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Notes on the new high-field phase in $PrFe_4P_{12}$ skutterudite

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The most fascinating new experimental finding on the $PrFe_4P_{12}$ skutterudite is the appearance of a high-field phase very sharply located around the (111) magnetic field direction. Additionally, it was also found that the electrical resistivity shows an enhancement around the (111) field direction.

We found that only the Γ_1–$\Gamma_4^{(1)}$ low-lying scheme gives a level crossing point in the ground state uniquely for the (111) field direction which can be responsible for the appearance of the high-field phase. We examined the AFQ ordering model of the Γ_3 quadrupoles in the case of tetrahedral symmetry with Γ_1–$\Gamma_4^{(1)}$ low energy scheme. We assumed infinitesimally small energy separation between the Γ_1 and $\Gamma_4^{(1)}$ states, and introduced ferro-type interactions between the dipoles and $\mathcal{T}^\beta$ octupoles. With our model we can reproduce qualitatively the measured phase boundary for $\mathbf{H}\|(111)$. Changing the ferro-type interaction parameters, either two separated phases or continuous phase boundary can be obtained. We found parameter sets when the two phases have the same $\mathbf{q} = (1, 0, 0)$ ordering vector (right part of Figure 1) or when the low-field phase is $\mathbf{q} = (1, 0, 0)$ while the high-field phase is $\mathbf{q} = 0$ ordered phase (left part of Figure 1).

We calculated the electrical resistivity from the crystalline electric field states. With this very simple picture we can reproduce qualitatively the resistivity enhancement around the (111) field direction near the level crossing point at low temperatures.

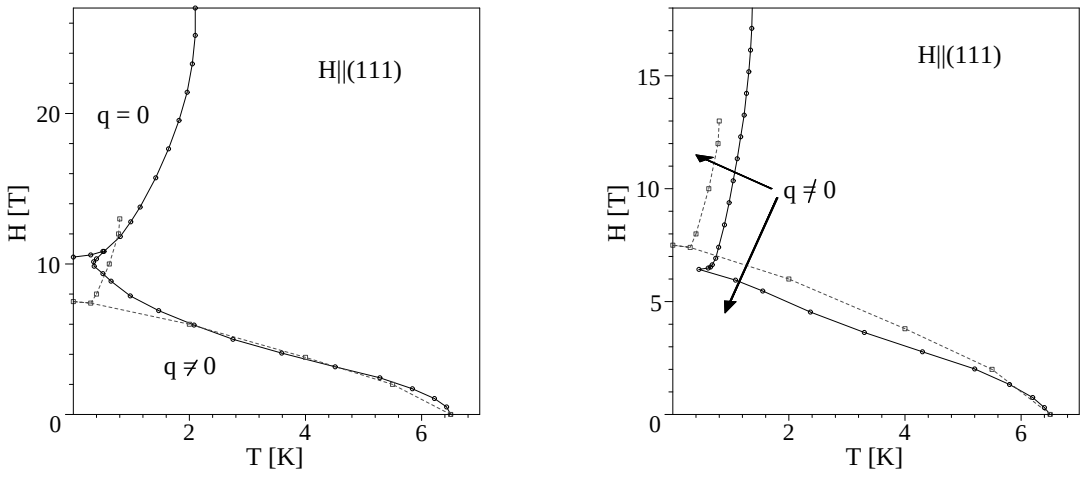

Figure 1: Temperature-magnetic field ($\mathbf{H}\|(111)$) phase diagram of the AFQ ordering model of the Γ_3 moments with inclusion of ferro-type dipolar and octupolar interactions. Dashed line shows the measured phase boundary. *Left:* The two phases have different $\mathbf{q}$ ordering vectors. *Right:* The two phases have the same $\mathbf{q} \neq 0$ ordering vector.

[1] T. Tayama, J. Custers, H. Sato, T. Sakakibara, H. Sugawara, H. Sato, J. Phys. Soc. Japan **73**, 3258 (2004)