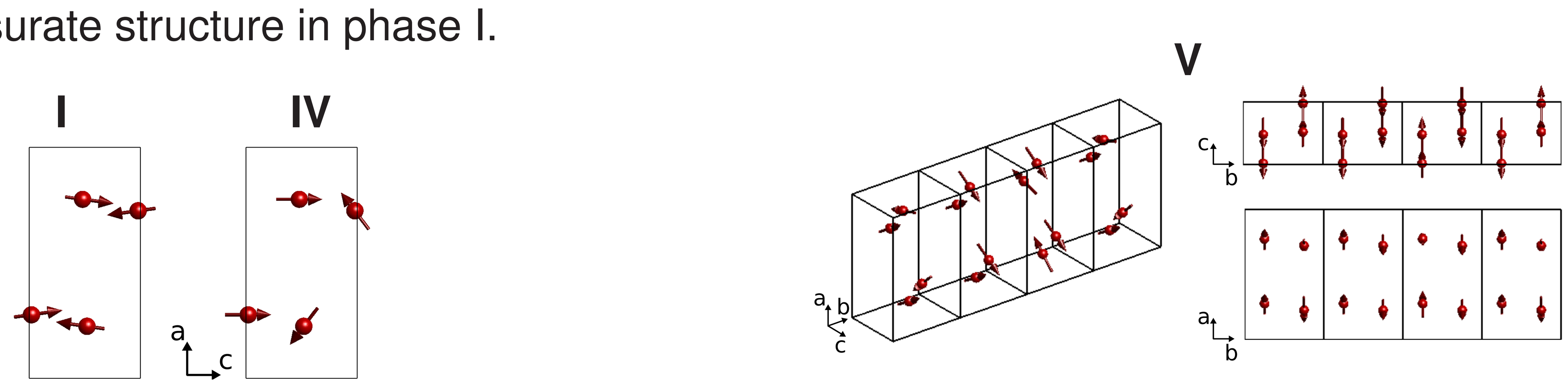

Figure 6: *Suggested spin structures of phase IV and V.*

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